Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

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Puisque toutes les études sélectionnées et retenues de la revue de littérature pédiatrique étaient publiées en anglais, les études et leurs résultats respectifs sont donc présentés dans la langue d'origine afin d'éviter la traduction et la validation de chaque outil de mesure.

This document was produced in English as all the selected studies obtained through the pediatric literature review were published in this language. The studies and their respective results are therefore presented in their original language in order to avoid the translation and the validation of each measurement tool.

Ce livre est dédié à tous ces enfants et familles
extraordinaires que nous côtoyons en réadaptation pédiatrique.

This manual is dedictated to all the exceptional children and families
seen in pediatric rehabilitation.

This reference manual is the collaborative work of Anne Parrot, pediatric physical therapist, Dr Michel Tousignant, scientific researcher and Dr Yvan St-Cyr, pediatric orthopedist. Ms Parrot is the author of the document.

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Introduction

Child development is a dynamic process which makes pediatric assessments a constant challenge. Ongoing neuro-developmental maturation and physiologic musculoskeletal changes present many variations in the healthy child and therefore it is important to take into consideration function and anatomy with regard to age, gender and cultural specificities. Many scientific studies have analyzed these normal variations in order to define what is considered "the limits of normal". These limits are defined as age normative reference values and are of interest to the healthcare professionals involved in diagnosing, monitoring or treating children with disabilities.

There are many advantages in using pediatric normative data as they provide guidelines for normal growth and development, set a basis for management and can be used as reminders for future observations in follow-ups. The data can also help to draw conclusions about changes in symptoms over time.
However, in order to be able to use the normative data as a means of comparison between the child with disabilities and the healthy child, the clinician needs to take into consideration the testing procedures of the method used to document the condition. Also, it is important to consider the strength and limits of the research study that analyzed the assessment tool (Number of subjects, validity, reliability…).

During the last decade, the demand for outcome measures and documentation has increased in clinical practice.[2, 3] However, as cited by Majnemer et al. (2002) [3] "…outcome determination in the field of pediatric rehabilitation is challenged by a lack of availability of sound instruments that are appropriate across age groups from infancy to adolescence…".

As defined by the Canadian Physiotherapy Association (2006)[8] "…best current research findings are provided by external evidence produced by clinically relevant research. Best current research findings can be provided by clinical practice guidelines, systematic reviews, randomized and controlled clinical trials, observational studies and case reports…". However, the access to the scientific data can be a challenge due to the vast amount of research reports published through the years by different means of communication. In everyday practice, the time needed to search for various pediatric studies is not always accessible to the clinicians. To address this challenge, a project was developed and put forward with the following objectives:

1. To review the pediatric scientific literature for clinically relevant research providing normative reference values obtained by easily implemented measurement tools in clinical practice.

2. To produce a reference manual presenting a compilation of the findings with normal baseline values and clinical practice guidelines for various musculoskeletal conditions and functional motor abilities.

Research Methodology

The pediatric scientific literature was reviewed for norm-referenced tests, appropriate for use with children from birth to 18 years of age. Norm-referenced tests are defined as "…measures that have been tested on a representative sample of the population of interest, typically a non-disabled population representing the ages, genders, environments, etc., of the people for whom the test was designed." [7]

Search Strategy

Focal points in the review centered around five topics:

1) Gait;
2) Muscle strength and physical fitness;
3) Range of motion;
4) Specific tests;
5) The foot.

The review covered the period from 1972 to 2006.

- A key word search conducted in the following electronic databases: PUBMED, EMBASE CINAHL ERIC and BIOSIS PREVIEW was used to query the following: children, validity, reliability, norms, assessment, outcome measures. These key words were combined to specific key words representing each topic such as:
    1) Endurance, speed, community for gait;
    1) Strength, grip, trunk, fitness for muscle strength and physical fitness;
    2) Joint motion, lower extremities, upper extremities for range of motion;
    3) Torsion, hypermobility, hypomobility, contracture, toeing-in for specific tests;
    4) Alignment, arch for the foot.
- The electronic review was performed by the library technician of the IRDPQ and by the pediatric physical therapist.
- Additional sources were Google and Copernic search engines. The reference lists of all the selected articles obtained by the electronic search were also scanned by the physical therapist to verify if any tests had been missed by the electronic search or to locate additional relevant articles.
- The research studies were identified by the following criteria:
  - Inclusion criteria:
    - The population sample consisted of children without disabilities, aged ≤18 years;
    - The variables that were studied had to be compatible with routine pediatric physiotherapy practice;
    - The reports' findings consisted of age related normative values obtained by the means of measurement tools that are clinically applicable;
    - The research study had to present good internal and external validity.
  - Exclusion criteria:
    - The population sample consisted exclusively of adult subjects or children with disabilities;
    - The testing procedures called for sophisticated equipment.

PROCEDURES FOR THE SELECTION OF THE STUDIES

- The first selection was undertaken by the pediatric physical therapist.
- The selected studies were then analyzed by a second reviewer qualified in research methodologies, who accepted or rejected them based on the following criteria:
  - Good internal validity (Selection bias and information bias);
  - External validity (On which population can we generalize results).

Search Results

- The pediatric literature search yielded 1012 reports.
- 250 articles were retained for analyses by the pediatric physical therapist based on the inclusion and exclusion criteria. Review articles were also excluded.
- 38 articles met the inclusion criteria established for this review, providing pediatric normative reference values obtained by methods that are easily applicable in a clinical setting.
- The selected data from these 38 reports was divided into 54 outcome measures. Table 1 summarizes the findings.

TABLE 1. SUMMARY OF THE FINDINGS FROM THE REVIEW OF THE PEDIATRIC LITERATURE

Topics	***Number of Analyzed Articles***	***Number of Outcome Measures***	***Comments***
Gait	39	7	Most assessments were conducted in gait analysis laboratories. There exists a paucity of research in children's mobility in a natural environment.
Muscle strength and physical fitness	48	9	There is a paucity of research in these domains and sample size is small in most of the selected studies. Only one study was selected for the assessment of trunk muscle strength. No relevant work was selected for physical fitness. A school fitness battery test is presented.
Range of motion	38	12	Pediatric reports are very limited in number and fewer studies were found for the upper extremities. There is a lack of current research in the range of motion in healthy children.
Specific tests	75	23	
The foot	50	3	Foot assessments are often reported as topics of some debate in the literature.
Total	250	54	Many reports were excluded based on the fact that they were not clinically applicable.

LIMITATIONS OF THE REVIEW

- The review aimed to identify norm-referenced tests with children without disabilities. The studies that consisted exclusively of impaired children were excluded. These studies may have presented additional relevant works or other testing methods.
- Certain norm-referenced tests that were selected are from descriptive normative studies and do not present all the psychometric properties of tests and measures.
- The selected methods have not all been tested by the authors in their clinical practice. Some of the methods might not be applicable due to the presence of articular difformities or other medical conditions.

- The list of the assessment tools and measures is not exhaustive. It represents various testing methods selected by the physical therapist based on their ease of application in routine clinical practice and the variable being measured.

The reference manual

TARGET PROFESSIONALS

- This manual was first intended for pediatric physical therapists. It will also be of interest to pediatricians, orthopedists, collegiate and university teachers, students and other professionals interested in the assessment of the pediatric population.

CONTENTS

- A basic understanding of anatomy and of the physiologic musculoskeletal changes is necessary to address the contents of this manual. It should be looked upon as a reference guide when assessing children in a clinical setting.
- The various standardized assessment tools and the normative reference values originate from the selected research studies. These assessments, as most methods, must be applied in regards to the child’s clinical history, symptoms, and functional limits.

TERMINOLOGY

- As a general rule, the term ‘’children’’ is used to cover the age range from “birth to 18 years”. However, if the terms infants, newborns, adolescents, etc., were specifically used in the research studies, the same terms were kept to avoid confusion when presenting the data.
- The male gender is used to define the population in general. Specificity for the female gender is used when the authors reported differences between sexes.
- Description of the testing procedures:
  - Standardization of the testing procedures and the application of the authors’ methods are essential for obtaining accurate results. The majority of the descriptions are the ones used in the studies and therefore there can be a difference in the description of the method for a similar test. No attempt has been made to bring into conformity this information.
  - Metric and English measures were used depending on the authors’ choice, but both are presented. Terms such as internal and medial rotations, external and lateral rotations were also used according to the studies.

PRESENTATION OF THE DATA

Maximum effort has been made to present the data in a brief and complete way, and to render it user-friendly. A brief summary of the literature review is presented with each topic followed by the selected assessment tools. This information, with a few exceptions, is divided into five parts:

1) Age range, clinical use and measurements
2) Testing procedures
   - Required equipment, testing positions and measurements are described.
   - Photos or figures are presented with certain testing procedures.
   - Additional information is presented for certain studies when the description for the method was incomplete.
3) Normative reference values
   - In order to respect authors' copyrights, the normative data is presented in their original tables or figures. Thus additional data that is not necessarily pertinent to the undergoing assessment may be present.

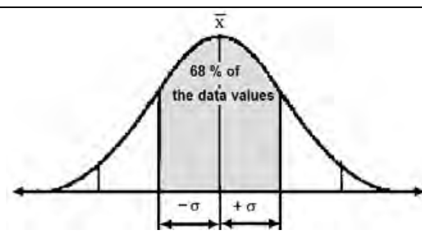
- However, for certain studies, we were unable to present the results due to the high cost of purchase. For these studies, the clinician will have to order the article in order to obtain the normative data. When possible, a summary of the data is presented but does not in any way replace the specific normative data from these studies.
- Clinical examples, for certain clinical conditions, are added to facilitate the interpretation of the data.

4) Clinical practice guidelines
   - Medical guidelines from the pediatric orthopedist are presented in the foot section and for a few clinical conditions in the specific tests section.
   - Clinical guidelines from each report are presented in a study summary or with the normative reference values.
5) Study summary
   - The summary of the research method, data analysis and the authors' conclusions are the main elements described in this section. This summary is presented after each measurement tool.
   - The study's summary will allow the clinician to take into account the strength and the limits of the study, and potential errors when interpreting results. A comment section was also added for additional information on our part.
6) Updated references are presented at the end of each section

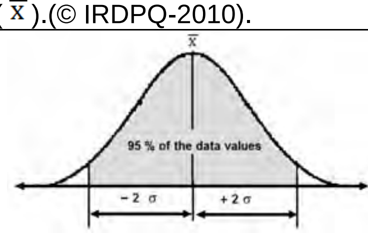
INTERPRETATION OF THE RESULTS

- Norm-reference tests present mean values and standard deviation (SD) obtained in a healthy population. "…An important attribute of the SD as a measure of spread is that if the mean and SD of a normal distribution are known, it is possible to compute the percentile rank associated with any given score..." [9]

In a normal distribution, about 68% of the scores are within one SD of the mean and about 95% of the scores are within two SD of the mean (Fig.1).[9] In other words, statistically, the term "normal" represents a condition that is within two SD of the mean which encompasses 95% of the healthy individuals.[4, 5] However, most of the selected studies have presented the data within one SD of the mean value. Thus, if need be, the clinician will have to calculate the mean values within the 2 SD. This is achieved by multiplying by two the one SD value.



A: In a normal distribution of data, about 68% of the data values will fall within one standard deviation (±σ) of the mean value ($\bar{x}$).(© IRDPQ-2010).



B: In a normal distribution of data, about 95% of the data values will fall within two standard deviations (±2σ) of the mean value ($\bar{x}$).(© IRDPQ-2010).

Figure 1. Interpretation of mean values and standard deviation. A: Data within one standard deviation (±σ) of the mean value. B: Data within two standard deviations (±2σ) of the mean value.

- How to use the results?

7) The results of the impaired child are compared to the normative reference values in order to document if restrictions exist and to determine the severity of the impairment. However, mean values and standard deviations are useful clinically but should not be analyzed in an absolute manner and interpreted as the only criteria for clinical decisions and determining the child's status. Evidence-based medecine is "…the conscientious, explicit and judicious use of current best evidence in making decisions about individual patients…" .[1,6] Identifying patient expectations and goals are important parts of best practice. [8] In summary, final clinical diagnosis, therapeutic decisions and interventions depend on research evidence, clinical expertise, the child's clinical - medical history, and the family' s preferences.

8) Children with disabilities usually do not present normal developmental patterns as compared to children without disabilities. Abnormal muscle tone, joint limitations, muscle weakness or various medical conditions are known as factors that can interfere in the child's development. Close follow-up is thus suggested with children presenting disabilities and who have a condition that is rated in the two SD limits, showing a potential risk to evolve towards functional and musculo skeletal problems.

Conclusion

This document is a compilation of different standardized tests for various musculoskeletal problems and functional motor abilities often seen in pediatric physical therapy. All the testing procedures are convenient for use by clinicians and acceptable for the pediatric patient. Clinical practice guidelines are presented with each research study. The content is, to the best of our knowledge, among the most current research findings that can be used in a clinical practice setting at the moment this review was undertaken.

Since standardization issues are critical for comparison of test results, the use of standardized tests presented in this document will help to achieve more objective measurements and results. These tests will also help to diminish errors when the child is assessed by different raters and in follow-ups.

The use of normative data will contribute to a better knowledge of the pediatric musculoskeletal developmental specificities and will be useful as a clinical reference in professional practice. It will also help to identify the restrictions and limitations regarding the child's age and guide program planning.

The literature review revealed a paucity of current studies presenting normative reference values with reliable outcome measures in the healthy pediatric population. There is variation in the quality in the studies, certain having a small sample size and lacking psychometric criteria. However the data can be used as baseline values. The more rigorous studies were undertaken in the last decade.

This work, we hope, is a step forward in answering the need and demand for outcome measures, documentation and objective testing in the field of pediatric rehabilitation. It will help to address the challenge in identifying the normal dynamic process in the child's development and hopefully stimulate future research projects to study other variables in the unimpaired and impaired pediatric population.

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Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

Part 1

Gait

Complete document :

www.irdpq.qc.ca/communication/publications/documents_disponibles.html



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Part 1

Gait

Summary 2

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5. Functional Ambulatory Mobility Test – Timed ‘Up and Go’ Test in Children 23
6. Timed-Walk Test – Six-Minute Walk Test–Outdoor 29
7. Timed-Walk Test – Thirty-Second Walk Test–Indoor 34

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Summary

Gait assessment is a major component in the evaluation of children with disabilities and, in order to make relevant comparisons, it is important to identify normative values before examining pathological gait. [20, 21, 32]

Gait velocity, walking endurance and balance are commonly assessed to quantify functional mobility in clinical practice. Gait performance in the environment is also an important variable to consider in order to document the overall functional walking ability of a subject.[8, 16] However, most studies retrieved from the review of the literature were conducted in gait analysis laboratories or in therapeutic settings, and only a few in a more natural environment. [5, 9] The measurement of children's activity in the community has received much less study and attention. [7]

When opting for gait assessment, the therapist must determine which variables need to be tested during an examination. Is it gait speed, walking endurance, symmetry in the gait pattern (step or stride lengths) or is it to obtain a global impression of gait performance? The choice of the measurement tools will differ depending on the need and the specificity of the child's disability. However, the clinician must be aware of the limitations in gait assessment performed in a therapeutic environment.

Limitations in Gait Assessment

A. Age

It is recommended when assessing young children to increase the number of trials due to their inherent variability. [6]

B. Visual and Videotaped Observational Gait Analyses

In a clinical setting, "live" gait observation is regularly used to assess different gait parameters. However, observational analysis is reported as having poor intra-rater and inter-rater reliability[4]. Many studies have examined the efficacy of videotaped observational gait analyses. As a general trend, this type of analysis is shown to be moderately reliable, within-raters [3, 30] and between raters [3, 27, 29, 30] or not sufficiently reliable to determine changes in gait. [27] The validity of certain sections of the Observational Gait Scale (OGS) was determined by viewing video recordings of children with spastic diplegia by comparison with three-dimensional gait analysis. The OGS was found to have acceptable inter-rater and intra-rater reliability for certain joint motions and low inter-rater and intra-rater reliability for others. [12]

However, it is reported [21] that clinical gait analysis using videography, temporo-distance measurements and a strict standardized protocol, was found to be consistent with measurements recorded in a gait analysis laboratory using a 16-mm cinematograhy (cerebral palsy and healthy children).

C. Gait Analysis Laboratories and Gait Analysis in Therapeutic Settings

Caution is to be considered in generalizing data issued from gait analysis laboratories to free gait on long walkways and in the community.[17] The data obtained from gait analysis laboratories are more representative of gait indoors, on small walkways,[17] and are performed with one child tested at a time.[5] Normal gait speed (self-selected speed) issued from long walkways tend to be higher than those obtained from short walkways but fast gait speed would be equivalent.[17]

Also, subconscious gait changes may occur in different environments and may be influenced by gridlines or narrow corridors.[4] Gait speed in children was reported to be faster in a school environment compared to gait speed in gait laboratories. [9] The gait pattern would be different in indoor and outdoor gait. [17]

The clinician must take into consideration that the walking courses used to assess gait speed in a therapeutic setting are usually straight courses and may not represent true walking abilities in a more demanding environment. Among environmental factors that may influence walking performances are the distance traveled, physical load, obstacles and the need to make postural transitions.[8]

DIFFERENT TYPES OF GAIT ASSESSMENT

A. Distance Walk Tests

Short-distance walk tests are used to assess gait for a specified distance (ex. 10-meter walk test). From these tests, short distance gait velocity and spatial gait parameters can be calculated. To the best of our knowledge and from the present review, there are no studies reporting normative data for the 10-meter walk test in children, in a clinical setting. The selected studies are issued from gait analysis laboratories presenting normative data for different gait variables (Table 1.1). It is suggested [22, 32] that the normative data obtained from these studies or from studies conducted in therapeutic settings [4] can be used as clinical guidelines.
The following measurements are reported to be, among others, sensitive indicators of gait maturation and also of gait deficits in pathological gait: [32]

- Gait velocity
  - Gait velocity is considered a valid and reliable measure in children with or without neuromuscular disability.[32] Many researchers and clinicians measure gait velocity to assess change in gait performance as a result of treatment.[4] Coutts et al. (1999)[4] cited that there is a significant correlation between gait speed and balance skills, quadriceps strength and length of the achilles tendon and therefore gait velocity (distance traveled / time) is often used as a clinical outcome measure;
  - Norlin et al. (1981)[15] report that, when describing gait ability, velocity is the most important factor to measure because it is the most descriptive variable and many gait parameters (cadence, step length, stride length, etc.) are correlated to velocity.

- Spatial gait parameters
  - Cadence can be measured with a reliable pedometer.
  - Stride length and step length can be measured more objectively by using the “Footprint Method”. This method consists in fixing moleskin inked tabs on the soles of the child’s shoes.[1, 4, 11, 17, 19, 32.]
  - Reliability of the “Footprint Method”: Adolph et al. (2003) [1] analyzed inked footprint sequences with 210 infants, 15 kindergartners and 13 adults. The authors evaluated the test-retest reliability of the method by measuring the correlation between the first and second footprint trials. Correlation coefficients were 0.97 for stride length and 0.97 for step length, showing consistency across consecutive sequences.

TABLE 1.1: SUMMARY OF THE STUDIES REPORTING NORMATIVE DATA FOR GAIT VELOCITY AND SELECTED SPATIAL GAIT PARAMETERS

Research Studies	Study Site	Gait Parameters			
		Gait velocity	*Cadence*	*Stride length*	*Step length*
Sutherland (1988)[32]	Lab. Indoors	✓	✓	✓	✓
Schuyler et al.(2000)[31]	Lab. Indoors	✓	✓		✓
Waters et al. (1988)[24]	Lab. Outdoors	✓	✓		

Lab: Gait analysis laboratory

B. Timed-Walk Tests

Timed-walk tests are used to assess gait for a specified length of time (ex. Six-Minute Walk Test). They are accepted as part of the measurement of gait [4] and are indicators of functional ambulatory capacity.[10] Timed-walk tests are simple, inexpensive, safe and reliable for the measurement of functional exercise capacity and the monitoring of treatment effectiveness.[18] The distance traveled is the main outcome measure obtained and the longer walking tests should be used to assess the more able patients. [4]

From these tests, gait velocity and cadence can also be calculated and compared to normative values. [4, 5]

Only two timed-walk tests were retrieved from the review of literature: The Six-Minute Walk Test (6-MWT) and the Thirty-Second Walk Test (30-SWT), the former being well documented in the literature:

- 6-MWT
  - The 6-MWT is a submaximal exercise test. It provides a reflection of daily living activities.[10, 33] It is among one of the most used walk tests[18] and is easy to use in a clinical setting.[10, 18, 20, 28] Li et al. (2005)[10] cite that "the 6MWT, which is easy to perform and cost-effective, has been proposed as the best indicator of functional capacity among all submaximal exercise tests.'' Using a submaximal test allows children with disabilities to participate whereas a maximal test might be too taxing. [20] The six-minute walk test is increasingly being used as a measure of " functional ability " in children with cerebral palsy.[13]
  - The 6-MWT may be used to monitor progress in children receiving therapy for a health condition. [20, 28] The strongest indication for the 6-MWT is for measuring the response to medical interventions in subjects with moderate to severe heart or lung disease.[33] It can be performed even by a patient with heart failure not tolerating maximal exercise testing.[14] If the test is performed with children with health conditions, the clinician should review the guidelines of the American Thoracic Society ATS Statement: Guidelines for the Six-Minute Walk Test. [33] Available at: http://ajrccm.atsjournals.org/cgi/content/full/166/1/111 (Accessed December 9-2009)
  - There would be no relationship between distance walked and body mass index in children.[20] Further studies are needed to determine the utility of the 6-MWT in different clinical situations.[33]
  - Validity and reliability
    - The 6-MWT is considered a valid test as a significant correlation was established between the 6-MWT and VO_2 max obtained during a treadmill exercise stress test.[10] A significant correlation was also found between the six minute walking distance and FEV1 (Force expiratory volume in one second).[10] The distance walked correlated with maximum expiratory pressure and maximal heart rate in children with cystic fibrosis. [28]
    - The 6-MWT is reported to be reliable[10, 28] in healthy children (ICC: 0.94)[10] and in ambulant adolescents with cerebral palsy (ICC: 0. 98) when carried out according to the American Thoracic Society guidelines.[13]
- 30-SWT
  - The 30-SWT measures the distance walked in a short period of time and is a general measurement of mobility.[9] This test was conducted in a more natural environment as it was performed in a school gymnasium.

C. Functional Ambulatory Mobility Test

- Functional mobility can be defined as the ability to manoeuvre independently and capably ones' body to accomplish everyday tasks. [25] Specific gait testing such as the "Timed Up and Go" (TUG) is reported as an outcome measure to assess ambulatory mobility including dynamic balance and the ability in making movement transition. [25] A major feature of the TUG is that it incorporates a series of tasks: standing up from a seated position, walking, turning, stopping, and sitting down, all of which are critical for independent mobility. [23]
- Timed 'Up and Go' Test in Children
  - William et al. (2005) [25] modified the procedure of the TUG test for the use in children to ensure that children clearly understood the task. Also, movement time rather than a combination of reaction time and movement time is measured. The Timed 'Up and Go' in Children (TUG-IC) incorporates a series of tasks requiring control of balance and movement through planning, initiating, executing and completing movement sequences frequently performed in the child's environment. This test could be considered a reasonably ecologically valid tool. [25]
  - Validity and Reliability:
    - Validity and reliability of TUG-IC scores were examined in 176 children without physical disabilities and in 41 young subjects with physical disabilities. The TUG-IC was compared to the Goss Motor Function Classification System and the Goss Motor Function Measure. The results are presented in the study's summary page (section 5.5).

CONCLUSION

The literature is devoid of normal values for a variety of age groups of children tested in natural environments [9]. It is important to keep in mind that most of the suggested gait assessments are more of an artificial nature and may not represent the usual state of the subject in his daily activities. Some authors suggest that there is a need for separate reference data for free gait outdoors or on a long walkway, and for short walkways in laboratory situations.[17]

Gait velocity, timed-walk tests and the Timed 'Up and Go' test in children are considered clinical outcome measures that can be used with the pediatric population. These walking tests are inexpensive, easy to perform and to understand for children. Certain spatial gait parameters can be analyzed more objectively by using the footprint method. [2, 19, 26, 32] The normative data issued from the selected studies can be used as a mean of comparisons with healthy individuals and as a baseline to monitor progress in gait.

Note : Updated references are presented at the end of this section.

1. The Footprint Method – Assessment of Spatial Gait Parameters

Age range: 1 year to 7 years. [32]

Age range: 3 years to 18 years. [31]

1.1 Clinical Use

- Provides a standard method for measuring step length and stride length.
- To identify asymetry in the gait pattern.

1.2 Measurements

- Stride length: the longitudinal distance between the initial contact of one foot (heel strike) and the next initial contact of the same foot.[34] (Fig. 1.1). Stride length is recorded in cm.

- Step length: the longitudinal distance between the two feet. Right step length is measured from the first point of contact of the left foot (heel strike) to the first point of contact of the right foot (heel strike). [34] (Fig. 1.1). Step length is recorded in cm.

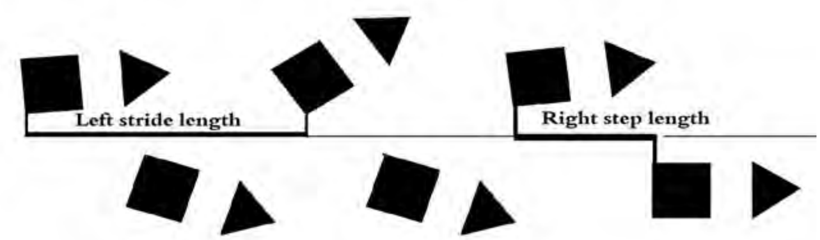

Figure 1.1. Calculation of spatial gait parameters. (© IRDPQ-2010).

1.3 Testing Procedures

- To optimize standardization, the following method is suggested based on the information collected from different research studies.

Required equipment

- A chair.
- Two different colors of ink, one for each foot.
- Tabs made of 1.5 cm square (0.98 in) and 1.5 cm triangle (0.98 in) moleskin pieces.[1] Other studies have used thin felt pads such as Dr Scholl's felt corn pads. [19]
- A long strip of butcher paper:
  - Width: 76 cm (30 in); [1]
  - Length: between 4.6 m (15 ft) [1] and 7.9 m (26 ft). [19]
- Masking tape to secure the paper to the floor.
- A ruler to measure the first and last meter (3.3 ft) of paper.

Pre-test

- The strip of paper is secured to the floor.
- The tabs are secured and placed on the midline of the sole of the shoes as follows (Fig.1.2):
  - Squared tabs are placed at the base of the heel;

- Triangles are placed in line with the third toe;
- The bottom edges of the tabs are always placed parallel to the edges of the child's heels. [2, 26, 35]

- Prior to testing, the child practices walking on the paper walkway. [19]
- The child is then seated and ink is applied on the tabs, a different color for each foot.

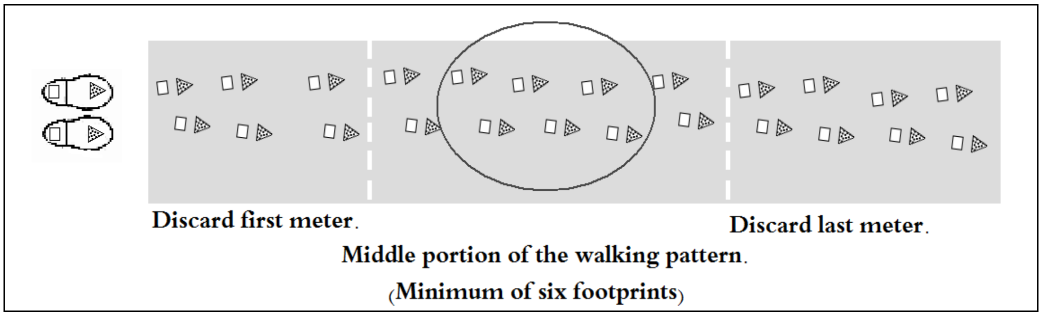

Figure 1.2. The footprint method. (© IRDPQ-2010).

TEST

- The child walks on the strip of paper leaving a sequence of footprints (Fig. 1.2). [2,19, 26, 35]
- From the footprint sequences, the gait parameters are measured as follows:
  - The first and last meter (3.3 feet) of paper is discarded to eliminate those steps taken at the beginning and end of the trial. [11, 19]
  - The middle portion of the walking pattern where it is believed that the child hit his stride is analyzed [35] (Fig. 1.2) and a minimum of three footprints per foot is measured. [35]
  - Step length and stride length are recorded in cm and the mean value of the three footprints is calculated.
- Results are compared to the normative reference values in Table 1.2 for step length and stride length at normal gait velocity (Free-speed walking. Age: 1 years-7 years) and in Table 1.3 for step length at normal and fast gait velocities (Age: 3 years-18 years).

1.4 Normative Reference Values

TABLE 1.2

Means and standard deviations for height, right and left leg lengths, right and left step lengths, and stride length in each age-group. All measurements are in centimeters.

Age	*N*	*Height*		*Right leg*		*Left leg*		*Right step*		*Left step*		*Stride*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
1	51	74.5	3.0	31.6	1.4	31.6	1.4	21.6	3.9	21.4	3.5	43.0	6.7
1½	40	80.2	4.1	35.5	2.2	35.5	2.2	25.1	3.6	24.4	3.4	49.5	6.6
2	45	86.2	3.6	38.9	2.0	38.9	2.0	27.5	3.2	27.4	3.6	54.9	6.3
2½	36	89.9	3.9	41.4	2.5	41.5	2.6	30.7	3.9	31.1	3.6	61.8	7.4
3	47	94.8	3.3	44.3	2.1	44.4	2.1	32.9	3.6	33.9	3.7	66.8	7.0
3½	40	98.3	3.9	46.5	2.6	46.5	2.6	36.5	3.9	37.5	4.4	74.0	8.1
4	39	102.6	3.5	49.3	2.1	49.2	2.1	38.5	4.2	39.1	4.0	77.9	8.5
5	42	108.8	4.1	53.4	2.9	53.4	2.9	42.3	4.2	42.9	4.1	84.3	10.2
6	44	115.6	4.6	57.0	3.3	57.0	3.4	44.1	4.4	45.2	4.3	89.3	8.5
7	46	122.2	4.9	61.5	3.8	61.5	3.8	47.9	4.3	48.7	4.1	96.5	8.2

© Sutherland, Olshen, Biden and Wyatt (1988), p. 56. [32]

1.5 Normative Reference Values

TABLE 1.3

Relevant temporal/spatial changes due to velocity and age*

	Velocity				Step Length				Cadence				Total support time			
	cm/s	% of norm walk	SD[1]	SD[2]	cm	% of norm walk	SD[1]	SD[2]	Steps/min	% of norm walk	SD[1]	SD[2]	% of gait cycle	% of norm walk	SD[1]	SD[2]
All fast	171	143	22	7	63	115	13	3	169	126	29	6	56	95	3	2
All normal	119	100	19	7	55	100	11	3	134	100	17	6	59	100	2	2
All slow	86	72	19	6	48	88	11	3	110	82	17	5	61	103	2	1
3–6 fast	155	130	19	8	50	91	9	3	190	142	20	8	56	94	4	2
7–11 fast	179	150	21	8	62	114	5	3	175	131	25	7	56	95	2	2
12–18 fast	179	150	18	5	78	143	7	2	138	103	12	3	56	96	2	2
3–6 normal	108	90	18	10	43	79	8	3	150	112	10	9	58	99	2	3
7–11 normal	119	100	18	5	54	99	6	2	132	99	12	5	59	100	2	2
12–18 normal	129	108	15	6	67	123	6	3	116	86	11	4	60	101	2	2
3–6 slow	76	64	15	7	37	68	7	3	124	92	14	7	60	102	2	2
7–11 slow	83	70	17	6	48	88	7	3	105	78	16	5	61	104	3	1
12–18 slow	99	83	17	5	60	109	7	2	99	74	12	3	62	104	2	1

SD[1] -standard deviation of the group as a whole *SD[2] –mean standard deviation of individual patients.*

1.6 Study summary

- Sutherland et al. (1988) [32]: Page 13.
- Schuyler et al. (2000) [31]: Page 15.

2. Distance Walk Test – Gait Velocity and Cadence–Indoor [31, 32]

Age range: 1 year to 7 years. [32]

Age range: 3 years to 18 years. [31]

2.1 Clinical Use

- Provides a standard method for measuring indoor gait velocity, and cadence on a level ground and in a controlled environment.

2.2 Measurements

- Gait velocity is recorded in cm/sec for comfortable self-selected speed (Table 1.4 – Table 1.5) or for fast gait speed (Table 1.5).
- Cadence: The frequency of steps is recorded in steps/minute (Table 1.4 – Table 1.5).

2.3 Testing Procedures

- The selected studies were conducted in gait laboratories. To optimize standardization, we suggest the following method based on the information collected from the consulted studies and on clinical experience.

REQUIRED EQUIPMENT

- Stopwatch.
- A reliable pedometer if measuring cadence.
- Tape measure.
- Masking tape for markers on the walking course.
- A chair needed during rest periods. The child's feet must be flat on the floor.

ENVIRONMENT

- Gait velocity is regularly measured in a clear large hallway on a ten meter (32.8 feet) walkway. [4, 15, 21]
- Distractions should be avoided to the maximum extent possible.

PRE-TEST

- Prepare a 10-meter walkway (32.8 feet) (Fig. 1.3):
  - Place small markers for the start and finish lines.
  - Place two other small markers at a distance of 2.5 m (8.2 feet) before the start line and after the finish line,[17] in order to obtain an acceleration and a deceleration distance.[15, 17, 22] This will allow the child to achieve a steady velocity before reaching the starting line and minimize the effect of deceleration before crossing the finishing line. Markers should be as discrete as possible.
- Have the child walk up and down the walkway a few times so that he becomes familiar to the environment.[32] This will also allow the clinician to visualize the gait pattern and will help to observe possible behavioral problems.
- Clothing: One of the selected study (Sutherland (1988)) assessed the child barefoot in his underclothing or in a swimsuit-style outfit. The other selected study (Schuyler et al. (2000)) did not mention the type of clothing.
- Instructions for the subject: Ask the child to walk on the command "GO" at his preferred walking speed and to stop when asked to do so.

TEST

- Number of trials: Have the child perform 3 repetitions and calculate the average time.
- Rest periods of ± one minute are suggested between trials.
- The child stands behind the acceleration line. On the command "GO", he starts walking at a comfortable self-selected speed and continues walking until he passes the deceleration line.
- Stopwatch is started when one foot crosses over the start line and stopped when, ideally, the same foot crosses over the finish line.
- The same method is used when testing fast gait speed.
- Results are compared to the normative reference values in Table1.4. for cadence and normal gait velocity and, in Table 1.5 for cadence, normal and fast gait velocities.

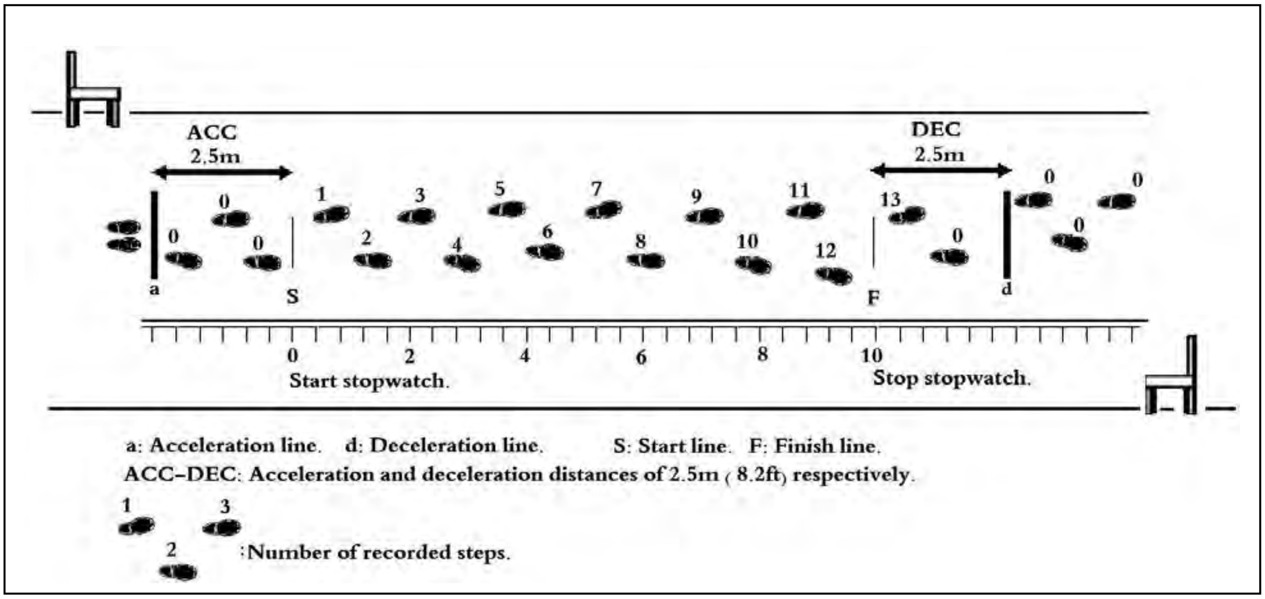

Figure 1.3. 10-meter walkway (32.8 feet). (© IRDPQ-2010).

2.3 Normative Reference Values

TABLE 1.4

Means and standard deviations for cycle time, cadence and walking velocity in each age-group.

Age	*N*	*Cycle time (secs.)*		*Cadence (steps/min.)*		*Velocity (cm/sec.)*	
		Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
1	51	0.68	0.09	176	24	64	16
1½	40	0.70	0.08	171	21	71	14
2	45	0.78	0.11	156	25	72	16
2½	36	0.77	0.08	156	17	81	15
3	47	0.77	0.07	154	16	86	14
3½	40	0.74	0.05	160	13	99	15
4	39	0.78	0.07	152	15	100	17
5	42	0.77	0.06	154	14	108	18
6	44	0.82	0.09	146	18	109	19
7	46	0.83	0.07	143	14	114	17

© Sutherland et al. (1988), p. 62. [32]

2.4 Normative Reference Values

TABLE 1.5

Relevant temporal/spatial changes due to velocity and age[a]

	Velocity				Step Length				Cadence				Total support time			
	cm/s	% of norm walk	SD[1]	SD[2]	cm	% of norm walk	SD[1]	SD[2]	Steps/min	% of norm walk	SD[1]	SD[2]	% of gait cycle	% of norm walk	SD[1]	SD[2]
All fast	171	143	22	7	63	115	13	3	169	126	29	6	56	95	3	2
All normal	119	100	19	7	55	100	11	3	134	100	17	6	59	100	2	2
All slow	86	72	19	6	48	88	11	3	110	82	17	5	61	103	2	1
3–6 fast	155	130	19	8	50	91	9	3	190	142	20	8	56	94	4	2
7–11 fast	179	150	21	8	62	114	5	3	175	131	25	7	56	95	2	2
12–18 fast	179	150	18	5	78	143	7	2	138	103	12	3	56	96	2	2
3–6 normal	108	90	18	10	43	79	8	3	150	112	10	9	58	99	2	3
7–11 normal	119	100	18	5	54	99	6	2	132	99	12	5	59	100	2	2
12–18 normal	129	108	15	6	67	123	6	3	116	86	11	4	60	101	2	2
3–6 slow	76	64	15	7	37	68	7	3	124	92	14	7	60	102	2	2
7–11 slow	83	70	17	6	48	88	7	3	105	78	16	5	61	104	3	1
12–18 slow	99	83	17	5	60	109	7	2	99	74	12	3	62	104	2	1

SD[1] -standard deviation of the group as a whole

SD[2] -mean standard deviation of individual patients.

2.5 Study Summary

Title: The Development of Mature Walking [32]	
Author	Sutherland, David H.
Publication	London: Mac Keith Press, 1988.
Purpose of the Study	▪ To outline changes in gait from the ages of first walking to 7 years. ▪ To define mature gait in terms of specific gait parameters. ▪ To provide substantial base for comparing children with possible gait problems with normal children of the same age.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of gait velocity and different spatial parameters on a short walkway in a therapeutic setting.

Methods

Subjects

- The study sample consisted of 309 healthy children. Mostly Caucasians. USA.
- Age range: 1 year to 7 years.
- Subjects were divided into ten age groups based on chronological age in years within six-month intervals. For gait analysis, each group consisted of 36 to 49 subjects.

Testing Procedures and Instrumentation

- Various gait parameters were assessed and analyzed in a laboratory setting.
- Different anthropometric variables and range of motion in the lower extremities were measured. For range of motion analysis, 392 to 438 measurements were performed in each group.
- Instrumentation: Gait analysis laboratory and various measuring devices were used depending of the variables analyzed. Testing was done in different standardized positions.

Data Analysis

- Motion data was subjected to Fourier analysis to determine mean rotations across the gait cycle.
- Prediction regions, defining boundaries within 95 % of normal children, were calculated using the resultant Fourier coefficients. Details are available therein.

Results

Due to the vast amount of information presented in this study, only the data concerning the variables that were used for this document are presented.
Psychometric Properties: Not applicable.

- Gait
  - Normative data for gait parameters are presented therein.
  - Walking velocity increases with age in a linear manner from 1 to 3 years at a rate of about 11 cm/sec per year. From 4 to 7 years, the rate of change diminishes to 4.5 cm/sec.
  - Cadence in the 1-year-old subjects was ~ 22.5% more than the 7-year-olds. The main reduction occurs between 1 and 2 years of age. Cadence in the 7-year-olds is ~ 26% more than the normal adult's mean.

Musculoskeletal Variables

- Mean values for range of motions are presented therein for the left and right sides. There was no significant difference between sides ($p< 0.01$) for any age groups and for either gender.
- Hip internal rotation has a substantial variability throughout 1 to 7 years of age. Median range of passive hip internal rotation varies between 53° an d 60°.

2.5 Study Summary (Continued)

Results
▪ Median range of hip adduction throughout 1 year to 7 years was 20°. ▪ Hip abduction at 1 year shows a median range of passive hip abduction of 55°. At 7 years, the median range of passive hip abduction has gradually diminished to 45°. ▪ At 7 years, the straight leg raise test exceeded range of motion of most adults. ▪ Ankle dorsiflexion, straight leg raise test, hip abduction and external rotation gradually decreased with age. Dorsiflexion, from 1 year to 7 years, shows a significant decline with increasing age, from 25° at 1 year to 15° at 7 years. At 1 year, hip ext ernal rotation is greater than hip internal rotation. At 2 ½ years, hip internal rotation is greater than hip external rotation. ▪ Complete extension of the hip to 10° across all ag e-groups is in disagreement with other authors. ▪ The greatest spread of data in normal children for femoro-tibial alignment was in the direction of valgus. Results show similar trends as other studies but with greater variability and may be due to different measurement methods such as X rays versus clinical measurements. ▪ Findings are consistent with other studies but some discrepancy exists with others which may be explained by the much larger sample size of the present study, the use of a permanent laboratory setting and in the assessment of free-speed gait.
Authors' Conclusion
Normative data for gait parameters, anthropometric and musculoskeletal measurements are available for normal children aged from 1 to 7 years. The ranges of motion are to be used as guidelines. The authors report that it would be unwise to label a child abnormal if he shows minor deviations from the presented values.

Comments
Internal and external validity (including sample size, *n* = 36 to 49 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

2.6 Study Summary

Title: Predicting Changes in Kinematics of Gait Relating to Age and Velocity [31]	
Authors	Schuyler J., Miller F., Herzog R.
Publication	Proceedings, 5th Annual Meeting of the Gait and Clinical Movement Analysis Society, Rochester, MN, March, 2000.
Purpose of the Study	To define temporal/spatial and kinematics variations that occur as a result of age and velocity changes.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of different gait speeds and spatial parameters on a short walkway in a therapeutic setting.

Methods

Subjects

- The study sample consisted of 92 healthy children. USA.
- Age range: 3 years to 18 years.

Testing Procedures and Instrumentation

- Gait was assessed in a gait motion laboratory by means of three trials at self-selected walking speeds that the child considered normal, fast or slow.
- Trials were combined within individuals to create child specific temporal/spatial information and time series averages for the three self-selected speeds.
- Height, weight, leg length and foot width were measured. Speed groups were subdivided by age.

Results

- **Psychometric Properties**: Not applicable.
- **Changes in Gait Related to Age:** With an increase in age there was an increase in steps, stride length and a decrease in cadence. Support time, non support time and step width remained the same across age groups. There was no clinically significant change in the distal segments of the body in the time series plots of gait which is consistent with other studies. Proximal segments exhibited some change with increasing age: Arm abduction decreases and trunk forward lean became slightly more posterior.
- **Temporal/Spatial Changes Related to Velocity:** With an increase in gait speed, there was an increase in ROM of shoulder flexion/extension and pelvic rotation and early heel rise, but no changes were observed with slow velocity.
- **Temporal/Spatial Changes Prediction:** The anthropometric measurements of leg length was not strongly correlated to any parameters but was found to provide a significant contribution to the prediction of step length, stride length and cadence when combined with age and variables.

Authors' Conclusion

Age and velocity related changes in the temporal/spatial characteristics were clinically significant. Step length and cadence should be normalized with respect to age and velocity.

Comments

Internal and external validity (including sample size, *n* = 92) seems good. The use of results as a trend for clinical guidelines is appropriate. However, sample size per age group was not mentioned.

3. Distance Walk Test – Gait Velocity and Cadence–Outdoor [24]

Age range: 6 years to 19 years.

3.1 Clinical Use

- Provides a standard method for measuring on a long walkway, comfortable gait velocity, fast gait velocity and cadence, outdoors, on a level terrain.

3.2 Measurements

- Gait velocity is recorded in m/min (Table 1.6).
- Cadence: The frequency of steps is recorded in steps/min (Table 1.6).

3.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- A reliable pedometer if measuring cadence.
- Masking tape to use as marker.
- A chair needed during rest periods. The child's feet must be flat on the floor.

ENVIRONMENT

- Level outdoor track.
- Distractions should be avoided to the maximum extent possible.

PRE-TEST

- Prepare a 60.5-meter-circular level outdoor track (198.5 ft) (Fig. 1.4).
- Place a small marker for the start-finish line. Marker should be as discrete as possible.
- Familiarize the child with the outdoor track.
- Instructions for the subject:
  - For comfortable gait speed: Ask the child to walk on the command "GO" at his preferred walking speed and to stop when asked to do so.
  - For fast gait speed: Ask the child to walk on the command "GO" as quickly as possible but safely, and to stop when asked to do so.

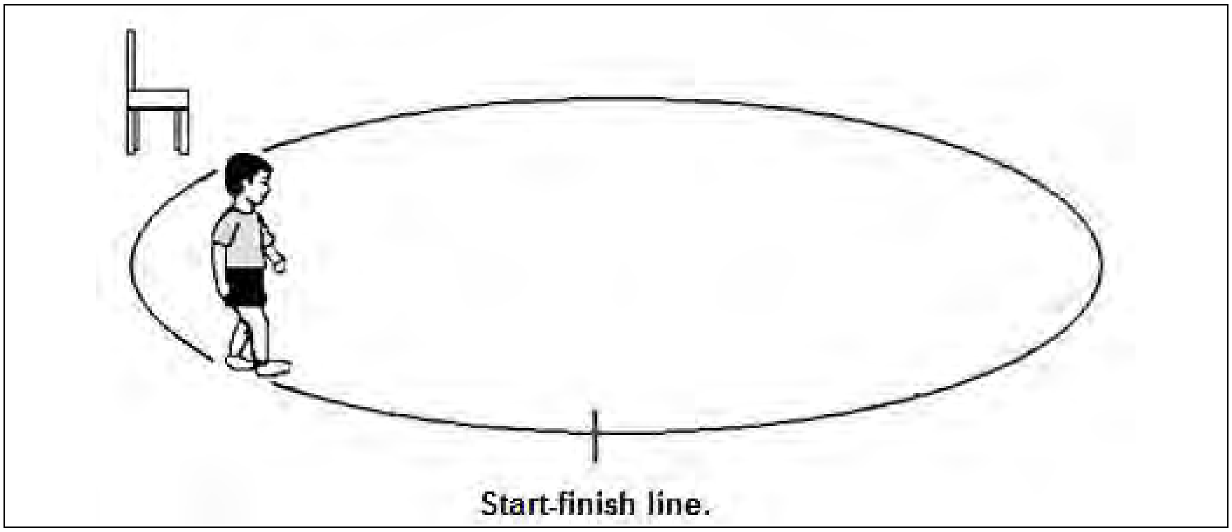

Figure 1.4. 60.5-meter-circular level outdoor track (198.5 ft). (© IRDPQ-2008).

TEST

- Number of trials: Have the child perform 3 repetitions of each condition and calculate the average time for each gait speed.
- Rest periods of approximately 3-5 minutes are suggested between trials.
- On the command "GO", the child starts walking at a comfortable self-selected speed and the stopwatch is started when one foot crosses over the start line.
- Stopwatch is stopped when one foot crosses over the finish line.
- The same method is used when testing fast gait speed.
- Results are compared to the normative reference values in Table 1.6 for gait velocities and cadence.

3.4 Normative Reference Values

ENERGY–SPEED RELATIONSHIP

TABLE 1.6. *Gait characteristics of customary normal, slow, and fast walking*[a]

Group	Velocity (m/min)			Cadence (Steps/min)			Stride length (m)		
	Normal	Slow	Fast	Normal	Slow	Fast	Normal	Slow	Fast
Children (6–12 yr)									
F	68.29	53.55	88.48	119.19	98.59[b]	135.23	1.148	1.086	1.261
	9.19	8.02	12.40	9.25	9.33	6.50	0.147	0.146	0.304
M	70.72	57.18	87.59	120.35	104.55[b]	136.18	1.178	1.069	1.291
	8.02	6.29	11.79	7.79	9.14	9.27	0.138	0.243	0.180
T	69.64	55.55	87.96	119.84	101.87	135.77	1.165	1.077	1.278
	8.57	7.28	11.96	8.42	9.62	8.14	0.142	0.204	0.241
Teens (13–19 yr)									
F	73.16	57.23	98.15	107.21[b]	95.26[b]	123.57[b]	1.364[b]	1.175	1.617[b]
	8.96	8.14	16.19	6.83	6.38	15.24	0.133	0.267	0.387
M	73.41	56.49	98.96	99.84[b]	89.17[b]	116.40[b]	1.465[b]	1.219	1.694[b]
	11.58	10.83	15.43	7.96	0.09	8.68	0.157	0.334	0.181
T	73.28[c]	56.89	98.53[c]	103.74[c]	92.39[c]	120.19[c]	1.412[c]	1.196[c]	1.654[c]
	10.17	9.39	15.69	8.23	8.24	12.98	0.152	0.298	0.308
Adults (20–59)									
F	77.67	37.01[b]	99.36[b]	117.59[b]	67.61	137.03[b]	1.319[b]	0.891	1.237[b]
	10.71	14.27	12.22	9.60	19.86	11.30	0.133	0.461	0.537
M	81.58	47.65[b]	110.44[b]	108.15[b]	76.30	125.43[b]	1.511[b]	1.033	1.673[b]
	9.41	16.02	12.65	9.11	16.70	11.50	0.141	0.472	0.420
T	79.76[c]	42.76[c]	105.57[c]	112.55[c]	72.31[c]	130.53[c]	1.422	0.967[c]	1.470[c]
	10.16	16.03	13.55	10.42	18.59	12.72	0.167	0.469	0.522
Seniors (60–80 yr)									
F	71.83[b]	48.28	85.37[b]	112.85[b]	84.93	124.04[b]	1.272[b]	1.085	1.318[b]
	10.04	10.53	9.65	9.21	13.85	9.81	0.130	0.268	0.304
M	76.64[b]	49.64	96.71[b]	105.85[b]	78.92	118.69[b]	1.450[b]	1.159	1.630[b]
	9.01	11.01	9.93	9.58	12.59	8.22	0.138	0.386	0.133
T	73.55[c]	48.91[c]	89.52[c]	110.36[c]	82.84[c]	122.08[c]	1.335[c]	1.112[c]	1.43[c]
	9.93	10.65	11.14	9.81	13.64	9.56	0.158	0.314	0.296

[a] Mean and 1 SD.
[b] Significant ($p < 0.05$) difference between male and female subjects.
[c] Significant ($p < 0.05$) difference between preceding value in younger age group.

© Waters, Lunsford, Perry, and Byrd (1988), p. 217. [24]

3.5 Study Summary

Title: Energy-Speed Relationship of Walking: Standard Tables [24]	
Authors	Waters R. L., Lunsford B. R., Perry J., & Byrd R.
Publication	Journal of Orthopaedic Research, 1988, 6, 215-22.
Purpose of the Study	To establish a standard reference for the energy expenditure of normal walking at different speeds and in different age groups for both male and female subjects.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of gait velocity and cadence outdoors.

Methods

Subjects

- The study sample consisted of 260 healthy subjects. USA.
- Age range: 6 years to 80 years.
- The subjects were divided into four age groups based on chronological age in years (between parentheses):
  - Group 1: Children, (6 to 12), n = 61;
  - Group 2: Teens, (13 to 19), n = 53;
  - Group 3: Adults, (20 to 59), n = 73;
  - Group 4: Seniors, (60 to 80), *n* = 73.

Testing Procedures and Instrumentation

- Gait characteristics (speed, cadence, stride length) on a 60.5 m-circular outdoor track, weight and leg length were measured. Oxygen consumption with a modified Douglas Bag technique was measured during the fourth and fifth minutes of each trial.
- Energy expenditure (rate of oxygen uptake, energy cost per meter and heart rate) for slow, normal and fast gait speeds was calculated.

Data Analysis

- Analysis of the data on the energy expenditure and gait characteristics was calculated to determine mean values of these variables.
- Linear regression analysis and analysis of covariance were calculated to analyze energy-speed relationship and the differences in slopes and intercept between age groups, respectively. Statistical significance was determined at ($p < 0.05$). Mean and standard deviations (SD) were calculated.

Results

- **Psychometric Properties**: Not applicable.

- The mean and SD of the velocity, stride lengh, and cadence for the group of young adults in this study are extremely close to the values reported in another study (> 2000 pedestrians walking in selected urban areas, unaware that they were being observed). On this basis , the authors of the present study concluded that the experimental subjects walked in an unrestrained manner and that their gait was not altered by the testing procedure.

3.5 Study Summary (Continued)

Results

The following information concerns the pediatric population only:

Gait Speeds and Energy Cost:

- Customary normal speeds for children and teens significantly increase with advancing age, averaging 69.64 and 73.28 m/min, respectively.
- There were no significant differences in:
  - Energy cost that depended on gender;
  - The velocity due to gender for children and teens at their normal speeds. Children had a shorter stride length and higher average cadence in all gait speeds;
- The values for rate oxygen uptake except for the group of children at their slow speed and seniors at their fast speed.
- There were significant differences in energy cost that depended on age. Energy cost in children at all speeds was significantly higher than the other age groups due to their higher rate of energy expenditure and slower gait velocity. Young adults were the most efficient ambulatory.

Heart Rate

- The mean heart rate was higher in females than in males in each group and at all three gait speeds and significantly higher in children.
- Results are presented therein.

Authors' Conclusion

- Normal and fast gait speeds for children and teens increase with age. Mean cadence is higher in children to compensate for their shorter stride. Mean heart rate is higher in women than in men in the three gait speeds. Higher heart rates were observed in children compared to older age subjects.
- Standard references for the energy expenditure of gait at three different speeds, in different age groups for both male and female subjects are presented therein.

Comments

Internal and external validity (including sample size, n = 53 to 73 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

4. Distance Walk Test – Gait Velocity in a School Setting [5]

Age range: 5 to 11 years. Children were classified by grade level, from kindergarten to the 6th grade.

4.1 Clinical Use

- To measure gait speed when walking as a line leader at school.
- To detect potential problems in walking at school among other students. The walking speed of the child with disabilities can be compared to the normative data from this study to estimate his capacity to conform to the pace of peers when walking at school.

4.2 Measurements

- The time it takes to walk a distance of 50 ft (15.2 m) is measured in seconds (Table 1.7).

4.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- Tape measure.
- Masking tape.

ENVIRONMENT

- Open level hallway at school (no stairs and no closed doors).

PRE-TEST

- Prepare a 50-feet walkway (15.2 m).
- Instructions for the subject: "*Walk as the line leader for the class, do not run. Begin walking when told to and stop when instructed to do so*".

TEST

- With the stopwatch, record the time to the nearest second that the first student in line takes to walk along the 50-ft path (15.2 m).
- Results are compared to the normative reference values in Table 1.7.

4.4 Normative Reference Values

TABLE 1.7

Line-leader walking speeds for each grade

Grade	No. of Line Leaders Timed	Mean No. of Seconds to Walk 50 ft	SD	Median No. of Seconds to Walk 50 ft	Range of No. of Seconds to Walk 50 ft	Mean No. of ft/s for Line Leader
K	58	13.5	2.7	13.5	8–25	3.7
1	57	13.1	2.6	13	9–21	3.8
2	61	12.6	2.3	13	7–18	4.0
3	60	12.1	2.1	12	6–19	4.1
4	56	11.6	1.8	12	7–15	4.3
5	63	10.8	2.2	10	5–17	4.6
6	15	10.6	1.1	10	9–13	4.7
Total	370					

K = kindergarten; SD = standard deviation.

4.5 Study Summary

Title: Expectations for Walking Speeds: Standards for Students in Elementary Schools [5]	
Authors	David K. S., & Sullivan M.
Publication	Pediatric Physical Therapy Journal, 2005, 17, 2, p.120-127.
Purpose of the Study	▪ To determine children's walking speeds in elementary school hallways. ▪ To determine what a teacher's slowest but "good enough" walking-speed would be if he or she had to slow down his or her class's line to accommodate a student with a mobility limitation.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of gait speed among peers in a natural setting (school hallways).

Methods

Subjects

- The study sample consisted of 370 healthy children and 290 teachers. USA.
- Age range: 5 years to 11 years.
- Line leaders were classified by grade level and not by age. Sample size from kindergarten to the 5th grade consisted of 56 to 63 children. Sample size in the 6th grade was the lowest (n = 15).
- Since walking speed is independent of gender, no attempt was made to identify or control gender.

Testing Procedures

- Time needed for line leaders to walk a 50 ft (15.2 m) path and "good enough" time that the teachers considered acceptable to walk this distance were measured with standardized procedures.
- Gait speed was assessed in school hallways. The speed of the class-line was defined as the speed of the first student in line.
- Therapists were requested to note comments and teachers' prompts during the timing.

Data Analysis

- Inter-rater reliability in measuring walking speed was analyzed with two physical therapists as they timed the same class–lines (20 observations) and teachers good enough time to walk the 50 ft (15.2 m) path.
- Intra-class correlation method 2 (Covariance matrix) analysis was calculated.
- One way ANOVA was used to identify the differences among the group means of the time to walk 50 ft (15.2 m). Multiple comparison test (Scheffé) were used to calculate more specific differences. Tamhane multiple comparisons were used because of unequal variances among grades. Median, mean, range and standard deviations (SD) were calculated.

4.5 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Inter-rater reliability was high for line leaders' walking speed (ICC= 0.99) and teachers' "good enough" time (ICC = 0.99). ▪ Significant differences were found among grades in mean seconds to walk 50 ft (15.2 m). (F =10.92, df = 6, $p < 0.001$). Kindergarten mean seconds was 13.5 seconds and 0.6 seconds for 6th grade. ▪ Teachers' "good enough" times were significantly different from the actual line-leader times at every grade level ($p < 0.001$). The difference of the mean time of the teacher and the mean time of the line leader ranged from 5.8 sec to 12.2 sec. This may suggest that for children with slower walking speed, adaptation by slowing the gait speed when walking in a class-line can be acceptable. ▪ Results support the existence of a standard for walking in elementary schools when class-lines are used among the usual different environmental variables found in school hallways. Prompting by teachers was found in 46% of the time and decreased with increasing grade. ▪ Generalizing the study is limited by not obtaining a randomized sample and potentially homogeneous school structure. ▪ When comparing walking speed data of the present study with other studies, speeds were higher than walking speeds in gait laboratories and were lower than walking speeds in a gymnasium. Speed in a natural environment as a line leader appeared to be affected by multiple variables including the teacher's position and verbal prompts.
Authors' Conclusion
▪ The authors report that the model of data collection could be replicated easily. ▪ Normative data of the present study gives a more ecological functional standard than gait laboratories values and allows therapist to project more realistic goals. Time to walk 50 ft (15.2 m) decreased from kindergarten to 6th grade. ▪ Teachers' expectation for "good enough time walking" was significantly less than the actual line leader at every grade level and teachers were willing to slow down to that good enough time. This may permit students with slower gait speeds to be a member in the class-line when moving through hallways.

Comments
▪ Internal and external validity (including sample size, *n* = 56 to 63) seems good and the use of results as a trend for clinical guidelines is appropriate. However, sample size is small in the 6th grade (*n* = 15) and the use of results must be interpreted with caution.

5. Functional Ambulatory Mobility Test – Timed 'Up and Go' Test in Children [25]

Age range:
- Preschool age children: 3 to 5 years;
- Primary school age children: 5 to 9 years.

5.1 Clinical Use

- To assess gait control through a typical activity in children who present balance problems and difficulty in turning during gait.
- To monitor change over time, particularly following interventions that aim to improve gait, speed of transitions and turns in children with physical disabilities. [25]

5.2 Measurements

- The time it takes a child to rise from a sitting position on a chair, walk a 3-meter distance (9.8 feet), touch a target on a wall and come back to the initial sitting position is recorded in seconds (Fig.1.5, Fig.1.6).

5.3 Testing Procedures

REQUIRED EQUIPMENT

- Goniometer to assess knee angle.
- Stopwatch.
- An armless straight-backed chair. The child's feet must be flat on the floor with a knee angle at 90° flexion (SD: 10°).
- A cut-out star.
- Masking tape.

ENVIRONMENT

- A clear unobstructed hallway with a wall at one end of the walkway.
- In the present study, the TUG test was conducted in familiar settings.

PRE-TEST

- Prepare a 3-meter walkway (9.8 feet) (Fig. 1.5):
  - Place the chair at the beginning of the path;
  - At the end of the walkway, secure the star on the wall at the child's shoulder height.
- The TUG is performed without a practice trial. However, a demonstration of the TUG is provided by the tester so that the child becomes familiar with the testing environment.
- The child must understand the test instructions and, if not, the test is suspended.
- Instructions for the subject and the tester (between parentheses):
  - *"This test is to see how you can stand up, walk and touch the star, then come back and sit down.The stopwatch is to time you. I am going to ask you to do the test three times (hold up three fingers) or twice (if child has a disability). After I say "go", walk and touch the star, and then come back and sit down. Remember to wait until I say "go". This is not a race; you must walk only, and I will time you. When you are ready…go! Dont forget to touch the star, come back and sit down''.*

TEST

- Number of trials: In the present study, the healthy child was tested three times. The child with disabilities was tested twice. The mean was calculated with the amount of trials tested.
- The test is repeated if the child exhibits behavioral variations.
- Starting position: The child sits in the chair with a knee angle at 90° flexion (SD: 10°) with feet f lat on the floor.
- The child uses his customary walking aids (cane, walker, foot orthoses…). No physical assistance is given.
- After "go", the child stands, walks and has to touch the star on the wall before returning to the chair. Verbal instructions are repeated during the test.
- Timing: The procedure consists in measuring movement time only:
  - Stopwatch is started as the child leaves the seat and not on the instruction "go";
  - Stopwatch is stopped as the child's bottom touches the seat.
- Scoring: Time for 'Up and Go' test: _________sec.
- Results (time in sec) are compared to the normative reference values in Fig. 1.6.

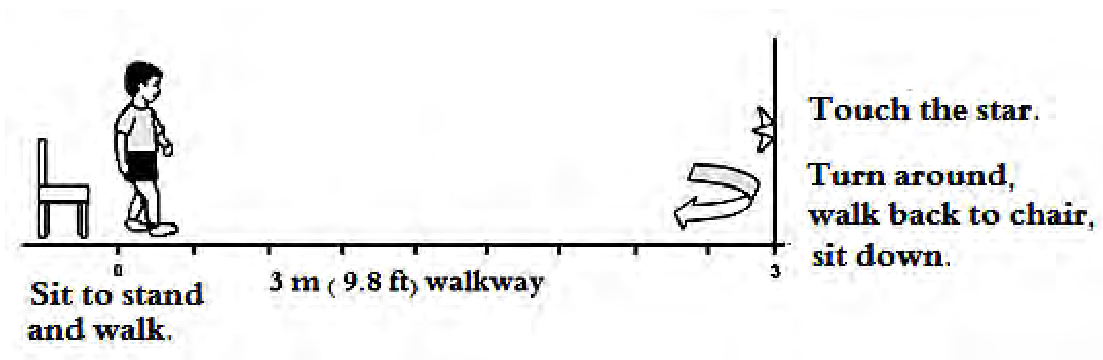

Figure 1.5. Testing procedures for the TUG-IC. [25] (© IRDPQ-2008)

- Additional clinical observations:

YES	NO	
☐	☐	Takes excessive time to rise from the sitting position?
☐	☐	Postural instability, steppage, sway?
☐	☐	Unstable when turning?
☐	☐	Differences between turning to the left and turning to the right? ___________

5.4 Normative Reference Values

- **The mean TUG score in seconds for preschoolers was 6.7 (SD: 1.2) and for primary school children, 5.1 (SD: 0.8).** [25]

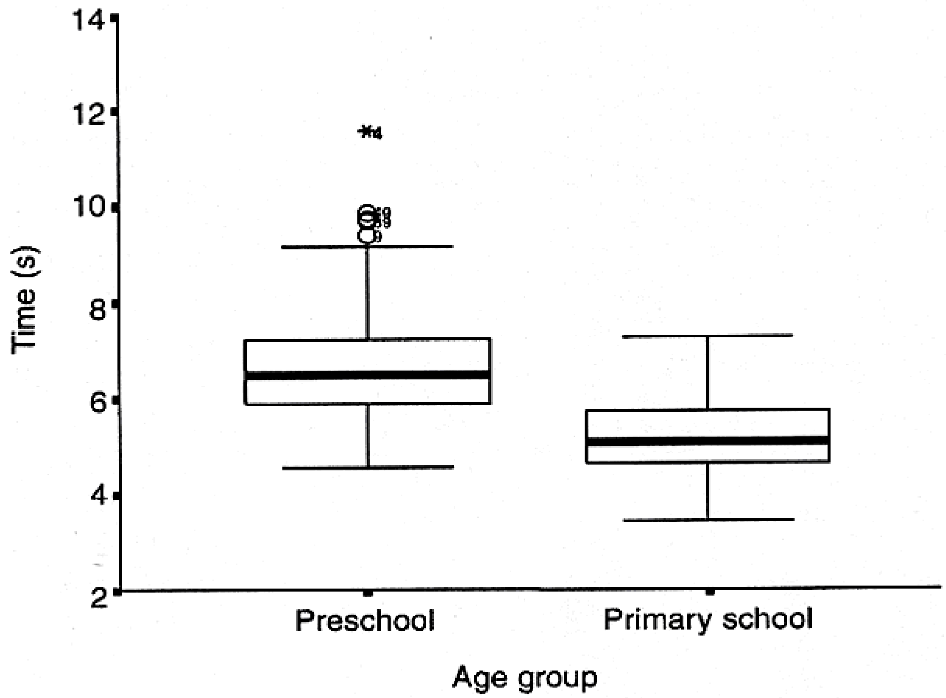

Figure 1.6. *Box plot showing preschool (n=86) and primary school (n=90) groups comparing timed 'Up & Go' scores for all participants at time 1. Rectangles represent 50% of participants, whiskers show range of values, and bold line shows median value. ○, mild outliers; *, extreme outlier.*

© Williams, Carroll, Reddihough, Phillips and Galea. (2007), p. 521. [25]

5.5 Study Summary

Title: Investigation of the Timed "Up & Go" Test in Children [25]	
Authors	Williams E. N., Carroll S. G., Reddihough D. S., Phillips B. A., & Galea M. P.
Publication	Developmental Medicine and Child Neurology, 2005, 47, 18-24.
Purpose of the Study	▪ To determine if children can reliably perform the timed "Up & Go" test (TUG) and if the TUG was responsive to change over time. ▪ To examine validity and reliability within session.
Type of Population	☒ Normal ☒ Other: Cerebral palsy, spina bifida
Clinical Relevance	▪ Assessment of dynamic balance and the ability in making movement transition during gait. ▪ To monitor progression in gait, over time.

Methods

Subjects
The study sample consisted of two groups of children:

- Children without disabilities: *n* = 176 (82 ♀, 94 ♂); age range: 3 years to 9 years;
- Children with disabilities: *n* = 41 (33 cerebral palsy, 8 spina bifida); age range: 3 years to 19 years;
- Australia.

Children without Disabilities

- All children were divided into two groups based on school grade:
  - The preschool group consisted of 86 children aged 3 to 5 years;
  - The primary school group consisted of 90 children aged 5 to 9 years.

Testing Procedures and Instrumentation

- A pilot study with children without disabilities (3 years to 6 years) and one 8-year-old child with cerebral palsy (CP) was undertaken prior to the study to adapt the test to a pediatric population.
- The TUG test was conducted in familiar settings in small groups. Behavioral variations were noted.
- Measurements were conducted by the same tester with healthy children. Three trials within one session were conducted. After a rest period of 10 – 20 sec, another three trials were repeated. Other retests were done one week and five months later.
- Three experienced physical therapists assessed the children with disabilities. Reliability in children with disabilities was performed by same day retesting.
- Instrumentation: Stopwatch and a standard goniometer.

Data Analysis

- Statistical analysis was performed using SPs for Windows. Reliability was analyzed using the ICC, including the 95% confidence intervals (CIs). Standard error of measurements (SEM), parametric tests and independent *t*-tests were calculated. The independent *t*-test and paired *t*-test level of significance was set to 0.025 using a Bonferroni correction. Non parametric Krusdall-Wallisand, one way ANOVA, Mann-Whitney *U*-test and Spearman's non parametric correlation coefficient were used for analyzing different variables. Mean and standard deviations (SD) were calculated.
- The TUG was compared to the GMFCS and the GMFM.

5.5 Study Summary (Continued)

Results
CHILDREN WITHOUT DISABILITIES 176 children were assessed at Time one. 173 children returned for retest on the same day (Time 2). One week later (Time 3), 151 children were reassessed and, five months later (Time 4), 128 children were retested. ▪ **Psychometric Properties:** Good reliability was reported for within-session trials for time 1-2-3 (ICCs = 0.80, 0.89, 0.85), respectively. Response stability was good (ICC = 0.89; 95% CI = 0.86 to 0.92) as was test-retest reliability (ICC = 0.83; 95% CI = 0.77 to 0.88). For the preschool group, there was good response stability (ICC= 0.82) and moderate test-retest stability (ICC = 0.61). When children with behavioral variations were excluded, reliability improved in response stability (ICC = 0.88) and in test-retest stability (ICC = 0.71). Good reliability in response stability was reported in the primary school group (ICC = 0.76) and in test-retest stability (ICC = 0.83). ▪ There was no statistically significant difference in mean scores between genders (p = 0.859). Preschool children took longer to complete the test (p = 0.001) than older children. Mean time was 6.7 seconds (SD 1.3) and 5.2 seconds (SD 0.8), respectively. ▪ Responsiveness**:** Sensitivity was assessed in children five months later. There was a significant decrease in mean TUG scores in the preschool group (*p* = 0.001) and a smaller change in the primary school group (*p* = 0.02). **CHILDREN WITH DISABILITIES** All patients were independent in walking and the assistive devices were kept consistent in each testing session. ▪ **Psychometric Properties:** Good reliability was reported for within-session trials for Time 1 (ICCs = 0.98; 95% CI = 0.97 to 0.99) and Time 2 (ICCs = 0.98; 95% CI = 0.88 to 0.99). Reliability for same day retest was also high (ICCs = 0.99; 95% CI = 0.91 to 0.99). ▪ TUG compared to GMFCS and lesion level**:** There were significant differences between participants (*p* = 0.001) at GMFCS level 1 – 2 – 3. ▪ TUG compared to GMFM: There was a moderate negative correlation between the scores of the two tests with lower TUG scores being associated with higher % in GMFM scores for the standing and walking domains (*rho* = -0.524, *p* = 0.012). The moderate negative correlation between the TUG scores and the GMFM indicates the potential for the TUG to be administered between testing sessions to provide an indication of progress or deterioration with regard to mobility. Further study in a larger group may provide stronger evidence. All the tested children could complete the TUG test. After a demonstration, the test was reliable in children with or without physical disabilities. Behavioral variations in children less than 5 years of age affected the most the range and reliability of the TUG scores. Test should be repeated if the child presents behavioral variations such as hopping or running. A contraindication in the use of this test is the inability to understand instructions. This is consistent with other authors. Mean time score in the healthy children to perform the TUG was 5.9 sec, (range of 3 to 13 sec) without considering behavioral variations. Range of scores for the older group was 3.1 to 8 sec and range of scores for the younger group was 3 to 13 sec. Results are consistent with other studies. The TUG in children was demonstrated to be responsive to changes in time and appears to be sensitive to changes in functional mobility as demonstrated by other authors. Subjects were a convenience sample and therefore may not be representative of a wider population but were representative of the children in their age groups at school. Some of the children were very young which may have influenced the results. The number of subjects in children with disabilities was small compared to the healthy children.

5.5 Study Summary (Continued)

Authors' Conclusion
Results indicate that the modified TUG for children could be useful as an objective measurement test of disability for the mobility domain and could be used clinically to monitor changes over time. It is reliable in young children if they understand the instructions and performs without behavioral variations. The responsiveness of the TUG was demonstrated by significant change over time in the younger children. It is reliable and valid for ambulant children with disabilities.

Comments
Internal and external validity (including sample size: 176 children without disabilities and 41 children with disabilities) seems good and the use of results as a trend for clinical guidelines is appropriate.

6. Timed-Walk Test – Six-Minute Walk Test–Outdoor [20]

Age range: 7.5 years to 9 years.

6.1 Clinical Use

- The Six-Minute Walk Test (6-MWT) is a useful measure of functional capacity. It is a test of cardiovascular fitness and walking endurance.

6.2 Measurements

- The distance walked in six minutes, at a normal, self-selected walking speed is measured in meters (Table 1.8 – Table 1.9) or in feet (Table 1.9).
- Repeat testing should be performed about the same time of day to minimize intra-day variability. [33]

6.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- 7.62-m tape measure (25-foot).
- 8 cones.
- Plastic straws.
- We suggest using chairs for rest periods, if necessary.

ENVIRONMENT

- The study was performed on the school's playing fields (grassy fields) and children were tested in groups.

PRE-TEST

- Prepare a 60.96-meter outdoor square-shaped track (200-foot). (Fig 1.7).
- Place a cone at each corner as well as four cones marking every 7.62-m (25 feet) from the corners.

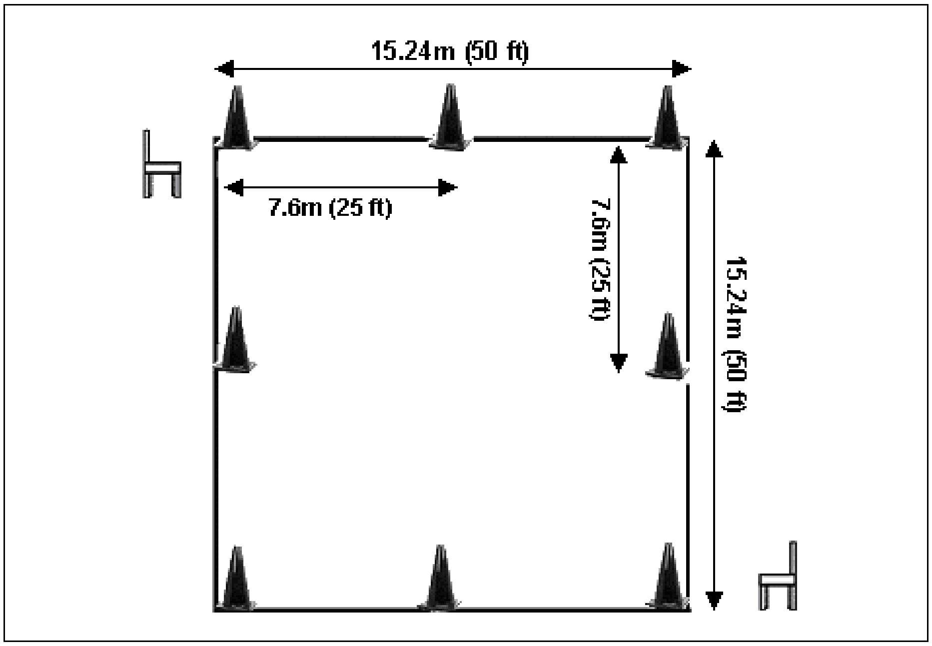

Figure 1.7. 60.96-m outdoor square-shaped course (200-foot). (© IRDPQ-2008).

- Instructions for the subject :
  - *"On "Start", you must walk, don't run, skip or hop";*
  - *"You must stay around the outside of the cones";*
  - *"A plastic straw will be given to you after the completion of each lap. You will hold the straws until the end of the 6-MWT and until I collect them'';*
  - *"After six minutes, I will say "freeze", which indicates the completion of the test. At "freeze", you will stop walking, and stay in place until the measurements are completed''.*
- If the test is performed with children with health conditions, the clinician should review the guidelines of the American American Thoracic society ATS Statement: Guidelines for the 6-MWT [33] are available at: http://ajrccm.atsjournals.org/cgi/content/full/166/1/111

TEST

- During the 6-MWT, the child is given words of encouragement such as "*Good job*" or "*Keep up the good work*".
- After the completion of each lap, the tester gives a plastic straw to the child. This will help calculate the distance traveled.
- Timing:
  - The stopwatch is started on the command "Start".
  - After six minutes, the tester states "freeze" and the stopwatch is stopped.
- On the command "freeze" the child stops walking and stays in place. The straws are collected and the distance walked is measured.
- Results are compared to the normative reference values in Table 1.8 (Mean distance walked by gender) and in Table 1.9 (Percentile rank for mean distance walked by gender).

NOTE

- For children who are unable to hold the straws, we suggest using a container into which the tester can drop a straw after the completion of each lap.
- During the 6-MWT, most patients do not achieve maximal exercise capacity; instead they choose their own intensity of exercise and are allowed to stop and rest during the test. [33] A chair is supplied to allow a rest period, if necessary. Elapsed time continues during the rest periods.

6.4 Normative Reference Values

TABLE 1.8. Means, Standard Deviations, Skewness, Kurtosis, and 95% Confidence Intervals for distanced walked.

	Females		Males	
	Body Mass Index (kg/M²)	Distance (meters)	Body Mass Index (kg/M²)	Distance (meters)
Mean	16.3	532.2	15.5	581.7
SD	2.9	52.6	2.0	58.1
N	38	38	38	38
Skewness	0.95	-0.26	0.96	-0.76
95% CI Lower Limit	0.15	-1.06	0.16	-1.56
95% CI Upper Limit	1.75	0.54	1.76	0.04
Kurtosis	0.69	-0.26	1.00	0.5
95% CI Lower Limit	-0.92	-1.87	-0.61	-1.11
95% CI Upper Limit	2.30	1.35	2.61	2.11

© Roush, Guy, and Purvis (2006), p. 4. [20]

6.5 Percentile Chart

TABLE 1.9. Percentiles for distanced walked by gender.

	Females			Males	
Percentile	Distance Walked (m)	Distance Walked (ft)	Percentile	Distance Walked (m)	Distance Walked (ft)
P95	619	2030	P95	677	2222
P90	600	1967	P90	656	2152
P85	587	1925	P85	642	2106
P80	576	1891	P80	631	2069
P75	568	1863	P75	621	2037
P70	560	1837	P70	612	2009
P65	552	1813	P65	604	1982
P60	546	1790	P60	597	1957
P55	539	1768	P55	589	1932
P50	532	1746	P50	582	1908
P45	526	1724	P45	574	1885
P40	519	1702	P40	567	1860
P35	512	1680	P35	559	1835
P30	505	1655	P30	551	1808
P25	497	1630	P25	542	1780
P20	488	1601	P20	533	1748
P15	478	1567	P15	522	1711
P10	465	1525	P10	507	1664
P05	446	1462	P05	486	1595

© Roush et al. (2006), p. 4. [20]

6.6 Study Summary

Title: Reference Values and Relationship of the Six-Minute Walk Test and Body Mass Index in Healthy Third-Grade School Children [20]	
Authors	Roush J, Guy J, & Purvis M.
Publication	The Internet Journal of Allied Health Sciences and Practice 2006, 4, 3.
Purpose of the Study	To establish reference values of the six-minute walk test for children and to determine the relationship between BMI and walking distance.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of walking endurance and cardiovascular fitness during gait.

Methods

Subjects

- The study sample consisted of 76 healthy subjects: (38 ♀ and 38 ♂). USA.
- Age range: 7.5 years to 9 years.

Testing Procedures and Instrumentation

- Weight and height were measured and body mass index (BMI) calculated.
- Subjects walked at a normal, self-selected, walking speed on a grassy field for six minutes. Distance traveled was measured by the same tester to maintain consistency. Time (six minutes) was measured with a stopwatch and distance traveled with a standard tape measure.

Data Analysis

- Testing was performed on two different days, during a five-day period, and the mean distance of the two tests was calculated for data analysis.
- Weight and height, distance walked, age and BMI were measured. Data analysis was performed using descriptive analyses including means, standard deviations, skewness, kurtosis and percentiles. A t-test was performed to determine if there were significant differences in distance walked according to gender. Partial correlations were calculated to determine the relationship between BMI and distance walked with the influence of age removed.

Results

- **Psychometric Properties**: Not applicable
- Data Analysis: At an alpha level of 0.05, there was a mean difference according to gender of 49.45 m (t =3.892; df=74;p=0.002). Mean walking distance was 581.70 m (sd=58.10) for males and 532.20 m (sd=52.60) for females. A 95% confidence interval was used to test the null hypothesis that the data fit a normal distribution. It was concluded that the data did not differ from a normal distribution. Percentile charts were calculated separately for males and females and are reported therein.
- The partial correlation between BMI and distanced walked with the influence of gender removed was 0.10 ($p > 0.05$). The partial correlation between BMI and distanced walked with the influence of age removed was 0.02 ($p > 0.05$). Mean BMI was 15.50 (sd=2.00) for males and 16.30 (sd=2.90) for females. There was no relationship between distance walked and BMI.
- Limitation of the study: The authors report that, when instructed to walk, some children, ran, galloped or skipped or, when asked to stop walking, some students may have taken extra steps. They also report that the sample size may be criticized for the small number of subjects but that data fitted the normal distribution and was a good representation of the population.

6.6 Study Summary (Continued)

Authors' Conclusion
There is no relationship between distance walked and BMI. Reference values of the six-minute walk test for healthy, third-grade school children were calculated and are presented separately for each gender.

Comments
Internal and external validity (including sample size, *n* = 76) seems good and the use of results as a trend for clinical guidelines is appropriate.

7. Timed-Walk Test – Thirty-Second Walk Test – Indoor [9]

Age range: 6 years to 13 years.

7.1 Clinical Use

- Provides a standard method for measuring gait in a natural environment (gymnasium) during a short period of time.
- This test is useful for children having difficulty walking long distances.

7.2 Measurements

- The distance walked in 30 seconds is measured in feet or in meters (Fig 1.9).

7.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- Standard 100-foot (30.48 m) metal tape to prepare the walking course.
- Standard ¾-inch (1.9 cm) white masking tape to use as markers.

ENVIRONMENT

- School gymnasium.

PRE-TEST

- Prepare an oval walking course. The authors of the study used a walking course measuring 60 x 30 ft (8.2 x 9 m) or 64 x 40 ft (19.5 x 12.1 m). The four corners are taped in a curved fashion to eliminate the sharp 90^0 corners.
- Place small markers at every 1 foot (30.48 cm) increments. This will help to calculate the distance walked (Fig.1.8).
- Instructions for the subject: "…*Walk as if you were a line leader for the class, walk at a comfortable speed, do not run. Begin walking when told to "go!" and stop when instructed to "stop!"…" "At stop you will stop walking and stay in place until the measurements are completed"*.

TEST

- Clothing: Regular clothes and shoes.
- The child is to walk at a natural and comfortable speed in a counter-clockwise direction, beginning with the longest length of the gym.
- Timing:
  - Start stopwatch on "go!";
  - Stop after 30 seconds.
- Measure the distance to the nearest inch by measuring the most advanced part of the foot in contact with the ground. When you call ''stop'', observe the placement of the foot (Fig. 1.8):
  - If heel strike is complete, the measurement is taken to the heel;
  - If midstance is complete, the measurement is taken to the toe of the shoe.
- Results are compared to the percentile chart in Fig. 1.9.

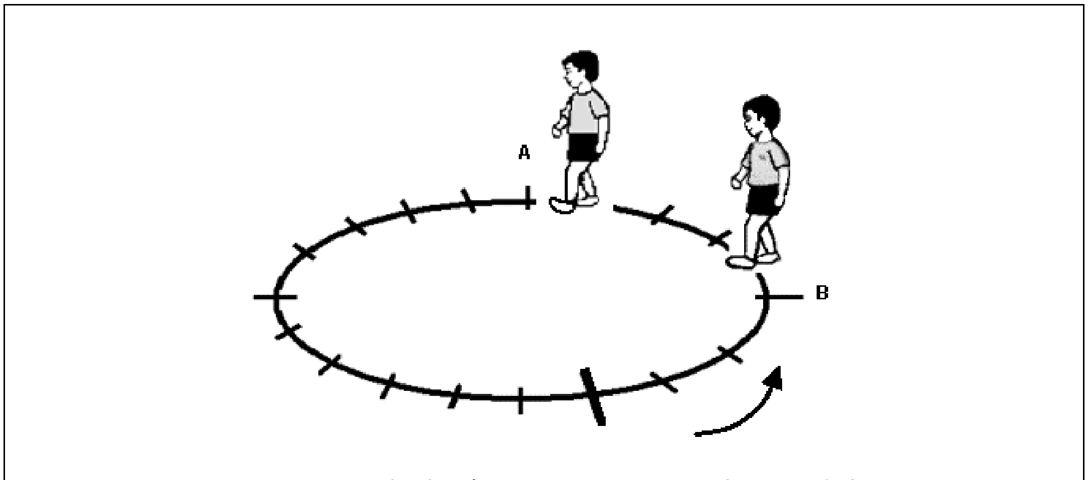

Figure 1. 8. The thirty-second walking course. (© IRDPQ-2008).

7.4 Percentile Chart for the Thirty-Second Walk Test

The authors report that age is the easiest value to ascertain in clinical situations and have chosen to present the normative data by using the percentile chart according to age.

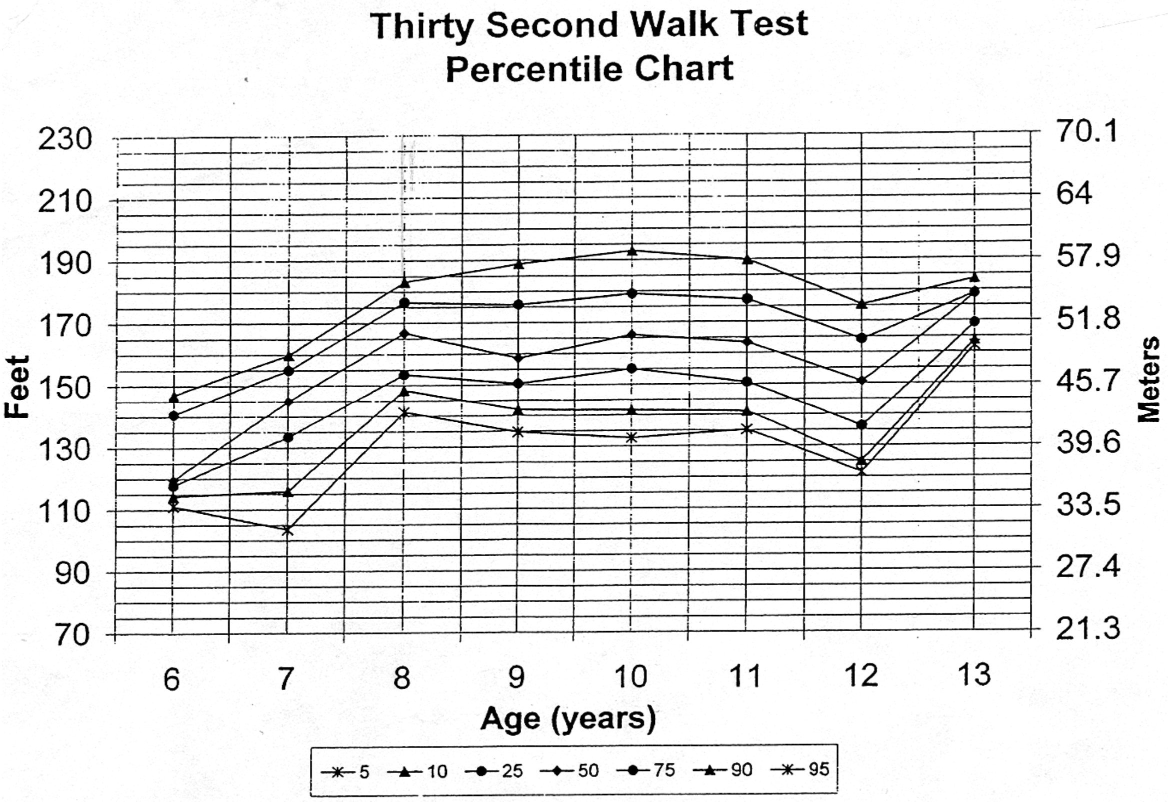

Figure 1.9. Thirty-Second Walk Test percentile chart. For clinical use, enter the chart according to the child's age, then move vertically to find the corresponding feet (left margin) or meters (right margin) that the child walked in 30 seconds. Enter a mark with a colored pen to indicate the child's performance compared with age-matched able-bodied peers.

© Knutson, Schimmel, P. A., and Ruff, A. (1999), p. 188. [9]

7.5 Study Summary

Title: Standard Task Measurement for Mobility: Thirty-Second Walk Test [9]	
Authors	Knutson L. M., Schimmel P. A., & Ruff A.
Publication	Pediatric Physical Therapy Journal, 1999, 11, 4,
Purpose of the Study	To establish a normal database on distance walked in 30 seconds.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of functional mobility in a natural environment (gymnasium).This short test is useful for children presenting difficulties in walking long distances.

Methods

Subjects

- The study sample consisted of 227 healthy children (116 ♀, 111♂). USA.
- Age range: 6 years 6 months to 13 years 6 months.
- 213 Caucasians; 11 Hispanics and 3 Asians.
- The number of children varied in each group, with less children in the 6-, 8-, and 13-year-old groups.
- Children were recruited from two elementary schools.

Testing Procedures and Instrumentation

- A pilot study was conducted prior to the research study to streamline different variables.
- Weight, height and right leg length were measured. Gait was assessed with standardized procedures.
- Instrumentation: Stopwatch.
- Three testers and three assistants acquired the data with standardized instructions and equipments.

Data Analysis

- Descriptive statistics were calculated on all variables for each age group.
- ANOVA with Newman-Keuls follow-up tests were used to assess the differences in walking distance across the age groups.
- Pearson product moment correlation and stepwise multiple regression were used to study the association of the variables.
- Mean and standard deviation (SD) were calculated for each age group.

7.5 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Not applicable for the present study. Note: A follow-up study was conducted on 10 new subjects to verify repeatability of distance walked in 30 seconds. Results showed a positive correlation between the first and second test (*r* = 0.81). ▪ The normal database according to the 5th through the 95th percentiles for distance walked in 30 seconds at each age group is presented therein. There was a significant difference in distance walked by age groups (F = 8.591, p = < 0.001). ▪ There was no significant increase in the distance walked in 30 sec, after the age of 8 years. A significant increase between 7- and 8-year-old children differs from other studies which suggest walking behaviour is mature by 7 years and for some variables as early as 4 to 5 years of age between the mean. Finding that children aged 12 years walked slower than 10 and 11 year-olds was unexpected and unexplained. ▪ Of the variables selected as significant in the stepwise multiple regression, leg length was the strongest single pairwise correlation to distance walked. Weight was not significantly correlated to distance walked. ▪ Children walked faster than in other studies. Assessment in a natural environment may have influenced gait speed when compared to studies performed in gait laboratories. ▪ Limits of the study: A population of convenience resulted in 9 to 12 year-olds composing 80% of the data and 7 to 12 year-olds composing 94% of the data. The population sample consisted mostly of Caucasians. ▪ Repeatability of measurements was not calculated, this may be considered more open to error.
Authors' Conclusion
▪ Database describing the distance walked in 30 seconds in children, aged between 6 and 13 years of age was created. This test may provide physical therapists with a standard test for measuring mobility. The percentile chart gives means for comparison and progress monitoring. ▪ The Thirty-Second Walk Test indicated that students walked faster in the school environment compared to gait lab data, suggesting that this test is preferable to use when assessing the child's gait performance.

Comments
▪ Sample size is small in the 6-, 8- and 13- year-old groups and, in this context, the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution. ▪ Internal and external validity seems good in the other age groups (including sample size) and the use of results as a trend for clinical guidelines is appropriate.

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Aquino ES, Mourão FA, Souza RK, Glicério BM, Coelho CC. (2010). Comparative analysis of the six-minute walk test in healthy children and adolescents *Rev. bras. fisioter*. vol.14 no.1 São Carlos Jan./Feb. . http://dx.doi.org/10.1590/S1413-35552010000100012	Comparative analysis of the 6MWT in healthy children and adolescents in two corridors of different lengths: a 30.5-meter corridor, as standardized and proposed by the ATS, and a 20-meter corridor. Data was collected from 67 children aged seven to 14 years . Regarding the cardiac overload and the work rate, there were no significant differences between the corridors. In relation to the walked distance, the two tests carried out in each of the corridors showed no significant difference ($p > 0.05$). However, the comparison of the best test between corridors showed a significant difference ($p < 0.05$). Participants walked longer distances in the 30.5-meter corridor, however the difference in distance was less than 10%, Therefore, the 20m corridor had a good reproducibility for the population of this study.
Dini PD; David AC. (2009) Repeatability of spatiotemporal gait parameters: comparison between normal children and children with hemiplegic spastic cerebral palsy . *Rev. bras. fisioter.* vol.13 no.3 São Carlos. http://dx.doi.org/10.1590/S1413-35552009005000031	Two groups of children aged six to 13 were assessed to evaluate the repeatability of spatiotemporal gait parameters by means of a comparative study between normal children and children with CP. The children were instructed to walk along a 10m path, at a self-determined speed. Both the normal children and those with CP had an excellent to moderate repeatability for all the parameters analyzed. Gait parameters recorded in the laboratory with a one-week interval have sufficient repeatability and serve as a comparative reference for normal children as well as children with spastic hemiplegia CP, when six attempts are used.
Knutson, L. M. PT, PhD, PCS; Bushman, B. PhD, FACSM; Young, J. C. EdD, CHES; Ward, G. PT, ATC. (2009). Age Expansion of the Thirty-Second Walk Test Norms for Children. *Pediatric Physical Therapy:* - Volume 21 - Issue 3 - pp 235-243. doi: 10.1097/PEP.0b013e3181b170d4	Children (n = 302; age, 5-17 years) were tested for distance walked in 30 seconds. Distance walked increased from 5 to 10 years of age, decreased slightly at age 11 years, followed by a more gradual decrease from 12 to 17 years. A significant difference in distance walked was found across ages. Right leg length, age, and weight explained 11.5% of the variance in walk distance. Conclusion: A percentile chart of the pooled data (previous and current, n = 529) should facilitate the use of the 30-second walk test when examining children for mobility limitations.
Holm I, Tveter AT, Fredriksen PM, Vøllestad N. (2009). A normative sample of gait and hopping on one leg parameters in children 7-12 years of age. *Gait Posture*. Feb;29(2):317-21. Epub 2008 Nov 18	360 girls and boys between 7 and 12 years were instructed to walk at four different speeds and to hop on either leg with as long serial jumps as possible across the whole walkway of the GAITRite system. While step length only showed a small increase from 7 to 12 years of age, hop length showed significant increase both in absolute and normalized values. The variability, however, was large, indicating that a normative sample of hop length measurements includes a wide range of values for each age group.

Lammers A E, Hislop A A, Flynn Y, Haworth S G (2008). The 6-minute walk test: normal values for children of 4–11 years of age. *Arch Dis Child* 93:464-468 doi:10.1136/adc.2007.123653	328 healthy children (54% male) aged 4 to 11 years were assessed. Main outcome measures were the distance walked in 6 minutes, and oxygen saturation and heart rate during the 6 minutes and during a 3-minute recovery period. Mean oxygen saturation at baseline and during the 6MWT was 97–99%. Heart rate increased from 102±19 bpm at baseline to a maximum of 136±12 bpm. Distance walked correlated with weight and height with no significant difference between gendres. The distance walked increased significantly year on year from 4 to 7 years; further modest increases were observed beyond 7 years of age. This study provides data on normal children against which the performance of sick children and the response to therapeutic intervention can be judged.
Geiger R, Strasak A, Treml B, Gasser K, Kleinsasser A, Fischer V, Geiger H, Loeckinger A, Stein JI. (2007). Six-minute walk test in children and adolescents. *J Pediatr*. Apr;150(4):395-9, 399.e1-2.	280 boys and 248 girls completed a modified test, using a measuring wheel as incentive device .This modified 6-minute walk test (6MWT) proved to be safe, easy to perform, and highly acceptable to children. It provides a simple and inexpensive means to measure functional exercise capacity in children, even of young age, and might be of value when conducting comparable studies.
Ana Cristina de David, Claudia Esteves, Thiago Nunes, Patrícia Dini, Eliane Manfio University of Brasília – Department of Physical Education, Brasília, Brazil, acdavid@unb.br; Estácio de Sa University Biomechanics Laboratory, Rio de Janeiro Brazil.ABSTRACT (2006) WALKING AND RUNNING SPATIO-TEMPORAL VARIABLES IN CHILDREN FROM THREE TO SIX YEAR OLD. *The International Society of Motor Control* ***Accessed October 31, 2011:*** http://demotu.org/pmcvi/viewabstract.php?id=192	20 healthy children participated in this study. Spatio-temporal data was obtained using two synchronized video. Children walked for 10 meters in the laboratory at self-selected speed, then slow, fast and ran (3 trials per side). Analysis of variance one-way was used to compare stride length between speeds groups. A significance level of 0.05 was used. Stride length was normalized by leg length. The average walking speed increased from a 3-year-old group to a 6-year-old, as expected. Major differences were observed between the ages of four to five. Can it be due to maturation? The average speed of the 5-year-old group and the 6-year-old group was closer. Age-related increase in normalized stride length from 4-year-olds to 6-year olds. Three age group had higher averages than the 4-year-olds. When considered, the total number of children as a group, between normal and fast speed only, at right and left stride length, the differences weren't significant. Higher variation in speed and stride length was found in running. The results provided stride length and speed data for walking and running in children aged from three to six. ***Accessed October 31, 2011:*** http://www.health.uottawa.ca/biomech/csb/Archives/csb2006.pdf
Zaino C.A., Gocha Marchese V, Westcott S.L. (2004). Timed up and down stairs test: preliminary reliability and validity of a new measure of functional mobility. *Pediatric physical therapy* Volume: 16, Issue: 2, Pages: 90-98	The reliability and validity of the Timed Up and Down Stairs (TUDS), were examined in 47 children (20 CP, 27 typical development (TD). The TUDS presents adequate reliability and validity in children with and without CP and appears to complement current clinical measures of functional mobility and balance. Further investigations on across larger age ranges and samples are warranted.

Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

Part 2

Muscle Strength and Physical Fitness

Complete document :

www.irdpq.qc.ca/communication/publications/documents_disponibles.html

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Part 2

Muscle Strength and Physical Fitness

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Summary

Muscle function and muscle force are two fundamentally different parameters of the motor system that are closely related and both are often tested during neurological examination in children[7]. Muscle strength is an indicator of function and weakness may contribute to different levels of disabilities. [6,13]

The assessment of muscle strength allows monitoring the evolution of a pathological condition and is used in diagnostic and therapeutic decisions.[15] In clinical practice, muscle strength can objectively be measured in children by using accurate testing procedures such as:

- Assessment of strength through various functional motor activities.
- Assessment of maximum isometric strength with the hand-held dynamometer.

Physical fitness tests are usually performed in a context of group evaluation in physical education class to teach the students the principles of fitness while measuring different health-related fitness components such as muscular strength and endurance, cardio-respiratory, flexibility and body composition.

Assessment of Strength Through Functional Motor Activities

Muscle strength can be measured in functional activities by testing, in standardized positions, the subject's capacity to perform or not specific abilities. These measurements can be performed by using timed performance tests.
Timed performance tests (TPT) are considered an important adjunct to manual muscle testing and refer to the amount of time it takes a subject to perform a specific test.[6, 19, 28] TPT are measured by giving a score that represents the child's performance and by comparing current performance to the last performance, it will be possible to document gain or loss of muscle strength in follow-ups.[28] In a group of Duchenne muscular dystrophy (DMD) ambulant patients, timed functional testing was the most sensitive parameter to determine the extent of disease progression.[6]

In the review of the literature, very few reports documented TPT. Two studies were selected:

- Beenakker & al. (2005)[6] have established normative values for girls and boys for two TPT:
  - Running a distance of 9 meters;
  - Rising up from the floor.
- Rennebohm & al. (2004)[28] have validated the Childhood Myositis Assessment Scale-9 (CMAS-9) in healthy children:
  - The CMAS-9 is a composite of nine physical maneuvers that measures proximal and distal muscle groups in various activities. The nine activities of the CMAS-9 were chosen from the original scale, the CMAS-14, which is a composite of 14 activities. Description of the CMAS-14 standardized method for conducting the assessment is available at the American College of Rheumatology web-site:http://www.rheumatology.org/publications/ar/2000/octAppendixA.asp[53] (Accessed May 6th, 2010).

  - Validity and reliability

    The CMAS-14 was developed and validated by the Juvenile Dermatomyositis Disease Activity, a collaborative study in children with juvenile idiopathic inflammatory myopathy (IMM).[19] Results showed very good inter-rater reliability (ICC: 0. 89). The CMAS score correlated highly with the Childhood Health Assessment Questionnaire score and manual muscle testing and correlated moderately with the physician-assessed global disease activity and with muscle magnetic resonance imaging, demonstrating good construct validity. The findings also indicated that the CMAS exhibits good responsiveness. The CMAS is reported as a valid instrument for the assessment of physical function, muscle strength, and endurance in children with juvenile IMM.[19]

1. Timed Performance Tests[6]

Age range: 4 years to 11 years.

1.1 Clinical Use

- To quantify functional impairment.
- To assess muscle functional capacity.
- To document gain or loss of muscle strength over a period of time.

1.2 Measurements

- Running is timed in seconds (Table 2.1).
- Rising up from the floor is timed in seconds (Table 2.1).

1.3 Testing Procedures

A. Running a 9 meter distance (29.52 ft)**.**

REQUIRED EQUIPMENT

- Stopwatch.
- Masking tape to use as markers on the floor.

ENVIRONMENT

- A quiet hallway to minimize distractions.

PRE-TEST

- Prepare an unobstructed running path (Fig.2.1).

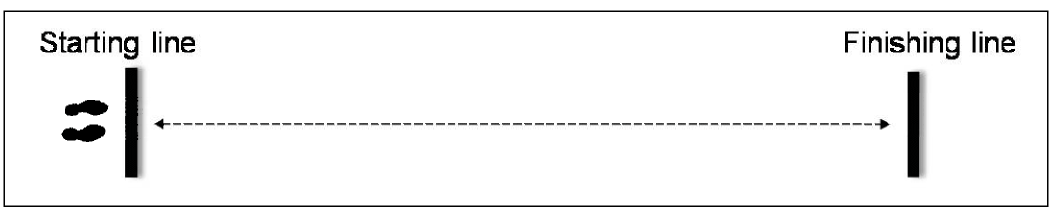

Figure 2.1. 9-meter running path (29.52 ft). (© IRDPQ-2009).

TEST

- Clothing: Underwear clothes. Barefoot.
- The child has to run the 9-meter runway.
- The child is timed while performing the task.
- Stopwatch is started when one foot crosses the starting line and is stopped when one foot crosses the finishing line.
- Results are compared to the normative reference values in Table 2.1.

B. Rising up from the floor

REQUIRED EQUIPMENT

- Stopwatch.

ENVIRONMENT

- A quiet environment is suggested to minimize distractions.

TEST

- Clothing: Underwear clothes. Barefoot.
- The child has to rise up from supine on the floor to a standing position as fast as possible.
- The child is timed while performing the task.
- Results are compared to the normative reference values in Table 2.1.

1.4 Normative Reference Values

Table 2.1.

Age-related reference values (mean, (SD)) for timed functional tests in each age group in normal boys (b) and girls (g). SD = standard deviation, yr = year, sec. = seconds.

Age [yr]		4	5	6	7	8	9	10	11
Number	b	9	9	8	7	7	11	8	7
	g	7	7	7	9	7	8	7	5
Running [sec.]	b	3,35 (0,48)	3,34 (0,34)	2,89 (0,35)	2,44 (0,30)	2,78 (0,27)	2,76 (0,25)	2,72 (0,28)	2,46 (0,28)
	g	3,43 (0,25)	3,32 (0,39)	2,67 (0,47)	2,53 (0,35)	2,57 (0,24)	2,85 (0,12)	2,97 (0,26)	2,68 (0,33)
Rising [sec.]	b	1,56 (0,56)	1,45 (0,16)	1,42 (0,29)	1,28 (0,33)	1,24 (0,24)	1,17 (0,24)	1,08 (0,25)	0,99 (0,14)
	g	1,52 (0,43)	1,45 (0,21)	1,17 (0,19)	1,19 (0,27)	1,03 (0,20)	1,06 (0,21)	1,42 (0,39)	1,13 (0,27)

Reprinted from European Journal of Paediatric Neurology, 9, Beenakker, E. A. C., Maurits, N. M., Fock, J. M., Brouwer, O. F. and Van der Hoeven, J. H. Functional ability and muscle force in healthy children and ambulant Duchenne muscular dystrophy patients, p.389, © 2005 with permission from Elsevier. [6]

1.5 Clinical Examples

- Five-year-old boy
  - Time needed to run 9 meters = 3.0 sec.
  - The result indicates that his performance is within 2 SD from the mean of his age group. There is no indication of muscle weakness.
- Six-year-old boy
  - Time needed to rise from the floor is 2.9 sec.
  - The result indicates that his performance is not within 2 SD from the mean of his age group and may indicate muscle weakness.

1.6 Study Summary

Title: Functional Ability and Muscle Force in Healthy Children and Ambulant Duchenne Muscular Dystrophy Patients [6]	
Authors	Beenakker E. A., Maurits N. M., Fock J. M., Brouwer O. F. , van der Hoeven J. H.
Publication	European Journal of Paediatric Neurology. 2005, 9, 387-93.
Purpose of the Study	To determine normal values for timed functional tests in healthy children aged 4-11 years.
Type of Population	☒ Normal ☒ Other: Children with Duchenne muscular dystrophy (DMD).
Clinical Relevance	Assessment of muscle strength in functional activities.

Methods

Subjects

The study sample consisted of:

- 123 children (57 ♀, 66 ♂) with no disabilities. Age range: 4 years to 11 years.
- 16 ambulant patients with DMD. Age range: 5 years to 8 years.
- Children with no disabilities were divided into eight age groups based on chronological age in years.
- Number of subjects per age group varied from 12 to 19 children.

Testing Procedures and Instrumentation

- Weight, height and body mass index (BMI) were measured.
- Strength: Maximum isometric muscle force in 9 different muscle groups was tested.
- Time to run 9 meters and time to rise up from the floor were recorded.
- Instrumentation: Stopwatch, hand-held dynamometer.

Data Analysis

- Mean values and standard deviations (SD) were calculated for timed functional tests and in muscle groups, bilaterally.
- Sum scores were obtained for total muscle force.
- Student *t*-test, Mann-Whitney test, Shapiro-Wilk test, Pearson correlation coefficients and multiple regression analysis were calculated for comparison between groups and different variables.
- Normal values were compared with values obtained in 16 DMD ambulant patients to study the extent of functional impairment.

Results

- **Psychometric Properties**: Non applicable.

Healthy Children

- Timed functional tests: There was no significant difference between genders.
- Time needed to run 9 m correlated best with age in both genders. Time decreased with age up to 2.5 seconds at the age of 11 years and probably will not decrease much further in older children.
- Time needed to rise from floor correlated best with age in boys and with BMI in girls. Time decreased with age to a value of approximately 1 second at the age of 11 years.

DMD Children

- Timed functional tests: Time increased with age despite a small increase in force.There was a negative correlation for the time needed to run 9 m with summed muscle force. There was no significant correlation with any of the summed scores.
- All children scored below the normal range for muscle force (average ± 2 SD).
- The authors report that results differ from those of other studies and this may be due to differences in group size, disease severity and age of children.

1.6 Study Summary (Continued)

Authors' Conclusion
▪ In DMD ambulant patients, timed functional tests were the most sensitive parameters to determine the extent of disease progression. The authors suggest that functional ability also changes more than muscle force in intermediate disease stage of other muscular disorders. ▪ Timed functional tests may be considered as an additional outcome measure to evaluate the effects of therapy in ambulant patients with DMD and possibly in other neuromuscular disorders. ▪ Time needed to run 9 m decreased with age to 2.5 seconds at the age of 11 years and probably will not decrease much further in older children. ▪ Time needed to rise from floor decreases with age to a value of approximately 1 second at the age of 11 years.

Comments
Internal validity seems good. However, sample size is small per age group and gender (Table 2.1) and the use of results as a trend for clinical guidelines is appropriate but should be interpreted with caution.

2. Childhood Myositis Assessment Scale-9 [28]

Age range: 4 years to 9 years.

2.1 Clinical Use

- Quantification measurement of physical performance in functional activities.
- To document gain or loss of muscle strength over a period of time.

2.2 Measurements

- Nine functional abilities (CMAS-9), chosen from the CMAS-14, are tested and a score is given for each of these nine activities. [28] The score for these nine items are summed to yield a total score ranging from 0 to 37 (Table 2.2).

Table 2.2. Nine CMAS maneuvers tested*

CMAS maneuvers		for each maneuver	
CMAS-14	CMAS-9	CMAS-9	CMAS-14
1. Head lift	Head lift	5	5
2. Leg raise/touch object			2
3. Leg lift/duration	Leg lift/duration	5	5
4. Supine to prone	Supine to prone	3	3
5. Sit-ups	Sit-ups	6	6
6. Supine to sit	Supine to sit	3	3
7. Arm raise/straighten			3
8. Arm raise/duration	Arm raise/duration	4	4
9. Floor sit	Floor sit	3	3
10. All fours maneuver			4
11. Floor rise	Floor rise	4	4
12. Chair rise	Chair rise	4	4
13. Stool step			3
14. Pick-up			3
Total		37	52

* CMAS = Childhood Myositis Assessment Scale.

2.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- Examination table.
- An armless chair. The child‘s feet must be flat on the floor.

TEST

- The CMAS-9 assessment consists in testing and scoring the maneuvers number 1, 3, 4 5, 6, 8, 9, 11 and 12 as described in Table 2.3. These nine maneuvers are to be assessed in the exact order as they are listed, one after the other.
- The score is based either on:
  - The child’s capacity to perform or not certain activities.
  - The time in seconds or in minutes that the child holds a position.
- For clinical use, a scoring sheet is presented in Table 2.4.
- Results are compared to the normative reference values in Table 2.5.

Table 2.3. Standardized Method and Scoring for Conducting the CMAS Maneuvers

1. **Head elevation (neck flexion).** The supine patient is asked to lift his or her head off the examination table for as long as he/she can. The arms are to be kept still at the patient's sides and are not to be used for support or leverage. The shoulders are to remain stationary. The patient receives credit for raising his/her head off the table if the examiner can freely slide his/her fingers under the patient's occiput. The examiner begins timing from the moment the patient raises his/her head off the table and stops when the patient can no longer keep his/her head off the table and the occiput touches the table. The patient is not required to maintain any particular degree (angle) of neck flexion while the head is off the table.

   A score of zero is warranted if the patient is unable to raise his/her head off the exam table so that the examiner can freely slide his/her fingers under the patient's occiput. A patient who is able to lift his/her head off the table for 1.9 seconds receives a score of 1, and so on (see Scoring Sheet). (If the patient can lift his/her head at least long enough for the examiner to slide his/her fingers under the occiput, the patient will be said to have raised his/her head for at least 1 second.)

2. **Leg raise/touch object.** The patient is supine with legs extended. In preparation for this maneuver, the examiner passively raises the patient's right foot and rests the heel of the patient's right dorsiflexed foot on top of the extended first toe of the left dorsiflexed foot to measure a distance of 2 patient foot lengths above the exam table. Having made this measurement, the examiner replaces the right leg/heel in a position of rest on the table.

   The examiner then holds his/her hand or an object (a toy for younger children) 2 patient foot lengths above the patient s resting right heel and asks the child to raise his/her leg so that the right first toe is able to touch the examiner s hand (or an object). The child may use a kicking motion to accomplish this, if necessary. That is, the leg need not be kept straight throughout ascent. However, the pelvis must be kept stationary in a neutral position.

   A score of 0 is warranted if the patient is unable to lift the right leg so that it clears the table. A score of 1 is awarded if the patient is able to lift the leg high enough so that it at least slightly clears the table, but not high enough to touch the examiner s hand (or object). A score of 2 is awarded if the patient is able to lift the leg high enough to touch the examiner s hand (or object). Once it is determined whether the patient is able to touch the object, the patient rests the leg for a few seconds before starting maneuver number 3.

3. **Straight leg lift/duration.**The supine patient is asked to lift his or her straightened right leg off the exam table so that the heel of the right foot is 1 patient foot length (the length of the patient s sole, from the posterior heel to the tip of the first toe) above the exam table. Counting starts as soon as the heel is lifted to the above-mentioned height. During the count, the patient must constantly keep the knee in extension and should be discouraged from raising the heel higher than 1 patient foot length above the table. The pelvis must remain stationary. During the count, the heel might drift downward; when this occurs the count continues, but the patient should be encouraged (repeatedly, if necessary) to again raise the heel to the desired height. Counting stops when the patient can no longer maintain the straightened leg off the table and the heel touches the table.

   Zero points are awarded if the patient cannot even momentarily lift the straightened leg to the desired height. One point is awarded if the patient can lift the straightened leg to the desired height and achieve a count (as described above) of 1 9 seconds, and so on (see Scoring Sheet).

4. **Supine to prone.**The supine patient is asked to roll over to the right into a prone position. Throughout the maneuver, he or she must keep the right arm flexed, and he/she must keep the right wrist inferior to the chin. First, the patient is to roll onto his/her right side, onto the flexed right arm, thereby pinning the flexed right arm against the table. As the patient continues to roll toward a prone position, he/she must pull the flexed right arm out from under his/her torso and free it as he/she finally rolls into a full prone position.

   The profoundly weak patient has difficulty even rolling onto his/her side; and, if able to do so, has difficulty even slightly freeing the right arm from its pinned position and can go no further. Such a patient receives 0 points. A slightly stronger patient (score of 1) can roll onto his/her side fairly easily, can move the arm much of the way under the torso, but is not able to fully free the arm and, therefore, is unable to fully assume a prone position. A mildly weak patient (score of 2) easily turns onto his/her side, has some difficulty freeing the right arm, but does so, and fully achieves the prone position. The patient who performs this maneuver with no difficulty is awarded 3 points.

5. **Sit-ups.**The patient is asked to perform sit-ups in 6 different ways in the following order:

   1) The patient is supine on the examination table and places his or her palms on his/her upper thighs. The examiner holds the patient s ankles firmly against the exam table (counterbalancing). The patient then does a single sit-up, without using the hands or elbows for added support or boosting. During the sit-up, the palms must remain close to (but not clutching) the thighs and the elbows must not touch the exam table.

   2) Same as number 1, except that the patient holds his/her arms folded across the chest (with hands resting on the opposite shoulders) throughout. The elbows may swing away from the chest during the sit-up, but the hands must remain in contact with the shoulders.

   3) Same as number 1, except that the patient holds his/her hands clasped behind the neck/occiput throughout the sit-up.

   4, 5, and 6) Same as 1, 2, and 3, respectively, except that the examiner does not provide counterbalancing. One point is awarded for each sit-up accomplished.

6. **Supine to sit.**The patient is asked to go from a supine position to a sitting position in which he or she is seated on the exam table, with the legs freely dangling over the side of the table. The hands and arms may be used in any way necessary to achieve this. The profoundly weak patient is unable to get into a sitting position and receives 0 points. A slightly stronger individual (score of 1) is barely able to get into such a sitting position, struggles greatly, and takes a long time to do so. A score of 2 is awarded if the patient struggles somewhat and is somewhat slow but does not just barely make it. A score of 3 is awarded if the patient has no difficulty.

7. **Arm raise/straighten.** The seated patient is asked to simultaneously raise both arms straight above the head so that the wrists are as high as possible above the head. (The younger patient is asked to reach to the sky; raise your hands as high as you can. A ball or toy can be held high above the child s head, and the child can be asked to reach or grasp the object with both hands.)

   Zero points are awarded if the patient cannot raise his/her wrists up to the level of the acromioclavicular (AC) joint. One point is awarded if the patient can raise the wrists at least up to the level of the AC joint, but not above the top of the head. Two points are awarded if the patient can raise the wrists above the top of the head, but cannot raise the arms straight above the head so that the elbows are in full extension and straightened arms are perpendicular to the exam table. Three points are awarded if the patient can raise his/her arms straight above the head, so that the elbows are in full extension and the straightened arms are perpendicular to the exam table. Once it is determined whether the patient can raise his/her arms to the fully strengthened position, the patient then rests his/her hands in his/her lap for a few seconds before starting maneuver 8.

8. **Arm raise/duration.**The seated patient is asked to simultaneously raise both hands from his or her lap to a position in which the wrists are as far as possible above the lap. The patient is then asked to maintain the wrists in the highest position possible for as long as possible.

   Zero points are awarded if the patient cannot even momentarily raise his/her hands from his/her lap so that the wrists are above the level of the top of the head. One point is awarded if the wrists can be raised above the top of the head and this position can be maintained for 1 9 seconds. Two points are awarded if the wrists can be maintained above the top of the head for 10 29 seconds, and so on (see Scoring Sheet). Counting starts as soon as the wrists are lifted above the top of the head, and counting stops as soon as the wrists fall below the level of the top of the head. Throughout the counting, the child should be encouraged to keep the forearms perpendicular to the exam table, but counting continues as long as the wrists remain above the level of the top of the head, even if the forearms drift out of the perpendicular position. Throughout the counting, the patient is encouraged to keep the wrists as high as possible, but it is to be understood that the patient may not be able to raise the arms so that the elbows achieve full extension. Throughout counting, the cervical spine should be kept in a neutral position.

9. **Floor sit.**The patient is asked to stand alone in the middle of the examination room, away from any potentially supporting chairs or tables. The patient is then asked if he or she thinks that he/she can safely descend into a sitting position on the floor without using a chair for support. If the patient is hesitant to try, he/she should not be encouraged to try. Such a patient should then be offered a chair to use for support during descent.

   The profoundly weak patient (score of 0) would not be able to go from a standing position to a sitting position on the floor without simply falling into a sit (which is not allowed or encouraged). Such a patient is afraid to try and refuses to try, even if allowed to hold onto a chair during descent. The slightly stronger patient (score of 1) is willing to try if allowed to use the chair for support and, with the availability of the chair, is able to descend into a sitting position. He/she is not able to safely descend without the use of the chair. A score of 2 is awarded if the patient can safely descend unassisted (without use of a chair for support), but has at least mild difficulty doing so. Such a patient descends abnormally slowly, does not have full control over the muscles or full balance as he/she descends, and/or excessively relies on supporting him/herself by placing his/her hands on his/her thighs, knees, or floor as he/she descends. The patient who requires no compensatory maneuvering and has no difficulty descending receives a score of 3.

10. **All-fours maneuver.** The patient begins this maneuver while in a prone position on the floor. The patient is then asked to rise up to an all-fours position, so that he or she is bearing all weight on the hands and knees. Once assuming this position, the patient is asked to keep the back straight and to raise the head up so that he/she can look straight ahead (with the plane of the face nearly perpendicular to the floor). Then, the patient is asked to creep (crawl) forward so that all 4 weight-bearing points are moved to new positions.

    A score of 0 is warranted if the patient is unable to go from a prone position to an all-fours position. That is, the patient is too weak to rise up into a weight-bearing position on his/her hands and knees. The patient is unable to even momentarily assume an all-fours position. A score of 1 is warranted if the patient is able to assume an all-fours position, but only barely and/or weakly so. The patient achieves the all-fours position, but is unable to raise the head to look straight ahead. A score of 2 is warranted if the patient can achieve and maintain an all-fours positions, with back straight and head raised; but the patient cannot creep (crawl) forward. A score of 3 is awarded if the patient can solidly maintain an all-fours position, raise head, look straight ahead, and creep (crawl) forward. A score of 4 is awarded if the patient is able to maintain balance while raising the head and extending and lifting one leg above the level of the body while in this position.

11. **Floor rise.** The patient is seated on the floor, away from any chair or table. The patient is then asked to get into a kneeling position. He or she may place his/her hands on the floor for support as he/she assumes this kneeling position. The patient is then asked to remain kneeling on the right knee, but to raise the left knee so that the left foot is planted in front of him/her, with the left knee and left hip each in 90 degrees of flexion. The patient is then asked to rise from this kneeling position to a standing position without using a chair for support and without placing his/her hand(s) on the knee(s), thigh(s), or the floor, if possible. A chair is provided if the child is unable to rise without the use of a chair for support.

    A score of 0 is warranted if the child is unable to rise to a stand even if allowed to place his/her hands/forearms on a chair for support. A score of 1 is awarded if a patient is able to rise, but only if using a chair for support. A score of 2 is awarded if the patient is able to rise to a stand without use of a chair, but needs to place one or both hands on the knees/thighs or floor during ascent. A score of 3 is awarded if the child can ascend without placing his/her hand(s) on the knee(s), thigh(s), or floor, but has at least some difficulty during ascent (struggles and/or ascends slowly). A score of 4 is awarded if the patient has no difficulty during ascent.

12. **Chair rise.**The patient is seated in an armless chair that is of appropriate size for the patient s age. (When a person sits in a chair of appropriate size and sits with the lower legs planted perpendicular to the floor, the distal thigh will be slightly higher than the proximal thigh). The feet are to be placed any distance apart, but the toes must be kept pointing forward (no out-toeing). The patient is allowed to rock forward, if necessary, during ascent.

    A score of 0 is warranted if the child is unable to rise to a stand, even if allowed to place the hands on the sides of the chair seat. A score of 1 is awarded if the child is able to rise to a stand, but needs to place the hand(s) on the side(s) of the seat in order to do so. A score of 2 is awarded if the child is able to stand up, but needs to place one or both hands on the knee(s) or thigh(s) to do so. A score of 3 is awarded if the child does not need to use his/her hands at all as he/she ascends to a stand, but has at least some difficulty during ascent (is slow, struggles somewhat, and/or needs to rock). A score of 4 is awarded if the child has no difficulty going from a sit to a stand.

13. **Stool step.** An age appropriate stool is placed next to the exam table, and the patient is asked to step up onto the stool. An age appropriate stool has a height equal to the distance from the floor to the top of an ordinary sock. For an older child this would be a 7 8-inch stool. The patient is encouraged to try to step onto the stool without placing a hand on the exam table (or on the examiner s hand/forearm for a shorter child) for support, and without placing a hand (or hands) on her stepping knee/thigh for support.

    A score of 0 is awarded if the child is unable (or appropriately unwilling to try) to step onto the stool even when allowed to place one hand on the exam table (or on the examiner s hand/forearm) for support. (Such a patient would be afraid of losing his/her balance if not allowed to place a hand on the table for support).

    A score of 1 is awarded if the child is able to step onto the stool, but needs to place one hand on the exam table (or on the examiner s hand/forearm) in order to do so. A score of 2 is awarded if the patient is able to step onto the stool without placing a hand on the exam table (or examiner s arm) but needs to place his/her hand(s) on the knee/thigh in order to do so. A score of 3 is awarded if the patient is able to step onto the stool without placing his/her hand(s) on either the exam table or his/her stepping thigh/knee.

14. **Pick-up.** The patient stands in the middle of the exam room and is asked to bend over to pick up a pen or pencil off the floor and to return to an erect standing position.

    A score of 0 is warranted if the patient is unable to pick up the pencil and return to an erect standing position. A score of 1 is awarded if the patient is able to pick up the pencil and return to a standing position, but relies heavily on support gained by placing his/her hand(s) on the knees/thighs and is barely able to perform the maneuver. A score of 2 is awarded if the patient has some difficulty, but not extreme difficulty, i.e., if the patient needs to at least briefly place his/her hand(s) on the knees/thighs for support and/or is at least somewhat slow in performing the maneuver. A score of 3 is awarded if the patient has no difficulty, requires no compensatory maneuvering and performs the maneuver quickly.

Data from: Standardized Method for Conducting the Childhood Myositis Assessment Scale of the American College of Rheumatology. [53] Available at: http://www.rheumatology.org/sections/pediatric/tools.asp. Accessed June 27, *2007*

Note : The maximun score for the nine tested maneuvers (1, 3, 4, 5, 6, 8, 9, 11,12) is 37.

Table 2.4.

APPENDIX A: CHILDHOOD MYOSITIS ASSESSMENT SCALE (CMAS) SCORING SHEET

1. HEAD LIFT:
   0 = Unable 3 = 30-59
   1 = 1-9 sec 4 = 60-119 sec
   2 = 10-29 5 = ≥ 2 min # of sec ____

2. LEG RAISE/TOUCH OBJECT:
   0 = Unable to lift leg off table.
   1 = Able to clear table, but cannot touch object (examiner's hand).
   2 = Able to lift leg high enough to touch object (examiner's hand).

3. STRAIGHT LEG LIFT/DURATION:
   0 = Unable 3 = 30-59 sec
   1 = 1-9 sec 4 = 60-119 sec
   2 = 10-29 sec 5 = ≥ 2 min #of sec ____

4. SUPINE TO PRONE:
   0 = Unable. Has difficulty even turning onto side; able to pull right arm under torso only slightly or not at all.
   1 = Turns onto side fairly easily, but cannot fully free right arm and is unable to fully assume a prone position.
   2 = Easily turns onto side; has some difficulty freeing arm, but fully frees arm and fully assumes a prone position.
   3 = Easily turns over, fully frees right arm with no difficulty.

5. SIT-UPS :
   Hands on thighs, with counterbalance ____
   Hands across chest, with counterbalance ____
   Hands behind head, with counterbalance ____
   Hands on thighs, without counterbalance ____
   Hands across chest, without counterbalance ____
   Hands behind head, without counterbalance ____
   Total Sit-up Score (0-6) ____

6. SUPINE TO SIT:
   0 = Unable by self.
   1 = Much difficulty. Very slow, struggles greatly, barely makes it. Almost unable.
   2 = Some difficulty. Able, but is somewhat slow, struggles some.
   3 = No difficulty.

7. ARM RAISE/STRAIGHTEN:
   0 = Cannot raise wrists up to the level of the A-C joint.
   1 = Can raise wrists at least up to the level of the A-C joint, but not above top of head.
   2 = Can raise wrists above top of head, but cannot raise arms straight above head so that elbows are in full extension.
   3 = Can raise arms straight above head so that elbows are in full extension.

8. ARM RAISE/DURATION: Can maintain wrists above top of head for:
   0 = Unable 3 = 30-59 sec
   1 = 1-9 sec 4 = ≥ 60 sec
   2 = 10-29 sec #of sec ____

The **maximum possible total score** for the 14 maneuvers is 52 (52 "points of muscle strength/function").

9. FLOOR SIT: Going from a standing position to a sitting position on the floor.
   0 = Unable. Afraid to even try, even if allowed to use a chair for support. Child fears that he/she will collapse, fall into a sit, or harm self.
   1 = Much difficulty. Able, but needs to hold onto a chair for support during descent. Unable, or unwilling to try if not allowed to use a chair for support.
   2 = Some difficulty. Can go from stand to sit without using a chair for support, but has at least some difficulty during descent. May need Gower's. Descends somewhat slowly and/or apprehensively; may not have full control or balance as maneuvers into a sit.
   3 = No difficulty. Requires no compensatory maneuvering.

10. ALL FOURS MANEUVER:
    0 = Unable to go from a prone to an all-fours position.
    1 = Barely able to assume and maintain an all-fours position. Unable to raise head to look straight ahead.
    2 = Can maintain all-fours position with back straight and head raised (so as to look straight ahead). But, cannot creep (crawl) forward.
    3 = Can maintain all-fours, look straight ahead and creep (crawl) forward.
    4 = Maintains balance while lifting and extending one leg.

11. FLOOR RISE: Going from a kneeling position on the floor to a standing position:
    0 = Unable, even if allowed to use a chair for support.
    1 = Much difficulty. Able, but needs to use a chair for support. (Unable if not allowed to use a chair.)
    2 = Moderate difficulty. Able to get up without using a chair for support, but needs to place one or both hands on thighs/knees or floor. (Unable without using hands.)
    3 = Mild difficulty. Does not need to place hands on knees, thighs or floor, but has at least some difficulty during ascent.
    4 = No difficulty.

12. CHAIR RISE:
    0 = Unable to rise up from chair, even if allowed to place hands on sides of chair seat.
    1 = Much difficulty. Able, but needs to place hands on sides of seat. Unable if not allowed to place hands on sides of seat.
    2 = Moderate difficulty. Able, but needs to place hands on knees/thighs. Does not need to place hands on sides of seat.
    3 = Mild difficulty. Does not need to place hands on seat, knees or thighs but has at least some difficulty during ascent.
    4 = No difficulty.

13. STOOL STEP:
    0 = Unable.
    1 = Much difficulty. Able, but needs to place one hand on exam table (or examiner's hand).
    2 = Some difficulty. Able, does not need to use exam table for support, but needs to use hand on knee/thigh.
    3 = Able. Does not need to use exam table or hand on knee/thigh.

14. PICK-UP:
    0 = Unable to bend over and pick up pencil off floor.
    1 = Much difficulty. Able, but relies heavily on support gained by placing hands on knees/thighs.
    2 = Some difficulty. Has some difficulty (but not "much-difficulty"). Needs to at least minimally and briefly place hand(s) on knees/thighs for support. Is somewhat slow.
    3 = No difficulty. No compensatory maneuver necessary.

PATIENT______________________ DATE__________ TOTAL CMAS SCORE: ______

Data from: Standardized Method for Conducting the Childhood Myositis Assessment Scale of the American College of Rheumatology. [53] Available at: http://www.rheumatology.org/sections/pediatric/tools.asp. Accessed June 27- *2007*

2.4 Normative Reference Values

- In the present study, all healthy children for all ages were able to achieve maximum possible scores for the following five maneuvers:
  - Supine to prone: 3; (number 4)
  - Supine to sit: 3; (number 6)
  - Floor sit: 4; (number 9)
  - Floor rise: 4; (number 11)
  - Chair rise: 4. (number 12)
- The scores of the other four maneuvers: head lift, (number 1), leg lift/duration, (number 3), sit-ups, (number 5), and arm raise/duration,(number 8) varied with age and gender. Normal possible maximum scores for the CMAS-9 are presented in Table 2.5.

Table 2.5.

Normal CMAS-9 scores*			
Age	Girls score (% of maximum)	Boys score (% of maximum)	Maximum
4	27 (73)	26 (70)	37
5	30 (81)	25 (68)	37
6	31 (84)	31 (84)	37
7	32 (86)	32 (86)	37
8	33 (89)	35 (95)	37
9	32 (86)	35 (95)	37

*Ninety percent of healthy children are able to achieve these scores at these ages. CMAS-9 = Childhood Myositis Assessment Scale.

© Rennebohm, Jones, Huber, and Ballinger, p.369. [28]

The authors report that even with the availability of these normative reference values, a considerable amount of clinical judgment is needed to decide whether or not the results are reflective of clinically significant weakness. [28]

2.5 Study Summary

Title: Normal Scores for Nine Maneuvers of the Childhood Myositis Assessment Scale[28]	
Authors	Rennebohm, R. M., Jones, K., Huber, A. M., & Ballinger, S.H., Bowyer, S.L., Feldman, B.M., Hicks, J. …Rider, L. G.
Publication	Arthritis & Rheumatism (Arthritis Care & Research). 2004, 51, 365-70.
Purpose of the Study	▪ To document and evaluate the scores that normal healthy children achieve when performing the nine maneuvers of the Childhood Myositis Assessment Scale. ▪ To understand if children with juvenile idiopathic inflammatory myopathy (juvenile IIM) score within the limits for a healthy child.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of muscle strength and endurance in functional motor activities.

Methods

Subjects

- The study sample consisted of 303 healthy children.
- Age range: 4 years to 9 years.
- Racial distribution: 70% White, 24% African American and 6% other.
- The children were divided into six age groups based on chronological age in years. Each group consisted of ~ 50 children (25 ♀, 25 ♂).

Testing Procedures and Instrumentation

- Timed performance or the number of trials in nine various functional activities were tested using "The Childhood Myositis Assessment Scale-9" (CMAS- 9). Children were asked to perform the CMAS-9 maneuvers on two separate occasions, at least one week apart. Each time they performed the maneuvers in the order listed and according to the same instructions. Minimum score = 0 and maximum score = 5 depending of the activity. Maximum CMAS-9 score = 37.
- Instrumentation: CMAS-9. The scale originates from the CMAS–14 which is a composite of fourteen activities. Score sheets for the scale are available at the American college of Rheumatology web-site: http://www.rheumatology.org/sections/pediatric/tools.asp.[53]

Data Analysis

- For analysis of individual maneuvers, statistical methods included descriptive statistics for the maneuvers and log-linear models for inferential tests of the effects of age and gender on measures that demonstrated variability.
- Regression equations were used to test age, gender, and age by gender for maneuvers measured in seconds.
- Additional information on the statistical methods is presented therein.
- Data from the nine individual maneuvers were used to create a composite score, the CMAS- 9 for the healthy children in the study and for a second cohort of children with juvenile idiopathic inflammatory myopathy (JIIM).
- The definition that provided the highest combination of sensitivity (an abnormal test in the JIIM cohort) and specificity (a normal score in the healthy cohort) was determined and was used to generate age- and gender-matched normal scores in the healthy population.

2.5 Study Summary (Continued)

Results
▪ **Psychometric Properties**: Non applicable. ▪ There were no statistically significant differences between the scores healthy children achieved at their first and second testing for all ages and both genders. ▪ All healthy children at all ages were able to achieve maximum possible scores for the following maneuvers: supine to prone, supine to sit, floor sit, floor rise and chair rise maneuvers. **CHARACTERISTICS IN THE OTHER MANEUVERS** ▪ Arm raise maneuver: The activity was achieved by all the healthy children with the maximum possible score except for one 4-year-old boy and one 4-year-old girl. ▪ Head lift, leg lift and sit-up maneuvers: The activities were age related and, to a lesser extent, a gender-related variability: **Head Lift Maneuver** ▪ 84% of the 4-year-old boys and 60% of the 4-year-old girls received a score of 1 or 2. The ability of the children to achieve a perfect score of 5, steadily increased with age (x 2 = 66.58, $p<0.001$). No statistically significant difference was found between the ordinal scale 0-5 of girls and boys (x 2 = 3.32, $p=0.068$). ▪ When head lift results were expressed in number of seconds, a regression model revealed that age and age by gender were significant: Girls aged 4-5 and 6 years performed better than age matched boys. But boys aged 7-8 and 9 performed better than age-matched girls. **Leg Lift Maneuver** ▪ Girls' perfect scores were achieved by all 5-, 6-, 7- and 9-year-olds and by all 8-year-olds except one. ▪ Boys' perfect scores were achieved by all 7, 8 and 9-year-olds and by all 6-year-olds except one. ▪ 5-year-old boys: 32% failed to achieve a perfect score. ▪ 4-year-old children: 27% boys and 8% girls failed to achieve a perfect score. **Sit-up Maneuver** ▪ Results were the most variable in this maneuver. ▪ Only 16% of the 4-year-old girls and boys were able to perform more than the first three sit-ups. ▪ A perfect score was not universally achieved by older children: 73% of 9-year-old boys and 71% of 9-year-old girls achieved a perfect score. ▪ Scores varied significantly with age but did not vary convincingly with gender. **Normal CMAS-9 Scores:** The 90% definition was thought to offer the best combination of sensitivity and specificity with a sensitivity of 68% and specificity of 87%. The 90% definition produced the age and gender -related normal scores for the CMAS-9. In summary: ▪ Head lift maneuver: Normal scores are age and gender dependent. ▪ Leg lift maneuver: Normal scores are much less age and gender dependent. ▪ Sit-ups maneuver: Results are the most variable and vary with age but not gender. ▪ Head lift was more difficult to achieve than the leg lift. **The authors report limits of the study** ▪ Nine maneuvers and not fourteen maneuvers were analyzed. Maximum CMAS- 9 score of 37 was not achieved by all healthy children hence the complete CMAS -14 with a possible perfect score of 52 cannot be expected for all children. ▪ Anthropometric measurements were not done and these factors may influence performance in the maneuvers both by healthy children and patients. ▪ Healthy children were less motivated than their ages match counterparts, which may have affected lower scores than they were capable of.

2.5 Study Summary (Continued)

Authors’ Conclusion
The data of the present study should help clinicians in interpreting the CMAS scores of their patients in the context of normative data derived by age and gender. However, even with the availability of these normative reference values, a considerable amount of clinical judgment is needed to decide whether or not the results are reflective of clinically significant weakness.

Comments
Internal and external validity (including sample size, *n* = 50 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

Assessment of Muscle Strength with the Hand-Held Dynamometer

Manual muscle testing is a method that is reported having poor sensitivity to detect changes in muscle strength [8] especially in grades 4 and 5.[2, 13, 32, 34] On the other hand, testing with the hand-held dynamometer (HHD) has been shown to be a reliable method to objectively measure maximal isometric contraction in children.[4, 8, 13, 18, 24, 35, 37, 36, 42, 45, 47]

To determine if muscle weakness is present in a child, reference values in typically developing children are needed.[13] The review of the literature revealed a paucity of research providing pediatric normative reference values for maximal isometric muscle strength. The study sample of most of the selected studies is also small.

3. Summary

3.1 Age

- Cooperation, motivation, attention and understanding of instructions may render force testing less reliable in children.[10] Gajdosik (2005)[15] and Rose et al. (2008)[31] have shown that isometric force assessment with the HHD can be reliably measured in young children from the age of 28 months when they are able to understand the commands and follow directions. To assure optimal attention in young children, an adjusted protocol was used by Beenaker et al. (2001) [7] in which fewer muscle groups were tested.

3.2 Make Test Technique versus the Break Test Technique

Two types of test procedures can be used to assess maximal isometric muscle strength with the HHD:

- The make test technique is when the examiner holds the dynamometer stationary while the subject exerts a maximum voluntary effort force against it. [8, 13, 20, 35] The tester does not attempt to exceed the subject's effort; [35]
- The break test technique is when the examiner holds the dynamometer and applies tension against the subject's muscle with increasing counterforce. [35] The tester gradually overcomes the maximum isometric contraction of the subject and stops at the moment the extremity gives way.[13, 20, 35]

The break test may cause pain, [20, 35] but in the make test, the examiner does not counterforce to "break" the isometric contraction of the muscle, so weak muscles can be tested more easily and there is less possibility of hurting the joint. The make test is more comfortable and allows proper stabilization procedures. Therefore, it may be more appropriate for generating consistent results when testing younger populations. [20, 35] The make test has been shown to have higher reliability than the break test. [5] However, the break test technique produces higher values than the make test [5, 15, 20, 35, 40] across a range joint positions, suggesting that it is a more valid measure of muscular strength. [20]

The two techniques assess different types of forces and results cannot be used interchangeably when comparing data. Whether one test is better than the other is disputable [15, 20, 35] and they should be used as appropriate for the population tested. [20]

3.3 Methods of Assessment

Two common methods for quantifying muscle strength with the HHD are to measure torque[8,13] and force [7, 8] "…Moment of force (also torque or simply moment) is the product when a force is applied around a pivot point and almost all human movements pivots round a centre, the joint…"[13] Torque is the product of force and distance from the joint axis being measured.[8, 13] Force is defined as the push or pull produced by the limb against an object. [8] Both were shown to be related to gross motor skills in children with cerebral palsy. [8]

The force measured on the HHD depends on the distance from the joint center.[13,45] To obtain comparable measurements, one must either place the HHD at the same distance from the joint or to measure the distance (lever arm) and calculate the torque (force x distance).[13] Force values are usually expressed in newton or kilograms and torque values are expressed in newton meters.

The measurement of muscle torque seems to be a more suitable method to assess muscle strength in growing children since strength is influenced by growth of lever and muscle mass.[3, 13] It is suggested that, when assessing muscle strength with the HHD, one should thus take into account the differences in lever arm length.[13, 18, 38, 45] However, it is reported that changes in strength measurements may be more dependent on the change in muscle mass,[3, 12] and the inter-relation between the lever arm lengths would be of lesser importance.[3]

Based on the previous information, three different studies to assess maximal isometric muscle strength in the extremities with the HHD were selected and only one reports reference values for muscle torque obtained with the make test.[13] **This method is firstly recommended.**

3.4 Duration of Time of Isometric Contraction

Isometric contraction is influenced by patient fatigue, posture, motivation and age. In respect to age, the development of isometric force and control in children was analyzed in a simple isometric task: [37]

- Younger children (5-6 years) needed more time to achieve peak muscle force compared to older subjects (Fig. 2.2).
- Younger children (5-6 years) needed 17% more time to relax than 7 and 8-year old children and 26% time more than adults.
- The difference in time needed to achieve peak muscle force (Fig. 2.2) and the time needed to relax between 11-and 12-year- old children and adults were not significant.

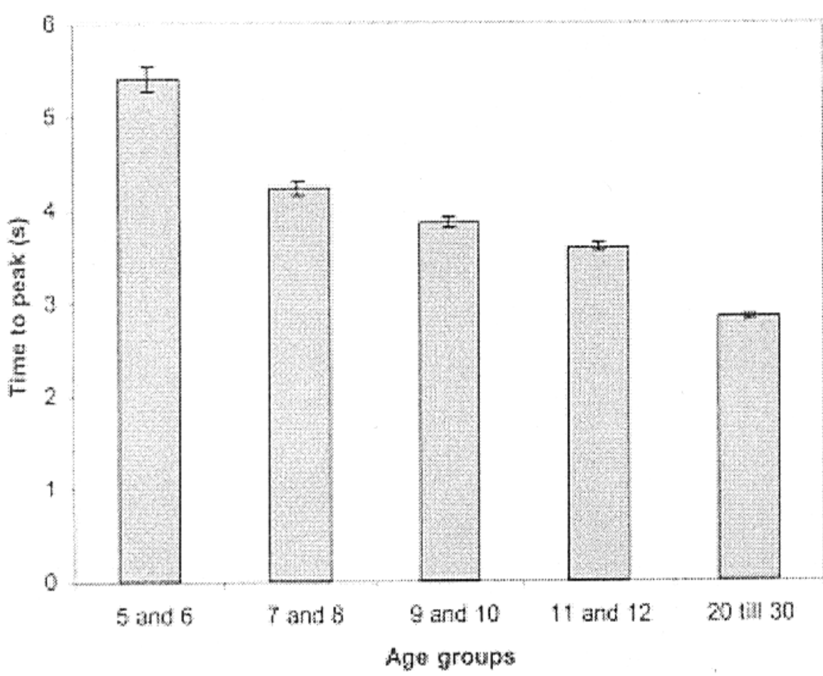

Fig. 2.2. Developmental trend in time to peak force. Mean time to peak force per age group (S.E.).

Reprinted from:Cognitive Brain Research,17, Smits-Engelsman, B. C. M. , Westenberg, Y., Duysens, J. Development of isometric force and force control in chidren, p.7 © 2003, with permission from Elsevier.[37]

3.5 Side to Side Differences

Hosking & al. (1976) [18] report a difference in isometric strength less than 15% between the left and right sides in isometric muscle contraction in healthy children when assessed on different occasions. In a study on knee flexor-extensor muscle strength, tested isokinetically, there was an overall average difference between sides of 15%. High variations over 25% between sides in the lower extremities were frequently found in healthy children who generated very low muscle torque. Variations decreased as peak torque increased. [16]

The dominant side is usually stronger than the non dominant side [4] but this is not a standard. Henderson & al. (1993) [16] report that the dominant side, in the lower extremities, was not uniformly stronger than the non dominant side.

Conclusion: Clinically, a difference between sides of ≤ 15% may be considered normal.

3.6 Differences between Measures on the Same Side

It would appear that strength testing in children, irrespective of muscle action or muscle joint assessed, has a test-retest variation of around 5-10%. [12] Saulnier et al. (2006) [45] suggest that if there is a difference > 10% between two measures, another test should be done. In healthy children, Hosking et al. (1976) [18] report that variations did not exceed ± 15% between test-retest with a 1-month interval between measures. A coefficient of variation of measurement error that varied from 6 to 16% between test-retest at an interval of 3 months is reported by Backman et al. (1989A).[3] Sapega et al. (1990) [32] suggest that great caution should be exercised when clinical judgments are based on small changes in performance (less than 15%).

Conclusion: Clinically, a difference of 10 to 15% between measures on the same side would be acceptable.

3.7 Testing Procedures

To maintain reliable measurements, different factors have to be considered:

PRACTICE SESSION

- Prior to the assessment, a practice session is suggested in order to familiarize the child with the HHD and the procedures,[12, 15, 50] and to diminish practice and learning during testing. [12 , 15, 20]
- Minimal training with the HHD must be acquired from the clinician.

PRE-TEST

- Physical activity must be limited before assessment. [1]
- The child should be in an optimal state. [1, 29]

TEST

- The tester has to be rigorous in the testing methods and stabilization in order to obtain repeated, reliable measurements. [13, 15,, 18, 29, 50]
- The test ends when force no longer increases. [20] If maximum effort was not achieved then measurement is repeated [10] after a rest period to avoid fatigue.
- Time of testing should be constant between each session. [1, 29]
- HHD instrument:
    - The instrument of choice is the HHD used in the study of reference. If another type is used, it should be adequately calibrated with known weights. Error in measure by using another type of instrument may be increased.

- The HHD's is placed distally at the segment tested. [13] The contact plate is positioned at a 90° angle to the limb segment and should provoke no pain. [8, 13]
- The same device has to be used in test-retests.

- Testing positions:
  - A key to reliability is stabilization of the HHD, of joints and posture. [13, 15, 18, 36, 38, 50] Weak children need more stabilization. They present more substitution movements.
  - The child' s position must be comfortable and stable for optimal conditions for muscle strength efforts [15, 39] and when pushing against the contact plate of the HHD. [15]
  - The tester's position must be stable when the child pushes against the HHD.
- Feedback: The information must be explicit. [50] Motivation[20] and muscle strength [40] were increased with feedback.
- Number of trials: Usually 2 to 3 trials per muscle group were used. Extra trials during test sessions may be needed for younger children. [15]
- Rest periods between trials: A minimum of 10 to 30 seconds is usually sufficient [27, 38, 42] and contra-lateral muscle groups can be tested during rest periods. [13]

4. Maximum Isometric Muscle Torque – Make Test Technique [13]

Age range: 5 years to 15 years.

4.1 Clinical Use

- To quantify muscle strength measurement.
- To document gain or loss of muscle strength over a period of time.

4.2 Measurements

- Maximum isometric torque in twelve muscle groups is tested: Four muscle groups in the upper extremity and eight in the lower extremity (Table 2.6.).
- Torque (T) values are recorded in newton meters (Nm): T = Force (Newton) x lever arm (meter) (Table 2.7. – Table 2.8.).
  - Note: To convert kilograms in Newton: N = Force in kg x 9.81. [45]
- Since children with disabilities may be small for their age, the authors of the study have calculated weight-related reference values with torque (Table 2.9.). The child's weight is measured in kilograms.

4.3 Testing Procedures

REQUIRED EQUIPMENT

- Calibrated Chatillon hand-held electronic dynamometer.
- Writing accessories.
- Electronic scale.
- Examination table.
- Hypoallergenic cosmetic crayon to mark anatomical landmarks that will be used to measure arm lever.
- Tape measure.

PRE-TEST

- Allow a practice session.
- In the present study, muscle strength was measured on the non-dominant side. If need be, determine hand dominance by having the child write his name on a piece of paper.
- Take the child's weight (kg) if the weight–related reference values are to be used (Table 2.9).
- Mark the anatomical landmarks according to the joint to be measured (Table 2.6, lever arm column).

TEST

- Number of trials: Three trials of five seconds each are tested for each muscle group. The maximum result is recorded.
- Allow rest periods between trials.
- Note: the authors tested four muscle groups in two different positions, useful when assessing stronger patients. They recommend using the positions that are easiest for the child.
- HHD position: To allow the longest lever arm as possible at a location where a strong pressure on the skin does not hurt, the HHD is placed distally at the segment tested, at a place that is comfortable for the subject.
- Procedures to measure lever arm length (example in Fig. 2.3):
  - Mark the anatomical bony landmarks according to the joint being measured;
  - Mark the position of the center of the head of the HHD on the skin;
  - With the tape measure, calculate the distance between the bony landmark and the position of the center of the head of the HHD. The result represents the lever arm length.
- The subject's position, joints' position, stabilization, resistance and lever arm for the assessment of muscle groups are presented in Table 2.6.
- Results are compared to the normative reference values in Table 2.7 and Table 2.8. Table 2.9 presents mean weight-related values.

Figure 2.3. Measurement of hip extension with the Chatillon dynamometer. Lever arm indicated with X.

Reprinted from Archives of Physical Medicine and Rehabilitation, 87, Eek MN, Kroksmark AK, Beckung E. Isometric Muscle Torque in Children 5 to 15 years of Age: Normative Data, p.1092 © 2006, with permission from Elsevier.[13]

Table 2.6. Standardization of the Method for the Assessment of Ten Muscle Groups [13]

Table 1: Muscle Groups

Muscle Group	Position	Stabilization	Resistance	Lever Arm From
Shoulder abductors	Sitting Shoulder abducted 90°, elbow flexed, opposite hand in knee		Humerus distally	Acromial process
Elbow extensors 1	Prone Shoulder abducted 90°, elbow flexed 90°	Lower part of humerus	Forearm distally	Lateral humeral epicondyle
Elbow extensors 2	Supine Shoulder adducted, elbow flexed 90°, forearm in neutral	Humerus	Forearm distally	Lateral humeral epicondyle
Elbow flexors	Supine Shoulder adducted, elbow flexed 90°, forearm in supination	Shoulder	Forearm distally	Lateral humeral epicondyle

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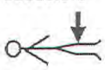
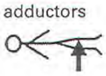
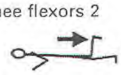
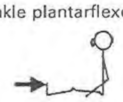
(Cont'd): Muscle Groups

Muscle Group	Position	Stabilization	Resistance	Lever Arm From
Wrist dorsiflexors 	Supine Shoulder adducted, elbow extended, forearm in pronation, fingers extended	Forearm	Dorsum of hand	Ulnar styloid process
Hip extensors 1 	Supine with legs outside the couch Not tested foot on the floor	Hold on to bench	Femur distally	Greater trochanter
Hip extensors 2 	Supine	Hold on to bench	Femur distally	Greater trochanter
Hip flexors 1 	Sitting	Hold on to bench	Femur distally	Greater trochanter
Hip flexors 2 	Supine Hip and knee flexed 90°	Hold on to bench	Femur distally	Greater trochanter
Hip abductors 	Supine Hip and knee extended	Hold on to bench Stabilization of the other leg	Femur distally	Greater trochanter
Hip adductors 	Supine Hip and knee extended Not tested knee flexed	Hold on to bench	Femur distally	Greater trochanter
Knee extensors 	Sitting	Hold on to bench	Shank distally	Lateral knee joint
Knee flexors 1 	Sitting	Hold on to bench	Shank distally	Lateral knee joint
Knee flexors 2 	Prone Knee flexed 90°	Hold on to bench	Shank distally	Lateral knee joint
Ankle dorsiflexors 	Supine Hip and knee extended, ankle 0°	Hold on to bench	Dorsum of foot	Lateral malleolus
Ankle plantarflexors 	Sitting Knee extended	Hold on to bench	Metatarsal heads	Lateral malleolus

NOTE. Description of position and stabilization of subject, position of the dynamometer's resistance to the body movement (arrows), and description of point for measuring lever arm.

4.4 Normative Reference Values

- Table 2.7: 5- to 12- year-olds.
- Table 2.8: 13- to 15- year- old boys and girls.
- Table 2.9: In relation to weight.

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Table 2.7. Mean Age – Related Values for Children 5 to 12 Years Old

Muscle Group	Age 5	6	7	8	9	10	11	12
Shoulder abductors	8.8±2.8	11.1±2.9	14.3±5.0	18.2±3.7	19.3±4.4	21.9±5.8	23.8±4.9	30.5±6.3
Elbow extensors 1	8.8±2.6	11.3±2.9	11.3±4.0	15.9±3.7	18.6±7.3	16.2±3.8	19.4±4.5	26.2±8.4
Elbow extensors 2	7.1±1.5	10.3±2.7	10.0±3.0	14.8±3.3	15.7±3.2	15.9±2.4	17.1±6.9	20.5±3.9
Elbow flexors	8.5±2.5	11.7±2.3	12.9±3.9	16.5±3.2	20.0±4.6	21.6±3.8	24.3±6.5	29.4±6.3
Wrist dorsiflexors	1.7±0.6	2.4±0.5	2.3±0.8	3.3±1.0	4.0±1.3	3.8±0.8	4.7±1.6	5.1±1.0
Hip extensors 1	20.1±6.6	32.1±11.0	35.8±16.2	49.3±11.9	56.0±16.6	58.9±14.9	68.7±22.2	95.1±31.4
Hip extensors 2	16.1±3.7	23.6±5.5	31.5±11.6	43.7±12.4	51.0±13.1	61.2±19.4	67.4±16.9	105.4±30.5
Hip flexors 1	15.8±3.9	24.1±5.5	27.0±8.9	38.6±11.5	46.3±10.6	54.0±13.8	62.6±23.2	73.7±15.7
Hip flexors 2	16.2±4.4	23.0±6.0	26.2±8.1	35.3±8.9	39.8±9.5	45.3±8.0	50.3±15.2	64.7±14.5
Hip abductors	16.6±4.5	22.1±4.4	25.4±5.6	40.7±11.2	45.0±9.4	56.7±13.0	62.4±18.8	72.1±18.3
Hip adductors	15.5±3.2	20.7±3.8	25.5±9.7	33.6±9.9	40.9±15.3	43.0±13.5	57.6±17.1	73.2±17.4
Knee extensors	21.0±5.8	26.0±4.0	30.2±8.5	45.4±12.1	42.9±5.9	61.4±14.9	63.3±17.0	74.3±12.7
Knee flexors 1	15.9±3.5	20.0±3.8	22.7±5.6	32.4±9.4	33.9±5.5	46.8±11.6	48.9±11.6	62.6±17.0
Knee flexors 2	12.5±3.6	16.9±4.3	17.4±4.0	24.1±5.1	29.1±6.7	34.7±10.2	36.8±11.7	47.0±12.9
Ankle dorsiflexors	8.1±2.8	10.6±2.1	11.7±3.8	14.4±2.4	21.3±3.8	19.9±3.6	22.5±6.9	27.1±7.1
Ankle plantarflexors	17.3±5.7	25.8±6.0	21.1±11.5	31.8±5.2	40.2±9.6	ND	ND	ND

NOTE. Values are mean newton meters ± SD.
Abbreviations: ND, no data, given that the children were stronger than the device could measure (>500N).

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Table 2.8. Mean Age – Related Values for Childrenfor Boys and Girls 13 to 15 Years Old

Muscle Group	Age 13		Age 14		Age 15	
	Boys	Girls	Boys	Girls	Boys	Girls
Shoulder abductors	36.5±10.0	33.9±4.9	42.8±9.8	39.0±7.2	42.2±8.3	36.6±5.0
Elbow extensors 1	27.7±4.2	27.4±9.2	37.1±8.8	29.8±8.5	31.7±9.8	27.0±7.3
Elbow extensors 2	25.4±8.9	23.9±5.5	33.0±6.9	25.3±5.0	31.7±6.0	23.6±4.8
Elbow flexors	35.2±11.9	33.3±7.8	46.0±9.2	35.7±6.1	47.5±12.9	34.0±10.6
Wrist dorsiflexors	7.2±2.5	6.1±2.4	9.1±3.5	8.0±1.6	11.9±2.7	9.4±3.2
Hip extensors 1	103.4±44.8	98.6±26.3	134.9±32.2	114.6±23.3	142.1±35.2	141.0±13.0
Hip extensors 2	105.9±30.8	103.9±23.4	138.0±34.1	127.6±24.6	161.6±15.8	144.1±22.3
Hip flexors 1	85.5±18.9	84.4±23.1	120.4±25.5	101.6±22.8	124.6±30.5	115.0±16.5
Hip flexors 2	64.5±19.3	70.2±21.8	78.9±18.2	73.0±13.5	80.4±16.7	75.8±9.8
Hip abductors	82.5±28.5	82.2±19.0	122.3±27.9	100.9±15.1	120.3±38.2	119.0±29.6
Hip adductors	83.7±27.7	85.2±28.5	111.9±19.8	92.8±23.5	130.5±36.6	110.8±17.0
Knee extensors	82.5±18.3	79.9±13.4	110.4±23.2	97.4±18.5	122.1±18.6	98.0±14.9
Knee flexors 1	67.9±24.9	68.2±17.5	89.2±22.4	79.3±13.2	104.4±36.4	82.7±9.1
Knee flexors 2	53.4±9.6	53.2±20.5	72.3±19.8	59.8±12.0	63.9±16.4	58.6±10.9
Ankle dorsiflexors	31.4±8.4	27.7±9.1	34.6±8.5	32.0±6.5	40.3±6.9	34.8±6.6
Ankle plantarflexors	ND	ND	ND	ND	ND	ND

NOTE. Values are mean newton meters ± SD.
Abbreviations: ND, no data, given that the children were stronger than the device could measure (>500N).

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MUSCLE TORQUE IN CHILDREN, Nyström Eek

Table 2.9. Mean Weight – Related Values

Muscle Group	Weight Group (kg) 15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64
Shoulder abductors	8.0±2.1	11.0±2.8	17.2±3.6	20.7±3.6	24.0±6.5	28.8±5.0	30.9±6.4	37.9±5.6	42.5±8.8	41.6±8.8
Elbow extensors 1	9.3±2.2	10.3±3.4	14.9±3.2	17.6±6.6	19.6±5.2	23.0±5.1	26.0±7.9	27.7±4.6	34.1±8.4	36.6±11.1
Elbow extensors 2	6.8±1.0	9.3±2.8	13.7±2.5	15.6±3.1	16.1±3.3	20.5±3.9	20.8±5.7	26.9±5.0	30.9±6.4	31.9±8.3
Elbow flexors	7.2±1.3	11.0±2.7	16.9±2.7	20.2±4.0	23.9±4.4	27.8±6.2	29.7±6.3	37.6±4.1	42.5±10.2	44.6±13.5
Wrist dorsiflexors	1.7±0.5	2.1±0.6	3.2±0.9	4.0±1.1	4.5±1.0	5.2±1.4	5.5±1.6	8.1±2.2	10.0±2.7	9.7±4.1
Hip extensors 1	ND	29.6±11.7	46.5±10.0	57.7±14.4	70.8±25.3	88.9±33.4	89.6±20.0	125.0±28.7	125.4±28.6	141.0±32.6
Hip extensors 2	17.1±4.6	22.3±6.1	43.7±8.3	55.3±12.6	68.4±24.4	88.2±22.8	95.9±29.6	127.2±23.6	139.3±23.9	151.2±35.5
Hip flexors 1	14.8±2.7	22.7±6.9	37.1±9.6	46.1±9.9	57.5±14.7	78.0±17.8	76.2±18.7	104.0±21.2	115.7±26.1	121.2±21.1
Hip flexors 2	13.3±2.4	21.9±5.7	34.1±4.4	41.6±8.9	48.4±12.1	57.8±11.0	62.2±15.6	79.5±16.9	74.8±12.6	79.5±19.6
Hip abductors	15.6±2.8	21.3±5.5	36.9±8.5	48.3±9.5	56.6±14.5	73.3±18.7	73.9±12.0	99.4±10.3	115.7±17.8	129.4±28.7
Hip adductors	14.8±2.2	19.2±4.3	34.5±7.9	42.4±13.3	54.0±16.1	76.8±32.6	73.3±18.4	96.8±17.5	100.6±22.3	113.7±15.7
Knee extensors	18.2±4.6	25.9±5.5	39.9±5.7	46.6±6.6	60.8±10.6	73.1±10.0	79.1±10.3	100.3±18.8	97.4±16.3	117.8±14.9
Knee flexors 1	14.0±2.2	19.7±4.0	29.5±5.3	37.2±7.6	49.0±11.4	57.3±7.9	64.3±12.9	75.2±18.3	85.3±15.2	98.2±22.4
Knee flexors 2	12.1±3.1	16.1±4.6	22.4±5.4	30.5±6.0	36.2±8.1	43.1±10.5	49.5±14.0	54.5±7.6	64.8±13.9	77.0±19.4
Ankle dorsiflexors	6.8±1.4	10.4±3.0	15.7±3.6	20.4±6.2	20.5±4.2	24.1±4.8	28.2±8.2	34.0±6.3	35.8±7.4	34.6±8.4
Ankle plantarflexors	15.7±4.4	25.4±9.0	26.8±8.4	40.5±11.8	ND	ND	ND	ND	ND	ND

NOTE. Values are mean newton meters ± SD.
Abbreviations: ND, no data, given that the children were stronger than the device could measure (>500N).

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4.5 Study Summary

Title: Isometric Muscle Torque in Children 5 to 15 Years of Age – Normative Data[13]	
Authors	Eek, M. N., Kroksmark, A. K. & Beckung, E.
Publication	Archives of Physical Medicine and Rehabilitation, 87, 1091-1099.
Purpose of the Study	To establish reference values of arm and leg muscle strength as measured by isometric torque production in healthy children.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	▪ Assessment of maximum isometric muscle torque. ▪ Normative reference values for muscle strength.

Methods

Subjects

- The study sample consisted of 149 healthy children (73 ♀, 76 ♂). Sweden.
- Age range: 5 years to 15 years.
- Number of children per age group varied from 11 to 27.

Testing Procedures and Instrumentation

- Weight and height were measured. Muscle strength was tested on the non dominant side. Maximum isometric force in twelve muscle groups was tested. Four muscle groups were tested in two different positions, useful to assess stronger patients. A special device was made for measuring ankle plantar flexion.
- Two trials of 5 seconds each were made with the make test technique for each muscle group. The maximum result was used. Rest periods were given between trials. Lever arm was measured. Torque was calculated in newton meters. Measurements were performed by three physical therapists.
- Instrumentation: Chatillon hand-held electronic dynamometer. The dynamometer was calibrated with known weights before and after the study.
- Inter-rater reliability was tested by 2 examiners during the same session on 3 muscle groups in 25 children. The testing positions were standardized for every muscle groups and subject's positions.

Data Analysis

- Mean and standard deviation were calculated for all muscle groups. Pearson product-moment coefficient of correlation was used for comparison between torque with age and weight and for comparison of the muscle groups tested in two different positions.
- *t*-test was used for comparison between boys and girls and for measurements of the muscle groups tested in two different positions. Significance levels were set to 0.05.
- Intraclass correlation coefficients (ICCs) and two way random – effects model were used for inter-rater reliability. Correlation coefficients were graded according to Fleiss.
- Regression equations were used to get predicted torque values in relation to age, weight and gender.

4.5 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Inter-rater reliability was excellent. There was no statistically significant difference between measurements. (ICCs range, 0.93 - 0.97). ▪ Findings are consistent with other authors. ▪ There was an increase in torque with age and weight for all muscle groups and a strong correlation with both age and weight for arm muscles (*r* range, 0.79 - 0.90) and leg muscles (*r* range, 0.84 - 0.95) except plantar flexors. There were few differences between boys and girls up to the age of 12. Age and weight were the strongest predictors of torque. Gender was included from age 13. Plantar flexors were not possible to measure in children older than 9 years, due to difficulties in stabilization and the maximum measurement range of the dynamometer. ▪ If it is not possible to use the weight – related reference values, the authors recommend the use of equations for predicted torque that take into account age, weight and gender (presented therein) for children with disabilities that are small for their age.
Authors' Conclusion
Studies on growing children require comparison to healthy (normal) children to assess the amount of deviation from normal and to be able to draw conclusions of change over time. The reference values for torque in combination with a predicted value based on the child's age, weight, and gender make it possible to compare over time and between subjects, and provide a tool for evaluation of physical status and efficacy of therapy.

Comments
▪ Internal validity seems good. However, sample size is small per gender and age groups and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution.

5. Maximum Isometric Muscle Force– MakeTest Technique [15]

Age range: 28 months to 59 months.

5.1 Clinical Use

- To quantify muscle strength measurement.
- To document gain or loss of muscle strength over a period of time.

5.2 Measurements

- Maximum isometric force in five muscle groups is tested: Three muscle groups in the upper extremities and two in the lower extremities (Table 2.10).
- Force values are recorded in kilograms (Table 2.11 – Table 2.12).

5.3 Testing Procedures

REQUIRED EQUIPMENT

- Calibrated Nicholas Manual Muscle Tester HHD (Lafayette Instrument). To decrease the risk of discomfort, the authors have padded the contact metal plate with thin dense foam.
- A small ball.
- A small chair. The child's feet are several inches above the floor.
- Wide cloth straps for stabilization of the trunk and hips to the chair.

PRE-TEST

- Allow a practice session.
- In the present study, muscle strength was measured on the dominant side. If need be, determine dominant side by having the child throw or kick a ball.

TEST

- Number of trials: The child is tested three times and the mean of the three is calculated.
- Child's position:
  - The child sits in the chair. The lower trunk and the hips are stabilized with a wide cloth strap wrapped around the child and the chair.
  - The child is allowed to stabilize himself by holding onto the edge of the chair.
- For each muscle group, the child is asked an isometric contraction until a constant force is recorded for three seconds.
- Standardization of the method for joint position, HHD position and stabilization for the assessment of five muscle groups is presented in Table 2.10.
- Results for the upper extremities are compared to the normative reference values in Table 2.11 and for the lower extremities in Table 2.12.

TABLE 2.10. STANDARDIZATION OF THE METHOD FOR THE ASSESSMENT OF MAXIMUM ISOMETRIC FORCE IN FIVE MUSCLE GROUPS

Muscle Groups	Joint Position		HHD Position	Stabilization
Shoulder flexors	Shoulder	In 90° flexion	On the dorsal surface of the forearm, just proximal to the styloid process	Rater stabilizes the shoulder with hand
	Elbow	In extension		
	Forearm	In pronation		
Elbow flexors	Elbow	In 90° flexion with the arm held beside the trunk	On the forearm just proximal to the wrist crease	Rater stabilizes the elbow with hand
	Forearm	In supination		
Elbow extensors	As for elbow flexors		On the forearm just proximal to the styloid process	Rater stabilizes the elbow with hand
Knee flexors	Hip and knee: Positioned at 90°		On the distal end of the leg, just proximal to the malleolus	Rater stabilizes at the distal thigh
Knee extensors				

Pediatric Physical therapy, 17, Gajdosik, C., Giller, P.T., Ability of very Young children to produce reliable isometric force measurements, p.253, © 2005. [15]

5.4 Normative Reference Values

- Table 2.11: Mean values (SD) for the upper extremities.
- Table 2.12: Mean values (SD) for the lower extremities.
- Note: The reference force range seems more appropriate to use compared to the mean values ± SD since, for certain muscle groups, the mean value minus 2SD gives a negative value.

Table 2.11

Mean, Standard Deviation (SD), Range of Force (kg), and ICCs (2, 1) of Upper Extremity Muscle Actions

	Mean ± SD	Range	ICC (2,1)
Shoulder Flexion			
Group 1 (n = 15)			
Session 1	0.77 ± 0.58	0.17–2.30	0.87
Session 2	0.83 ± 0.56	0.17–1.63	
Group 2 (n = 14)			
Session 1	1.13 ± 0.52	0.30–1.83	0.85
Session 2	0.96 ± 0.40	0.47–1.63	
Group 3 (n = 15)			
Session 1	1.77 ± 0.74	0.93–3.10	0.84
Session 2	1.52 ± 0.58	0.47–3.00	
Combined Group (n = 44)			
Session 1	1.23 ± 0.74	0.17–3.10	0.90
Session 2	1.12 ± 0.59	0.17–3.00	
Elbow Flexion			
Group 1 (n = 15)			
Session 1	1.22 ± 0.73	0.37–2.87	0.76
Session 2	1.05 ± 0.57	0.37–2.23	
Group 2 (n = 15)			
Session 1	1.86 ± 0.97	0.57–3.50	0.92
Session 2	1.52 ± 0.82	0.37–3.03	
Group 3 (n = 15)			
Session 1	2.86 ± 0.85	1.53–4.10	0.87
Session 2	2.67 ± 0.62	1.47–3.87	
Combined Group (n = 45)			
Session 1	1.98 ± 1.08	0.37–4.10	0.93
Session 2	1.75 ± 0.96	0.37–3.87	
Elbow Extension			
Group 1 (n = 15)			
Session 1	1.86 ± 1.06	0.27–4.40	0.89
Session 2	1.71 ± 0.81	0.33–3.63	
Group 2 (n = 15)			
Session 1	2.30 ± 1.00	0.53–4.53	0.90
Session 2	1.97 ± 0.79	0.27–3.50	
Group 3 (n = 15)			
Session 1	3.71 ± 0.89	2.20–5.30	0.94
Session 2	3.58 ± 0.99	1.93–5.50	
Combined Group (n = 45)			
Session 1	2.62 ± 1.25	0.27–5.30	0.95
Session 2	2.42 ± 1.19	0.27–5.50	

Reprinted from Pediatric Physical therapy, 17, Gajdosik, C., Giller, P.T., Ability of very Young children to produce reliable isometric force measurements, p.254, © 2005.[15]

Table 2.12.

Mean, Standard Deviation (SD), Range of Force (kg) and ICCs (2, 1) of Lower Extremity Muscle Actions

	Mean ± SD	Range	ICC (2,1)
Knee Flexion			
Group 1 (n = 15)			
Session 1	1.15 ± 0.81	0.33–3.20	0.91
Session 2	1.47 ± 0.80	0.43–3.50	
Group 2 (n = 15)			
Session 1	2.03 ± 0.84	1.07–3.97	0.86
Session 2	1.94 ± 0.87	0.57–4.00	
Group 3 (n = 15)			
Session 1	3.49 ± 0.80	2.47–5.10	0.86
Session 2	3.19 ± 0.88	1.77–5.60	
Combined Group (n = 45)			
Session 1	2.22 ± 1.27	0.33–5.10	0.94
Session 2	2.20 ± 1.11	0.43–5.60	
Knee Extension			
Group 1 (n = 15)			
Session 1	2.64 ± 1.21	1.13–5.57	0.82
Session 2	2.80 ± 1.02	1.20–5.30	
Group 2 (n = 15)			
Session 1	3.85 ± 1.27	2.10–5.63	0.90
Session 2	3.68 ± 1.14	2.20–5.47	
Group 3 (n = 15)			
Session 1	5.67 ± 0.81	4.33–6.87	0.54
Session 2	5.41 ± 0.84	3.77–7.17	
Combined Group (n = 45)			
Session 1	4.05 ± 1.67	1.13–6.87	0.92
Session 2	3.96 ± 1.45	1.20–7.17	

5.5 Study Summary

Title: Ability of Very Young Children to Produce Reliable Isometric Force Measurements[15]	
Author	Gajdosik C. G.
Publication	Pediatric Physical Therapy, 17, 251-257
Purpose of the Study	To examine the reliability of measuring isometric muscle force in very young children with a hand-held dynamometer (HHD).
Type of Population	☒ Normal ☐ Other
Clinical Relevance	▪ Assessment of maximun isometric muscle force in preschoolers. ▪ Normative reference values for muscle strength.

Methods

Subjects

- The study sample consisted of 45 children with no disabilities. USA.
- Age range: 2 years to 4 years.
- Majority of subjects were white.
- Children were divided into three age groups based on chronological age in years. Each group consisted of 15 children.

Testing Procedures and Instrumentation

- Isometric muscle force was obtained by the make test technique for shoulder flexors, elbow flexors, elbow extensors, knee flexors and knee extensors. Checklist was used to record the frequency of potential challenging behaviors (CB). Weight and height were measured. A practice session with the HDD was performed before assessment. Parents decided where the assessments took place: home, day care center or rater's test room. Testing position was standardized in sitting and for each muscle group.
- Instrumentation: Calibrated Nicholas Manual Muscle Tester (Lafayette Instrument).
- Test-retest reliability was performed within five to nine days by the same examiner, in the same location using the same procedures.

Data Analysis

- Mean, range and standard deviation (SD) for three trials were calculated. ANOVA for each muscle action was calculated for force differences among the three age groups. ICC (2, 1) was calculated for test-retest reliability.

Results

- **Psychometric Properties:** Test-retest reliability was excellent. Intraclass correlation coefficients (ICCs $_{2,1}$) for the combined group (n = 45) ranged from 0.90 to 0.95. For each age group, the ICCs $_{2,1}$ for the 2-year-old children ranged from 0.76 to 0.91; for the 3-year-old group from 0.85 to 0.92, and for the 4-year-old children from 0.54 to 0.94. The frequency of CB did not appear to be related to the level of reliability.
- **Upper Extremities:** In the 2-year-olds, elbow flexors force had fair reliability ICCs (2, 1) = 0.76. Other muscle actions were in the good to the excellent range.
- **Lower Extremities:** The 4-year-olds had poor reliability for knee extensors ICCs (2, 1) = 0.54. Other muscle actions were in the good to the excellent range.
- **Challenging Behaviors:** All children of groups 1 and 2, and 10 children of group 3 displayed CB. Inattentive behaviors accounted for 89% of all episodes. No pattern was observed between frequency of CB and the level of reliability for a specific muscle action. CB decreased with age.

5.5 Study Summary (Continued)

Results (Continued)
▪ All the 2- and 3- year-old children required extra trials during test sessions with an average of 2.5 extra trials per child for each session. Some 4-year-olds also needed extra trials with an average of 1.3 extra trials per child per session. Shoulder flexors required more trials than the other muscle groups, but no pattern was observed between the frequency of extra trials and the level of reliability for a specific muscle action. ▪ For shoulder flexors, on retest session, one child (3 yrs) could not push hard enough to record a value on the HHD. Data was excluded from the study. ▪ There is an increase in force with an increase in age. Force between the three age groups was statistically significant different ($p < 0.001$). For all muscle actions, force was significant different between the 2- and 4-year-olds ($p < 0.001$) and between the 3- and 4- year-olds ($p < 0.007$). ▪ Results indicate that children as young as 28 months can reproduce reliable force measurements in controlled testing conditions. Level of reliability was slightly higher than other studies. ▪ The 3-year-old children's performance was the most consistent. Poor reliability for knee extensors in the 4-year-olds remains a question; no significant factors were related to it. ▪ Limits of the study as reported by the author: testing was done by one experienced pediatric physical therapist. Therapists with no experience with children may have more difficulty in achieving cooperation and best efforts in very young children. The inclusion of a practice session may not be feasible in all clinical situations; thus the level of reliability may be different if a practice session is not done. Results should not be generalized to very young children with disabilities. Children must be strong enough to push against the HHD. Last, results are limited to the muscle groups assessed and the positions used.
Authors' Conclusion
▪ Using a HHD and standardized procedures, isometric force can be measured with fair to excellent reliability in children who are typically developing and as young as 2 years of age. ▪ The majority of 3- and 4-year-old children successfully participated in muscles testing sessions but the 2-year-group were more likely to refuse to participate or show difficulty in generating force against the HHD. Tests trials with challenging behaviors were excluded which may have influenced the reliability of test results.

Comments
▪ Methodology is very good. ▪ Internal validity seems good. However, sample size is small (n =15 per age groups) and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution.

6. Maximum Isometric Muscle Force - Break Test Technique [7]

Age range: 4 years to 16 years.

6.1 Clinical Use

- To quantify muscle strength measurement.
- To document gain or loss of muscle strength over a period of time.

6.2 Measurements

- Maximum isometric force in eleven muscle groups is tested: neck flexors , five muscle groups in the upper extremities and five muscle groups in the lower extremities (Table 2.13).
- Force values are recorded in Newton (Table 2.14).

6.3 Testing Procedures

REQUIRED EQUIPMENT

- Calibrated hand-held dynamometer Type CT 3001 (CIT Technics, Groningen, The Netherlands).
- Examination table.

TEST

- Number of trials: The child is tested three times. If an inadequate performance is suspected, the highest value of three contractions is recorded, with a rest period of at least 30 seconds between trials.
- Subject, joint and HHD positions for the assessment of eleven muscle groups are presented in Table 2.13.
- Results are compared to the normative reference values in Table 2.14.

Table 2.13.

Muscle group, subject and dynamometer position: standard protocol

Muscle group	Subject position	Dynamometer position
Neck flexors	Sitting upright; head up at 90°	Centre of forehead, just above eyebrows
Shoulder abductors[a]	Sitting upright; shoulder 90° abducted, elbow 135° flexed, forearm pronated	Lateral epicondyle of humerus
Elbow flexors[a]	Supine; shoulder adducted, elbow 90° flexed, forearm supinated	Just proximal to wrist crease (flexor surface)
Elbow extensors	As for elbow flexors	Just proximal to wrist crease (extensor surface)
Wrist extensors	Sitting; forearm supported and pronated, wrist in neutral position, fingers flexed	Just proximal to third metacarpal head
Three-point grip[a]	Sitting; forearm pronated, wrist extended	Distal phalanx of thumb under applicator, distal two phalanges of dig 2 and 3 above collar
Hip flexors	Supine; hip and knee 45° flexed, ankle supported by examiner	Anterior surface of distal thigh
Hip abductors	Supine; hip 45° flexed, knee 90° flexed, contralateral knee supported by chest of examiner	Lateral epicondyle of knee
Knee extensors	Sitting; knee 90° flexed	Anterior surface of distal shunt just proximal to ankle joint
Knee flexors[a]	Sitting; knee 45° flexed	Heel
Foot dorsiflexors[a]	Supine; foot 90° dorsiflexed	Just proximal to metatarsophalangeal joints (dorsal surface)

[a] Adjusted protocol.

Reprinted from Neuromuscular Disorders, 11, Beenakker, E. A., Van Der Hoeven, J. H., Fock, J. M., & Maurits, N. M. Reference values of maximum isometric muscle force obtained in 270 children aged 4-16 years by hand-held dynamometry. Neuromuscular Disorders, p.442, © 2001 with permission from Elsevier.[7]

6.4 Normative Reference Values

Table 2.14. Age-related reference Values for 11 Muscle Groups in Normal Boys and Girls 4 to 16 Years Old[A]

Age-related reference values for 11 muscle groups in normal boys and girls aged 4–16 years[a]

Muscle group (N)		Age (years) 4	5	6	7	8	9	10	11	12	13	14	15	16
Neck flexors	Boys			48 (9)	64 (11)	56 (8)	66 (9)*	74 (20)	67 (13)	70 (16)	98 (40)	129 (42)	143 (36)	141 (33)
	Girls			55 (8)	60 (7)	56 (10)	55 (12)*	55 (25)	67 (15)	76 (15)	92 (17)	96 (15)	108 (27)	87 (14)
Shoulder abductors	Boys	62 (20)	55 (10)	97 (27)	92 (29)	98 (19)	110 (31)	136 (26)**	110 (39)	118 (29)	159 (46)	205 (44)	219 (36)**	253 (54)**
	Girls	68 (26)	47 (9)	75 (17)	91 (18)	94 (25)	91 (27)	81 (17)**	129 (25)	123 (27)	154 (26)	178 (18)	173 (29)**	173 (38)**
Elbow extensors	Boys			73 (8)	85 (16)	90 (18)	89 (22)	120 (18)**	103 (31)	104 (31)	128 (42)	158 (42)	175 (46)	182 (64)**
	Girls			73 (8)	85 (14)	82 (10)	91 (24)	84 (20)**	108 (25)	117 (24)	118 (26)	129 (23)	141 (37)	107 (36)**
Elbow flexors	Boys	78 (24)	70 (12)	103 (21)	121 (32)	124 (23)	134 (24)	173 (19)**	153 (30)	160 (25)	195 (26)	253 (50)*	287 (55)**	276 (68)*
	Girls	69 (21)	66 (12)	105 (9)	103 (20)	115 (16)	125 (28)	134 (21)**	172 (25)	168 (28)	201 (23)	193 (32)*	198 (48)**	215 (30)*
Wrist extensors	Boys			77 (11)*	89 (26)	87 (15)*	97 (15)*	121 (21)**	100 (19)	108 (21)	153 (42)	195 (41)*	218 (49)**	237 (58)**
	Girls			66 (6)*	74 (13)	75 (11)*	80 (21)*	80 (17)**	112 (16)	127 (23)	152 (14)	155 (6)*	166 (26)**	147 (28)**
Three-point grip	Boys	33 (10)	37 (9)*	46 (9)	50 (9)	56 (12)	58 (9)	78 (15)**	70 (24)	72 (16)	96 (25)	113 (17)*	127 (29)*	140 (22)**
	Girls	30 (4)	28 (3)*	44 (11)	47 (9)	53 (9)	56 (14)	54 (11)**	73 (13)	72 (11)	84 (11)	96 (13)*	99 (17)*	106 (18)**
Hip flexors	Boys			182 (39)	182 (57)	225 (40)**	232 (53)	261 (74)**	245 (65)	198 (38)	289 (60)	337 (66)	301 (69)	395 (102)*
	Girls			162 (31)	184 (50)	175 (36)**	195 (48)	177 (25)**	264 (55)	232 (61)	308 (51)	281 (72)	288 (70)	301 (42)*
Hip abductors	Boys			128 (40)	124 (32)	131 (30)	153 (33)	174 (47)**	151 (63)	158 (41)	225 (58)	306 (83)	356 (87)**	312 (106)
	Girls			109 (26)	122 (24)	117 (18)	124 (35)	104 (25)**	140 (22)	171 (44)	227 (52)	244 (30)	257 (68)**	244 (59)
Knee extensors	Boys			156 (33)	157 (38)	185 (41)	194 (30)	267 (47)**	239 (65)	225 (43)	296 (70)	370 (61)*	362 (76)	396 (90)
	Girls			148 (24)	177 (47)	166 (30)	173 (57)	198 (57)**	265 (36)	250 (71)	346 (49)	280 (69)*	325 (79)	373 (81)
Knee flexors	Boys	111 (15)	105 (20)	158 (38)	180 (45)	185 (20)*	195 (40)	268 (48)**	218 (64)	201 (34)	273 (59)	307 (64)	327 (76)	382 (80)
	Girls	92 (25)	99 (15)	154 (33)	171 (35)	160 (23)*	180 (54)	175 (29)**	246 (52)	221 (54)	301 (38)	271 (76)	282 (61)	336 (57)
Foot dorsal flexors	Boys	71 (22)	76 (23)	104 (11)	130 (26)	137 (24)	141 (31)	154 (18)**	149 (26)*	170 (28)	218 (55)	257 (60)	267 (50)*	291 (60)*
	Girls	75 (20)	76 (15)	95 (17)	114 (18)	121 (17)	137 (32)	130 (21)**	178 (25)*	177 (34)	214 (29)	207 (31)	220 (40)*	232 (30)*

[a] Mean values (SD). Significant difference at $*P \leq 0.05$ and $**P \leq 0.01$.

6.5 Study Summary

Title: Reference Values of Maximum Isometric Muscle Force Obtained in 270 Children Aged 4-16 Years by Hand-Held Dynamometry [7]	
Authors	Beenakker, E. A., Van Der Hoeven, J. H., Fock, J. M., & Maurits, N. M.
Publication	Neuromuscular Disorders, 11, 441-446
Purpose of the Study	▪ To establish reference values of maximum isometric force in 11 muscle groups with hand-held dynamometry. ▪ To provide summed scores for upper and lower extremities, distal and proximal.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	▪ Assessment of maximun isometric muscle force. ▪ Normative reference values for muscle strength.

Methods

Subjects

- The study sample consisted of 270 children (131 ♀, 139 ♂) with no disabilities. The Netherlands.
- Age range: 4 years to 16 years. Children were randomly selected from school and were divided into age groups based on chronological age in years. Number of subjects per age group varied from 20 to 23 children. Number of subjects per gender varied from 7 to 13 children.

Testing Procedures and Instrumentation

- All measurements were done by the first author with a standard protocol.
- Weight and height were measured. Maximum isometric force in 11 muscle groups was tested bilaterally except for neck flexors.
- An adjusted protocol was used for younger children (4- and 5-year-olds): a minimum of five muscle groups were tested.
- Highest value of three contractions was recorded with an interval of at least 30 seconds if inadequate performance was suspected. Testing positions were standardized for each muscle group.
- Instrumentation: Calibrated hand-held dynamometer Type CT 3001. Muscle force was measured in Newtons.

Data Analysis

- Mean and standard deviation (SD) were calculated in bilaterally tested muscle groups.
- Summed scores, student’s t test, Pearson correlation coefficients (*r*) were calculated.

Results

- **Psychometric Properties:** Non applicable
- In boys: weight correlated best with muscle force for individual muscle groups as well for summed scores. For weight, Pearson correlation coefficients (*r*) ranged from 0.76 (for hip flexors) to 0.87 (for other muscle groups).
- In girls: weight and age correlated best with muscle force. For weight, Pearson correlation coefficients (*r*) ranged from 0.61 (elbow extensors) to 0.89 (foot dorsal flexors) and for age from 0.55 (elbow extensors) to 0.89 (foot dorsal flexors).
- Significant force differences can be first seen at age 5 in favour of boys. At 10, boys were significantly stronger than girls for all muscle groups except one. At 11-13, girls were stronger than boys but not significantly for nearly all muscle groups. Significance in favour of boys became definite at age 14.

6.5 Study Summary (Continued)

- Factors such as attention and difficulty in understanding the instructions diminish reliability. Significant force differences for leg muscles could not be demonstrated between boys and girls aged 15 and 16 because muscle force was high (some exceeded the chosen limit of 500 newtons).

Authors' Conclusion

- Reference values of the present study can be used to quantify possible muscle weakness or monitor the effects of therapy in children aged 4 to 16 years.
- Summed scores of total muscle strength versus age and weight are presented therein.
- Weight is strongly correlated with muscle force in both genders.
- Weight-related reference values can be used to classify muscle force more accurately in children with growth retardation.

Comments

- Internal validity seems good. However, sample size is small per gender and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution.

7. Hand Grip Strength-Summary

Grip strength refers to the pressure or strength displayed by a subject when firmly squeezing an object with the hand in order to maintain a tight hold on it. It is a good parameter to evaluate hand function.[11, 22, 29, 43, 48] Maximum hand grip strength is commonly used as an index of general health and as a screening test for the integrity of both the upper motor neurons and the function of the motor unit.[25, 33] It can be used to determine the degree of disability and to document changes resulting from specific treatment methods. [22]There is a progressive age-dependent gain in hand grip strength in both genders. Boys are stronger than girls.[23, 33]

It is imperative that reassessments be performed in the identical position and at relatively the same time of the day.[29, 48] If the testing position is altered during measurement, the strength of the grip will be altered. The American Society of Hand Therapists recommend the use of a standard position for administering grip strength with the Jaymar dynamometer (Fig.2.4).[11, 29, 48] It appears that the time of day influences the strength of grips. The grips performed in the early morning would be weaker than grips performed at later times in the day but would not vary importantly if performed at various other times during the day.[29]

Richards et al (1996)[29] cite that using both a single trial and the mean of three trials produced high inter-rater reliability but that the most reliable grip strength scores would be from the mean of three trials, each performed at relatively the same time on separate days.

Rest periods occur during testing when alternating hands. There would be no significant differences in grip measures when using 15, 30 and 60-second rest periods between measurements. [48] If multiple grip trials occur within a session, a 4-to-6-min rest period between trials would be necessary for preventing fatigue effects.[29]

Two studies were selected :

A) De Smet et al. (2001)[11] measured hand grips strength with the Jaymar dynamometer.

B) Sartorio et al. (2002)[33] measured hand grips strength with the Lafayettte pediatric dynamometer.

A) Assessment with the Jaymar Hand-Held Dynamometer [11]

Age range: 5 to 15 years.

7.1 Clinical Use

- Quantification measurement of hand grip strength in children.

7.2 Measurements

- Maximum grip strength is tested.
- Force values are recorded in kg (Table 2.15).

7.3 Testing Procedures

REQUIRED EQUIPMENT

- Calibrated Jaymar dynamometer.
- An armless chair with a backrest. The child‘s feet must be flat on the floor.
- A small ball or writing accessories.

PRE-TEST

- Determine hand dominance by having the child throw the ball, draw or write his name on a piece of paper.

TEST

- Number of trials: One
- Testing position: The standard test position (no 2) recommended by the American Society of Hand Therapists (Fig. 2.4).
    - The child sits on the chair.
    - Arms are unsupported.
    - Shoulders are adducted in neutral.
    - Elbow is flexed at 90°.
    - Forearm and wrist are in neutral position.
    - Feet are flat on the floor.
    - Variations from this position can significantly affect measurements and results.
- Muscle contraction: The child is asked to squeeze maximally.
- Results are compared to the normative reference values in Table 2.15.

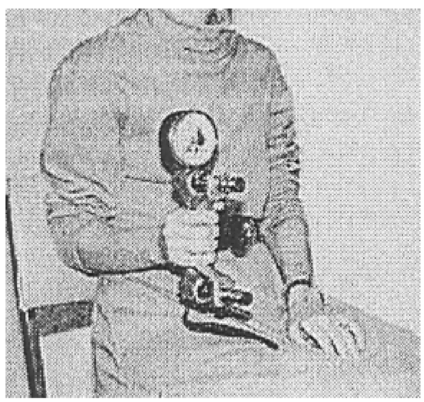


Figure 2.4. The standard position for grip strength measurement using a Jammar-type dynamometer as recommended by the American Society of Hand Therapists.
©Richards, L. & Palmiter-Thomas, P.90. [29]

7.4 Normative Reference Values

TABLE 2.15. *Grip force in right-handed and left-handed boys and girls, aged 5 years to 15 years, dominant and non-dominant hands*

Age (years)	Hand	Boys				Girls			
		Right handed		Left handed		Right handed		Left handed	
		Grip force	SD	Grip force	SD	Grip force	SD	Grip force	SD
5	Dominant	7.6	1.89	10.3	2.27	6.9	1.54	6.7	1.25
	Nondominant	7.3	1.61	9.7	3.16	6.2	1.79	6.7	1.25
6	Dominant	9.8	1.41	6.0	0.00	10.0	1.41	9.5	0.50
	Nondominant	8.2	1.67	9.0	0.00	8.7	0.88	10.0	0.00
7	Dominant	11.4	1.57	10.0	0.00	9.6	2.79	10.0	0.00
	Nondominant	10.6	1.80	10.0	0.00	8.7	2.94	10.0	0.00
8	Dominant	13.5	3.59	10.3	1.07	11.2	1.48	13.0	0.70
	Nondominant	13.7	2.81	12.0	1.41	11.2	1.77	11.8	2.28
9	Dominant	15.0	4.07	19.0	0.00	14.4	2.01	–	–
	Nondominant	14.1	4.36	18.0	0.00	14.5	2.21	–	–
10	Dominant	18.8	4.12	18.5	2.50	15.3	4.24	–	–
	Nondominant	18.0	3.76	17.5	0.50	14.9	3.75	–	–
11	Dominant	21.8	4.73	18.5	0.50	18.5	2.59	11.0	0.00
	Nondominant	20.6	3.59	18.5	0.50	17.5	3.48	12.0	0.00
12	Dominant	24.1	3.45	22.3	3.16	24.6	4.78	20.0	3.27
	Nondominant	22.6	3.05	22.2	3.15	22.8	4.88	18.7	1.70
13	Dominant	29.9	6.71	23.6	7.96	22.5	5.36	20.2	2.50
	Nondominant	27.6	6.25	21.8	8.59	25.2	4.59	19.4	4.22
14	Dominant	34.3	6.64	38.8	7.02	27.6	4.62	33.0	7.81
	Nondominant	32.5	6.56	35.5	6.69	25.8	3.84	32.3	6.52
15	Dominant	38.4	8.46	41.0	6.32	29.1	4.53	31.0	3.67
	Nondominant	34.6	7.98	40.8	3.37	28.2	3.38	30.5	3.20

SD, Standard deviation.

7.5 Study Summary

Title: Grip Strength in Children [11]	
Authors	De Smet, L., & Vercammen, A.
Publication	Journal of Pediatric Orthopaedics, Part B, 10, 352-354
Purpose of the Study	To construct a normative data bank for grip strength in children related to sex, hand dominance and age.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hand grip strength.

Methods

Subjects

- The study sample consisted of 487 healthy children (219 ♀, 268 ♂). West European.
- Girls: 192 right handed; 27 left handed.
- Boys: 225 right handed; 41 left handed.
- Age range: 5 years to 15 years.
- Children were divided into 11 age groups based on chronological age in years and gender. Number of children varied between groups and gender from 9 to 51. Hand dominance was determined by questioning.

Testing Procedures and Instrumentation

- Standardized procedures were used during all measurements. Hand grip strength was tested once due to the large number of children to be tested. Testing position was standardized in sitting.
- Instrumentation: Calibrated Jaymar dynamometer.

Data Analysis

- Non paired Student *t* test was calculated and significance was set at ($p < 0.05$). Mean and standard deviation (SD) were calculated.

Results

- **Psychometric Properties**: Non applicable
- There was a high variation in grip force that varied between 6.9 kg in 5-year-old girls to 38.4 kg in 15-year-old boys.
- Up to the age of 12 years, there was a striking parallelism between boys and girls. At the age of 13 years, the difference became significant ($p < 0.01$). Between 13 and 15 years, the average grip strength in girls is 25% lower than boys.
- The difference between the dominant (d) and non dominant (nd) hand grip was not significant ($p < 0.05$). Difference between right and left hand was not significant ($p < 0.05$) but, in boys, the right hand was constantly stronger by 10% for right-hand dominant children. This was not observed in the left-hand children but these groups were too small to allow statistical conclusions.
- Grip strength increases with advancing age and the difference between genders at age 12 is consistent as confirmed in other studies. In two other studies, difference was reported at a younger age. Small children may have difficulty in using the device.

7.5 Study Summary (Continued)

Authors' Conclusion
▪ Data bank for hand grip strength was established for children aged between 5 years and 15 years. ▪ Difference between the d and nd hand is certainly no more than 10% in right-handed children. ▪ Difference in grip strength between boys and girls is only significant starting from the age of 12 years.

Comments
▪ Internal validity seems good. However, sample size is small in some age categories and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution. ▪ The use of only one measure may be considered as a weakness in methodology. However, other methodological aspects are excellent. ▪ Inter- and intra-reproducibility was not measured.

B) Assessment with the Lafayette Pediatric Hand-Held Dynamometer [33]

Age range: 5 to 15 years.

7.6 Clinical Use

- Quantification measurement of hand grip strength in children.

7.7 Measurements

- Maximum grip strength is tested.
- Force values are recorded in kg (Fig. 2.5).

7.8 Testing Procedures

REQUIRED EQUIPMENT

- Calibrated Pediatric Lafayette hand-held dynamometer.
- An armless chair with a backrest. The child's feet must be flat on the floor.
- A small ball or writing accessories.

PRE-TEST

- Determine hand dominance by having the child throw a ball, draw or write his name on a piece of paper.

TEST

- In the present study, assessment was done in a spirit of competition among school peers to encourage best effort. Children were tested in groups.
- Number of trials: The child is tested three times with a sixty-second rest between each trial.
- The child is asked to squeeze maximally. The best score among the three trials is used.
- Testing position: The standard position (no 2) recommended by the American Society of Hand Therapists (Fig. 2.4).
    - The child sits on the chair.
    - Arms are unsupported.
    - Shoulders are adducted and neutrally rotated.
    - Elbow is flexed at 90°.
    - Forearm is in neutral position.
    - Wrist is between 0° - 30° dorsiflexion and between 0° - 15° ulnar deviation.
    - Feet are flat on the floor.
    - Variations from this position can significantly affect measurements and results.
- Results are compared to the normative reference values in Table 2.5 for males and females.

7.9 Normative Reference Values

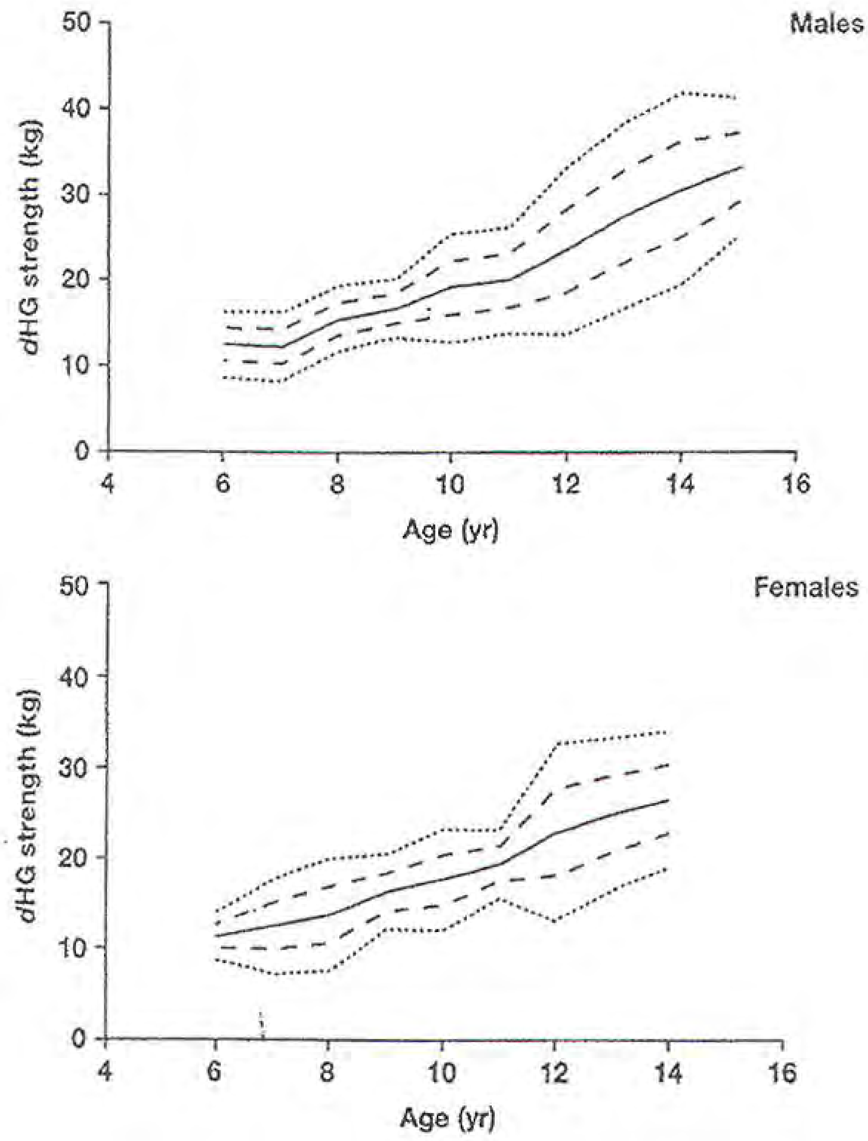


Figure 2.5. Average values of maximal dominant hand-grip (dHG) strength (heavy line) as a function of age, observed in males (top panel) and females (bottom panel). Ranges of variability: ±1SD (broken line) ans ± 2SD (dotted line). Due to the relative small number of females aged 15 yr, the corresponding data for HG strength are not shown in the figure.

7.10 Study Summary

Title: The Impact of Gender, Body Dimension and Body Composition on Hand-Grip Strength in Healthy Children [33]	
Authors	Sartorio, A., Lafortuna, C. L., Pogliaghi, S., & Trecate, L
Publication	Journal of Endocrinological Investigation, 25, 431-435
Purpose of the Study	▪ To develop normative maximum hand-grip (HG) strength in normal children. ▪ To evaluate the influence of gender, anthropometric variables, age and hand dominance on strength.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hand grip strength.

Methods

Subjects

- The study sample consisted of 278 healthy children (113 ♀ and 165 ♂). Northern Italy.
- Age range: 5 years to 15 years.
- Children were divided into three age groups based on pubertal development (Tanner stages):
  - Group 1 = Tanner stage 1. Age 7.6 yrs (± 0.9 yrs), n = 54.
  - Group 2 = Tanner stage 2,3. Age 10.8 yrs (± 0.7 yrs), n = 66.
  - Group 3 = Tanner stage 4,5. Age 13.2 yrs (± 0.9 yrs), n = 158.
- Number of subjects in each group varied from 54 to 158 children.

Testing Procedures and Instrumentation

- Standardized procedures were used. Random selection was used for first tested hand.
- Hand grip strength was tested by three trials for each hand. Anthropometrics measurements were height, weight, body mass index (BMI), fat free mass (FFM), body surface area (BSA) and percent body fat (BF).
- To encourage best efforts of children, in a spirit of competition, measurements were made in presence of classmates. Testing position was standardized in sitting.
- Instrumentation: Lafayette pediatric hand dynamometer.

Data Analysis

- For each hand, the highest value of three trials was used for analysis. Mean and standard deviation (SD) were calculated for all the parameters.
- Two ways ANOVA, Tukey test, linear correlation, multiple linear regression and conventional regression equation comparison were calculated. Significance was set at ($p < 0.05$).

7.10 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Non applicable. ▪ Most children were right-handed (91%). Weight, height, BSA, BMI, BF and FFM increased progressively and significantly from the younger to the older age group. ▪ Findings confirm a progressive age dependent increase in HG strength in both genders, a significant 10% difference being evident between genders at all ages for *d* and non dominant (*nd*) hand. ▪ HG strength is highly correlated with the age dependant FFM. ▪ In either gender, a curvilinear relation was detected between HG strength and age, with best fit for the *d* hand. ▪ For both genders, *nd* hand was significantly weaker than d hand in the older age groups (2 and 3) while no difference was detected in the younger group (5 to 8-year-old). These results disagree with the findings from other authors who reported similar HG strength of *d* and *nd* hand. ▪ Age and gender-dependent differences in HG strength (but not differences between *d* and *nd* hand) disappear if HG strength is normalized for FFM. ▪ Results of the present study might be slightly higher than those found when a child is tested individually. Assessment in small groups may have facilitated performances in simple motor task.
Authors' Conclusion
▪ The present study indicates that the age-dependent increases of HG strength as well as the between-gender differences are strongly related to changes of FFM values occurring during childhood. ▪ The study provides standard normative values for maximal HG strength in healthy children.

Comments
Internal and external validity (including sample size, n= varied between 54 and 158) seems good and the use of results as a trend for clinical guidelines is appropriate.

Trunk Muscle Strength

Summary

The review of the literature produced very few articles on the assessment of trunk muscle strength in young children. Only one study was selected for the assessment of trunk flexors and no studies were selected for trunk extensor muscle strength.

Among twelve abdominal exercises, curl-ups resulted in the highest abdominal muscle activation to compression download in the upper and lower rectus abdominus and authors report that the curl-up would be a more specific and safer test than a full sit-up.[52] In children, strength is shown to be a separate and integral component of physical fitness, essential for adequate performance in daily activities.[17] The testing of the trunk flexor muscles strength is important since they contribute in acquiring adequate motor patterns throughout the child's normal development.[21, 30] Trunk flexor muscles maintain an important role in postural stability throughout the ages and are thus an integral part in the development of refined skill movements in the child.[30] Adequate muscle abdominal strength is also important in assisting the respiration process.[30]

8. Trunk Flexor Muscle Strength [21]

Age range: 3 years to 6 years 11 months.

8.1 Clinical Use

- To measure abdominal strength and endurance.

8.2 Measurements

- Isometric Test A: Half-hold hooklying supine flexion posture (Table 2.16). Performance is timed in seconds (Table 2.19).
- Isometric Test B: Supine flexion posture (Table 2.17). Performance is timed in seconds (Table 2.19).
- Isotonic Test: Hooklying sit-ups (Table 2.18). Number of sit-ups is recorded (Table 2.20).

8.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Sit-up board (A padded plywood platform with an ankle strap).
- Hypoallergenic skin cosmetic crayon.

PRE-TEST

- Provide a demonstration or an illustration of the activity so that the child becomes familiar to the testing procedures.
- Verbal instructions needed for the test are explained to the child. (Tables 2.16 through 2.18).
- Mark the following anatomical landmarks: the inferior angle of scapulae, the lateral malleolus, the lateral side of the knee joint and the greater trochanter.

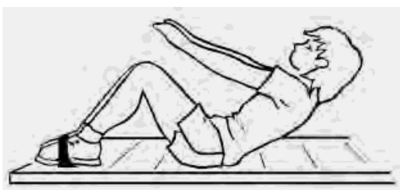
Before each test, the child lies in supine, knees flexed to 90° flexion (measured with a goniometer and the lower limb anatomical landmarks previously described).

TEST

- Rest periods: one to ten-minute rest periods between tests.
- Standard testing positions and rating procedures are presented in Table 2.16 (Isometric Test- A), Table 2.17 (Isometric Test-B) and in Table 2.18 (Isotonic Test).
- Results are compared to the normative reference values in Tables 2.19. – 2.20.

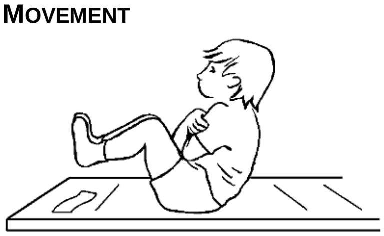
- **ISOMETRIC TEST-A**

TABLE 2.16. TESTING PROCEDURES STANDARD FOR HALF-HOLD HOOKLYING POSITION

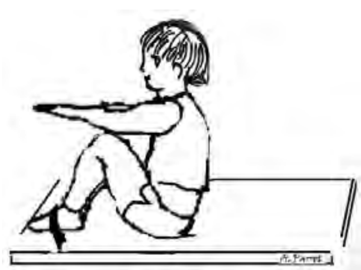
STARTING POSITION	▪ Supine with the arms extended anterior to trunk. ▪ Knees: 90° flexion. ▪ Both feet are flat on the sit-up board and secured by a strap across the dorsa of the feet.
VERBAL INSTRUCTION	"*Hold it as long as you can*".
MOVEMENT  **Figure 2.6.** (© IRDPQ).	▪ The child raises his head slowly, followed by the shoulders and upper chest until the scapulae is entirely off the board. ▪ Accepted position is reached when the inferior angle of the scapulae can be palpated. ▪ If the child is unable to assume accepted position, the therapist places the child in the testing position.
RATING PROCEDURE	▪ Performance is timed in seconds from the moment the therapist says "hold it as long as you can" to the moment the child's head and chest begin to lower from the test position.

- **ISOMETRIC TEST-B**

TABLE 2.17. TESTING PROCEDURES STANDARD FOR SUPINE FLEXION POSTURE

STARTING POSITION	▪ Supine with the arms crossed over the chest. ▪ Knees: 90° flexion. ▪ Both feet flat on the sit-up board.
VERBAL INSTRUCTION	"*Roll into a ball*" and "*Hold it as long as you can*".
MOVEMENT  **Figure 2.7.** (© IRDPQ).	▪ On the command, "*Roll into a ball*", the child flexes simultaneously his neck, upper trunk and hips to bring his knees to his chest. ▪ Accepted position is reached when the child is unable to further flex his neck, upper trunk and hips or therapist is unable to flex those body parts any further. ▪ If the child is unable to assume accepted position, the therapist places the child in the testing position.
RATING PROCEDURE	▪ Performance is timed in seconds from the moment the therapist ascertains that the position is correct to the moment the child's head and extremities begin to lower from the accepted position.

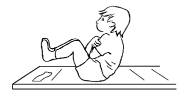
- **ISOTONIC TEST**

TABLE 2.18. TESTING PROCEDURES STANDARD FOR HOOKLYING SIT-UPS	
STARTING POSITION	▪ Supine with the arms extended anterior to the trunk. ▪ Knees: 90° flexion. ▪ Both feet are flat on the sit-up board and secured by a strap across the dorsa of the feet.
VERBAL INSTRUCTION	▪ *"Bring your nose to your knee"* or "*Sit up without using your hands"* depending on the child's level of understanding. ▪ "*Do as many sit-ups as you can*".
TRIALS	▪ Three trials are permitted to attain upright position. ▪ If the child is able to assume accepted upright position, the therapist gives the instruction: "*Do as many sit-ups as you can*". ▪ If the child is unable to perform one complete sit-up, he is given a score of zero.
MOVEMENT  **Figure 2.8.** (© IRDPQ).	▪ The child flexes first his neck, then his upper trunk and finally his lower trunk. ▪ The child is allowed to move at his own rate of speed. ▪ Accepted upright position is attained when the therapist observes that the child's head and trunk are in a plane perpendicular to the sit-up board.
RATING PROCEDURE	▪ The number of sit-ups are recorded.

8.4 Normative Reference Values

- **ISOMETRIC TESTS**

A) Half-Hold Hooklying Position
Figure 2.9. (© IRDPQ)



B) Supine Flexion
Figure 2.10. (© IRDPQ).

TABLE 2.19

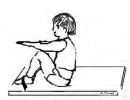
Means and Standard Deviations of Half-Hold Hooklying and Supine Flexion Test Results and *t*-test Results Between Boys and Girls

Test	Age (yr)	n	Test Scores[a] Boys $\bar{X}$	Boys *s*	Girls $\bar{X}$	Girls *s*	*t*
Half-hold hooklying position	3	40	18.9	2.3	16.2	13.0	NS[b]
	4	40	20.1	9.9	23.6	7.0	NS
	5	40	28.3	22.9	43.4	23.4	NS
	6	40	71.5	29.9	74.2	47.3	NS
Supine flexion	3	40	15.5	6.7	15.8	8.2	NS
	4	40	17.0	6.7	20.1	9.1	NS
	5	40	27.4	11.5	29.5	14.9	NS
	6	40	55.4	29.1	52.0	39.7	NS

[a] Scores measured in seconds.
[b] NS = not significant at .05 level.

Data from: Lefkof MB.[21]

- **ISOTONIC TEST**



Hooklying Sit-ups
Figure 2.11. (© IRDPQ).

TABLE 2.20

Means and Standard Deviations of Hooklying Sit-up Test Results and *t*-test Results Between Boys and Girls

Age (yr)	n	Test Scores[a] Boys $\bar{X}$	Boys *s*	Girls $\bar{X}$	Girls *s*	*t*
3	40	1	3	3	9	NS[b]
4	40	13	9	16	17	NS
5	40	17	13	16	9	NS
6	40	60	39	34	23	$p < .00005$

[a] Scores measured in number of sit-ups completed.
[b] NS = not significant at .05 level.

Data from: Lefkof MB.[21]

8.5 Study Summary

Title: Trunk Flexion in Healthy Children Aged 3 to 7 Years [21]	
Author	Lefkof M. B.
Publication	Physical Therapy, 1986, 66, 39-44.
Purpose of the Study	To establish normative reference values for trunk flexor musculature capabilities.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of trunk flexor muscle strength.

Methods

Subjects

- The study sample consisted of 160 healthy children (80 ♀, 80 ♂). USA.
- Age range: 3 years to 7 years.
- Majority of the subjects were white, from lower middle class to upper middle class.
- Children were divided into four age groups based on chronological age in years.
- Number of subjects per group = 40.

Testing Procedures and Instrumentation

- Weight and height were measured in random selection. Muscle strength was assessed with two isometric trunk flexor tests and one isotonic trunk flexor test. Positions were standardized for each test.
- Instrumentation: Stopwatch, goniometer and a sit-up board.

Data Analysis

- Test-retest reliability was obtained by random selection of 5 subjects from each age interval. Test-retest was performed at a one-week interval. The type of coefficient that was used to measure reliability is not defined.
- Reliability scores were computed for the entire population and for individual age intervals on each test.
- Normative data and student's *t*-tests were computed from test score for both genders at each age interval.
- One way analysis of variance (ANOVA) was used to determine the effects of age, height and weight on the scores of half-hold hooklying and supine flexion tests.
- Two ways ANOVA was computed on hooklying sit-up test scores to obtain the effect of age, gender and interaction of age and gender on test results.
- Linear regression analysis was performed on height, weight and gender for the hooklying sit-up test scores in the 6-year-old group to account for size difference between the genders.
- A Pearson product-moment correlation was used to identify the degree of association between scores of half-hold hooklying and supine flexion tests.
- Mean, standard deviation (SD) and *t*-test were calculated for each age group and gender.

8.5 Study Summary (Continued)

Results

ISOMETRIC TESTS

- **Psychometric Properties:** Average test-retest reliability was 0.75 to 0.86 for all age groups. Highest score was in the 5-year-age group and lowest score was in the 6-year-age group.
- A significant correlation was found between scores on isometric tests at all age levels (except 4-year-old girls) and for each gender. Strong correlation between the two tests suggests that either test may be used to determine isometric trunk flexion strength in this age group. There was no statistically significant difference between genders. There was a statistically significant difference between age groups ($p < 0.0001$).

ISOTONIC TEST

- **Psychometric properties:** Average test-retest reliability scores was 0.83 for all age groups. Highest score was in the 3-year-old group and lowest score in the 6-year-old group.
- There was a statistically significant difference between genders in the 6-year-old group ($p < 0.5$). Multiple regression data showed that 6-year-old boys averaged 20 points more than girls ($p < 0.4$).

ANTHROPOMETRIC MEASUREMENTS

- Height was found to be a significant predictor of tests results for the three tests ($p < 0.0001$). Results are consistent with other studies. The average scores were higher than the averages listed for comparable movements and different factors might be the cause such as fatigue, test position, high motivation in the subjects of the present study (rewards, group motivation).
- Trunk flexor muscle capabilities improve with age. This is consistent with other studies. Pattern of movement appeared to influence performance on the isotonic test. Ones that scored the highest used hip extension prior to trunk flexion and dorsiflexion against the strap.

Authors' Conclusion

- 95% of healthy children, aged between 3 and 7 years, were able to perform isometric trunk flexion contractions against gravity.
- By age 6, all the children were able to perform isotonic trunk flexion contractions against gravity.
- Isometric tests were consistently performed at a younger age compared to the isotonic tests.
- Younger children exhibit more strenuous movement than the older children.
- Isometric vs. isotonic strength: A significant difference in the performance of the isometric and isotonic strength was found among age groups. Trunk flexion strength improves with age.

Comments

Internal and external validity, (including sample size, $n = 40$ per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

Health-Related Fitness Batteries

Summary

Assessing physical fitness in youth has changed from a motor fitness emphasis to a health related emphasis in Canada, the USA and abroad.[14, 44] Interest in school-based physical activity interventions is currently high, in large part due to the trend towards physical inactivity, overweight and obesity in children and youth.[49] Physical education, in particular, was correlated with significant decreases in the risk of both overweight and obesity, a finding that demonstrates the value of physical education classes to the health of children.[49]

Physical fitness test promotes a basic level of fitness among students, through performances in five physical fitness tests: curl-ups or partial curl-ups, shuttle run, endurance run/walk, pull-ups (right angle push-ups, flexed-arm hang), and V-sit (sit and reach). Freedsom & al. (2000) [14] cites that "…even though some of the test items lack empirical data to identify that they provide a reasonable estimate of the fitness parameter, there would be a consensus on these health-related fitness components: cardio-respiratory fitness, muscular strength and endurance, flexibility and body composition…"

Fitness tests are usually performed in a context of group evaluation in physical education class by trained instructors. [9] The term student will thus be used in this chapter.

There exist different health-related fitness batteries that use different standards to assess physical fitness and a child may meet the standards of one test but not those of another. [14] Among these test batteries , there is the Fitnessgram /Activitygram program that uses criterion-referenced fitness standards for determining fitness achievement. [52] It was developed by the Cooper Institute. Information about the assessments are available in the Fitnessgram/Activitygram Reference Guide and uses the Fitnessgram /Activitygram software. [52]

Another test battery is the President's Challenge Fitness Awards which is a norm-referenced based award [52] that promotes for people of all ages to be physically active on a regular basis. It was developed as a tool by the President's Council on Physical Fitness and Sports to assist in teaching students the principles of fitness while measuring health-related fitness components. The Presidential Physical Fitness Awards and test instructions can be obtained on their web-site. [51] The tested activities are performed with minimal equipment and include the five health-related fitness components previously mentionned. It offers motivational awards and a flexible approach to assess physical fitness by using three levels of performance : [44]

- **The Presidential Physical Fitness Award** - which recognizes students who achieve an outstanding level of physical fitness (> 85th percentile on 1985 School Population Fitness Survey) on five required test items.

- **The National Physical Fitness Award** - for students who reach a moderate standard of performance (50th percentile on 1985 School Population Fitness Survey) on five required test items.

- **The Participant Physical Fitness Award** - to recognize the participation of other students (< 50th percentile) on one or more events.

Validity and Reliability

Field tests measurements are reported as topics of some debate. There are conflicting results in the literature and different levels of evidence to support their validity [14, 44] and reliability. [14] The shuttle run test is reported to be a valid measure of aerobic fitness and has been adapted to use with ambulant children with cerebral palsy. [41] The findings of Pate et al. (1993)[26] for five field tests of muscular strength/endurance in subjects, aged 9-10 years indicate that the five field tests, though invalid as measures of absolute strength and muscular endurance, manifest concurrent and construct validity as measures of weight-relative muscular strength. Bender et al. (2006) [46] has challenged the validity of the President's Challenge actvities for testing physical fitness in children aged 10-14.

A summary of measurements characteristics from Freedson et al. (2000) [14] is presented in Table 2.21 showing different levels of validity and reliablilty. A detailed review on the validity and reliability of different field tests can also be obtained via internet in the Fitnessgramm / Activitygram Reference Guide. [52]

TABLE 2.21. SUMMARY OF MEASUREMENTS CHARACTERISTICS OF FIVE MAJOR HEALTH-RELATED FITNESS TESTS

Health-related Fitness Components	Tests	Subjects	Validity	Reliability
Abdominal strength and endurance	Curl-ups Partial curl-ups	Adolescent boys and girls	Moderate	Moderate to high
Upper body strength/endurance	Pull-ups Right angle push-ups	Age of subjects not mentioned	Low to moderate	High
Flexibility	Sit and reach	Age of subjects not mentioned	Low	High
Cardio-respiratory fitness	1-mile run test for time	Age of subjects not mentioned	Moderate to high	Moderate to high
	Modified multistage 20-m shuttle run	8-19 year olds 12-15 year olds	Moderate to high	Excellent

Data from Preventive medicine, 31, Freedson, P. S., Status of field-based fitness testing in children and youth, p. S77-S85 © 2000. [14]

9. The President's Challenge Physical Fitness Awards [51]

Age range: 6 to 17 years.

9.1 Clinical use

- To assess health- related fitness components and to promote and provide basic level of physical fitness among students.

9.2 Measurements

ABDOMINAL STRENGTH AND ENDURANCE

- Curl-ups: the number of curl-ups performed in one minute is recorded.
- Partial curl-ups (option to curl-ups): the number of completed curl-ups is recorded.

SPEED AND AGILITY

- Shuttle run: performance is timed in minutes and seconds.

HEART/LUNG ENDURANCE

- One mile run/walk: performance is timed in minutes and seconds.

UPPERBODY STRENGTH/ENDURANCE

- Pull-ups: the number of pull-ups is recorded.
- Right angle push-ups (option to pull-ups): The number of push-ups is recorded.
- Flexed-arm hang: alternative to pull-ups or right angle push-ups. Performance is timed in seconds.

FLEXIBILITY OF LOWER BACK AND HAMSTRINGS

- V-sit reach: flexibility is measured in inches .
- Sit and reach (option to the v-sit reach): flexibility is measured to the nearest centimeter.

9.3 Testing Procedures

REQUIRED EQUIPMENT

- Stopwatch.
- Metronome.
- Two blocks 2 x 2 x 4 inches.
- Masking tape to use as markers on the floor.
- Horizontal bar for pull-ups.

PRE-TEST

- To enhance reliable results, the tester will have to be rigorous during fitness test administration. The tester should : [44]
  - Have a good knowledge of the testing procedures;
  - Provide proper demonstration and instructions to the child;

- Develop adequate preparation through practice trials with children. Practice trials, mostly in young children, are necessary so they can learn how to perform the tests and provide consistent results.

TEST

- We refer the clinician to the test instructions and scoring for the five activities (normative data and award benchmarks) presented at the Presidents Challenge Web sites (Accessed November 2010) **:**

  - http://www.presidentschallenge.org/challenge/physical/index.shtml
  - http://www.presidentschallenge.org/challenge/physical/benchmark.shtml
  - http://www.djusd.k12.ca.us/CesarChavez/shunt/documents/Presidentialchallengetest.pdf

9.4 Study Summary

No summary page is presented for the President's Challenge Physical Fitness Awards. Information can be obtained by consulting the President's Challenge web-site. [51]

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Hébert LJ, Maltais DB, Lepage C, Saulnier J, Crête M, Perron M.(2011). Isometric muscle strength in youth assessed by hand-held dynamometry: a feasibility, reliability, and validity study.*Pediatr Phys Ther*. Fall;23(3):289-99.	Maximal isometric torque (MIT) of selected upper and lower limb muscle groups was assessed (n = 74; age = 4-17.5 years) using a standardized, hand-held dynamometry protocol. Mean intra- and interrater reliability (ICC)] varied from 0.75 to 0.98, except for ankle dorsiflexor interrater reliability (mean ICC = 0.67). The standard error of measurement varied from 0.5 to 4.9 Nm and was highest for hip extensors. Mean concurrent validity (ICC) varied from 0.78 to 0.93, except for ankle plantar flexors (mean ICC = 0.48). The HHD protocol was feasible over a wide age range and most MIT values were valid and reliable.
Lundgren SS , Nilsson JÅ, Ringsberg KA Karlsson MK (2011) Normative data for tests of neuromuscular neuromuscular performance and DXA-derived lean body mass and fat mass in pre-pubertal children. *Acta Paediatr.* Oct;100(10):1359-67. doi: 10.1111/j.1651-2227.2011.02322.x.	Lean body mass (kg) and fat mass (%) were estimated by dual-energy X-ray absorptiometry in 246 boys and 190 girls aged 6-12 years in Tanner stages 1 and 2. Isokinetic concentric peak torque at 60 and 180°/sec of the right knee extenso rs, and flexors were evaluated by a computerized dynamometer. Vertical jump height (VJH) was evaluated with an electronic mat and postural control with a one-leg stand test and a blindfolded one-leg stand test. This report, provides normative gender-specific data on muscle strength, muscle and fat mass and VJH and show, in Swedish children aged 6-12 years, that there seems to be a linear increase with age and no structural gender differences.
Yocum A, McCoy SW, Bjornson KF, Mullens P, Burton GN (2010). Reliability and validity of the standing heel-rise test. *Phys Occup Ther Pediatr*. Aug;30(3):190-204.	57children developing typically (CDT) and 34 children with plantar flexion weakness performed three tests: unilateral heel rise, vertical jump, and force measurement using handheld dynamometry. ICCs varied from 0.85-0.99 for reliability analyses in both participant groups. Construct validity analysis revealed a significant difference between groups and age-related differences among CDT; 5- to 8-year olds (mean = 15.2, SD = 5.4) performed fewer repetitions compared to 9- to 12-year olds (mean = 27.7, SD = 11.7) ($p < .05$). Age explained 41% of the variance in the number of heel-rise repetitions. Correlations between the three tests ($r = 0.56$ to 0.66) provide evidence of convergent validity. The results indicate that the standardized protocol is both reliable and valid for use in 5- to 12-year-old children with and without plantar flexion weakness.
Macfarlane TS, Larson CA, Stiller C. (2008). Lower extremity muscle strength in 6- to 8-year-old children using hand-held dynamometry. *Pediatr Phys Ther*.; 20(2):128-36.	Age-referenced force/torque and cutoff values are provided for 6 lower extremity muscle groups. Torque increased with age and height for all muscles and with weight for all muscles except knee extensors. No gender differences were found. Children who participated in 3 or more hours per week in organized sports were stronger in 4 of 6 muscles; the number of hours spent in active play did not affect torque. This study provides hand-held dynamometer strength reference values to enable clinicians to determine if clients of the same age, height, and weight have muscle weakness

Christy Killman and J.P. Barfield, Battery Reliability of the President's Challenge. (2008). *Poster Session: Research on Teaching and Instruction in Schools and Higher Education*. The Preliminary Program for 2008 AAHPERD National Convention and Exposition (April 8 - 12)	The purpose of this study was to examine the battery reliability of the President's Challenge Physical Fitness Test Battery under two scoring conditions: 1) test items scored by administrators, and 2) test items scored by student partners. Middle-school students (n = 265), ages 12 to 15, were tested on sit-up (SU), pull-up (PU), v-sit (VSIT), and shuttle (SHUTTLE) by 8 administrators and retested one week later by the same administrators. Following a week of rest, students were tested on the one-mile run (MILE) by the same administrators and retested one week later. Students scored partners simultaneously with administrators on all items except SHUTTLE. and recorded scores in a separate location. The President's Challenge demonstrated acceptable reliability based on both instructor scores and student scores. Shared variance between administrations was similar to findings reported for middle-school students on a precursor to the FITNESSGRAM, but lower than findings reported for college students on the same battery . ICC values were also acceptable for instructor scores and student scores The President's Challenge recommends partner assistance in test administration and evidence from this study demonstrates similar reliability evidence under administrator and student scoring conditions. ***Accessed October 31, 2011:*** *http://aahperd.confex.com/aahperd/2008/preliminaryprogram/abstract_10901.htm*
Maurer C, Finley A, Martel J, Ulewicz C, Larson CA.(2007). Ankle plantarflexor strength and endurance in 7-9 year old children as measured by the standing single leg heel-rise test. *Phys Occup Ther Pediatr*.;27(3):37-54.	95 children, aged 7-9, performed SSL heel-rises until fatigue. The number of heel-rises were counted by two examiners and was determined from videotape. The children completed an average of 36 +/- 18 SSL heel-rises (COV = 50. Excellent inter-rater reliability , reliability between the motion analysis system and the examiners (ICC = 0.93), was established. Therapist visual observation can determine heel-rise count as accurately as when using a motion analysis system. Children who have functional limitations, who perform 13 or fewer heel-rises should repeat the SSL heel-rise test at a later date and/or perform other tests to confirm the plantarflexion muscle strength-endurance impairment prior to initiating an intervention program.

Bender, J.J.; Harris, C. D.; Harris, K. A.; Jensen, Holly J.; Kennedy, B.A.; Martin, S.; Rodd, D.; Underwood, F.; Rodd, D.. FACSM. (2006) Is the President's Challenge a Valid Test of Fitness in Children Ages 10-14?(Poster Presentation) *Medicine & Science in Sports & Exercise:* May - Volume 38 - Issue 5 - p S213	23 children, aged between 10 and 14 years completed two fitness testing protocols: 1) President's Challenge Protocol. 2) University of Evansville Protocol. The results challenge the validity of the President's Challenge as a valid means of testing physical fitness in children aged 10-14 years.
Haley SM, Fragala Pinkham MA, Dumas HM, Ni P, Skrinar AM, Cox GF. (2006). A physical performance measure for individuals with mucopolysaccharidosis type I. *Dev Med Child Neurol.* Jul;48(7):576-81.	The MPS Physical Performance Measure (MPS-PPM) is composed of eight timed functional tasks (FT-8) and two endurance tasks with a modified Energy Expenditure Index for comfortable walking (CW) and fast walking (FW) speeds. Age norms were derived from a convenience sample of 150 typically developing children and adolescents (75 males, 75 females; mean age 11y 2mo [SD 4y 5mo]; range 5-22y). Interrater reliability of the FT-8 and test-retest reliability of the FT-8 , CW and FW were good. Results of the age-based profiles in 10 individuals with MPS I indicate that the amount of time needed to perform functional tasks is severely affected by the disease, and most individuals were at or below the fifth centile for their age. These results suggest the utility of using this revised MPS-PPM to identify the extent of limitation in age-expected physical performance. Implications for using the MPS-PPM for monitoring physical performance changes during clinical interventions are discussed.

Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

Part 3

Range of Motion

Complete document :

www.irdpq.qc.ca/communication/publications



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Part 3

Range of Motion

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Summary

Goniometry is one of the few quantifiable assessment tools that is frequently used to document changes as a result of treatment in joint position and range of motion.[11, 17, 21] In the pediatric population, the assessment of range of motion (ROM) can contribute to early detection of hidden pathologies,[7,12, 27] therefore the knowledge of normal limits for ROM of the extremities is important in young subjects.

At the moment this review was undertaken, few studies reporting normative data for ROM in children were retrieved and most were not current. An ''up-to-date'' page is added at the end of the references pages in order to present summaries of any other relevant studies regarding normative and psychometric data. The reader will find a recent study published by Soucie et al. (2010) reporting passive range of motion reference values in subjects aged 2-69 years.

RELIABILITY

- Many studies report that, in general, intra-rater measurements are more reliable than inter-rater measurements.[3 5, 17, 18, 24, 26, 28] Acceptable reliability can be achieved if the methodology is reasonably standardized,[13, 23] the reliability of goniometric measurements being affected by the testing procedures.[13, 18] Several sources of error such as incorrect identification of bony landmarks, faulty testing positioning and inaccurate placement and reading of the goniometer will affect reliability.[18]

SUBJECT'S PHYSICAL CHARACTERISTICS

A. Muscle Tone

The reliability of goniometric measurements appears to be influenced by the subject's physical characteristics.[23] A need for caution is suggested when using goniometric measurements in clinical decision making such as specifying ''change'' in time[17, 18, 21] particularly in the more tone dependant biarticular muscles:[21]

- Martin et al. (2005)[20] report that there is little evidence for inter-rater reliability for plantar flexion range of motion but found ample evidence for intra-rater reliability for ankle dorsi- and plantar- flexion range of motion .
- Wide variability in intra-rater and inter-rater goniometric measurements, ranging from ± 10-15°, was reported in the upper extremities in a child with spastic quadriplegia;[17]
- Error in measurements for joint ranges in the lower limbs, recorded on different days, ranged from ±18-28° in ambulatory children with spastic cerebra l palsy (*n* = 12);[21]
- The reliability of ROM measurements in children with spastic diplegia (*n* = 25) and in a control group (*n* = 25) confirmed that significant errors in measurements can occur even when using standardized procedures by experienced physiotherapists. A change of more than 15° to 20° between sessions was required to be 95% confident of a true change in measurements in the lower extremities in the children with spastic diplegia. Similar results were reported in healthy children;[18]
- Clinicians must carefully consider the "normal" weekly variation in ROM measurements when determining change, for example a treatment effect.[18]

B. Age, Gender and Joint Motion

- ROM is different in neonates, children and adults.[2, 6, 8, 12, 15, 16] The full term newborn demonstrates a certain amount of flexion contracture secondary to the prolonged period the fetus spends with the legs folded up against the trunk.[4] No significant difference is reported between sexes,[8, 12, 15, 16, 25] except in the ROM of the shoulder and the ankle. Females, for all shoulder motions except active extension, had a significantly greater ROM than males[2] and greater ROM in passive plantar flexion and inversion.[1]

- It appears that the ROM of ankle dorsiflexion in children with no disabilities is extremely variable, the range of mean values varying between 7.1° and 21.5°, and would not be dependent on age testing. Norms for ankle dorsiflexion may not be the correct benchmark to use when testing the normal range of passive ankle dorsiflexion in children with a diagnosis of either cerebral palsy or juvenile rheumatoid arthritis. [26]

C. Healthy Limb Versus the Impaired Limb

- No significant difference is reported between sides [6, 10, 16] and the use of the healthy limb seems adequate as a means of comparison with the affected side [6, 30] with the exception of certain joint motions:
  - Significant differences for shoulder rotations between the right and the left side in healthy subjects are reported and comparisons between sides may be misleading for these joint motions; [2]
  - Variations of passive ROM of the ankle joint complex are large in healthy children and differences of more than 5° and even 10° were measured between the left and the right side. The findings suggest that the healthy ankle cannot necessarily be used as a reference for the injured foot. [1]
- The use of the normative data becomes useful when a bilateral deficit is present or suspected.

TESTING PROCEDURES

- The testing procedures in this document are the ones described by the authors of the studies. However, some authors did not detail the testing procedures and refer the reader to different methods such as the “traditional anatomical landmarks”, the “American Academy of Orthopaedic Surgeons Method” or the “International SFTR[a] Method of Measuring and Recording Joint Motion”. Clinicians must have knowledge of these methods to use the normative data from these studies. Occasionally, some information is added to complete the missing description.

- Number of evaluators: two testers are recommended to assess ROM in children in order to achieve good stabilization of joints and posture.

- Number of measurements: two measurements and the average value is recommended [18] but for experienced examiners, one measurement is usually sufficient. [5, 31]

ESTIMATES OF MEAN REFERENCE VALUES

- There is a wide normal variation in the degrees of motion amongst individuals of varying physical build and age groups.[30] The present document presents normative reference values for similar joint motions issued from different sources and the data may differ between them due to age, sample size, testing procedures and other possible physical characteristics. Although, these sources agree fairly well in their estimates of ROM, there are some differences. The clinician should therefore consider the study representing most appropriately the child’s characteristics (age, gender, etc.) or the objective of the assessment (what joint motion is being measured? Active or passive joint motion? Etc)

- The normative data is to be used as a guide and not as a standard.

---

a. SFTR: **S**agittal, **F**rontal, **T**ransversal **R**otation

1. Passive Range of Motion in the Premature Child [16]

Age range: approximately 37 weeks (gestational age) to 12 months (chronological age).

1.1 Clinical Use

- To assess developmental changes in joint motion during the first year of life in the premature child without central nervous system sequelae.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

1.2 Measurements

- Hip abduction (Table 3.1).
- Ankle dorsiflexion (Table 3.2).
- Elbow extension (Table 3.3).

1.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard plastic two-arm 360° goniometer. Arms were shortened to accommodate the limb segments of infants.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated:
  - Longitudinal axis of the femur;
  - Anterior aspect of the hip joint;
  - Lateral malleolus;
  - Lateral aspect of the elbow.

TEST

- Testing position, goniometer alignment and measurements are presented in Tables 3.1 through 3.3.
- Method: International SFTR Method of Measuring and Recording Joint Motion. This method refers to the neutral zero procedure. [14, 32]
- Results are compared to the normative reference values in Table 3.4.

Table 3.1. Hip Abduction

Testing Condition

- The infant must be in an alert, non crying state at all times.

Testing Position

- Supine with the knees extended (Fig. 3.1). Physiological hip and knee flexion will be present in infants.

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the anterior aspect of the hip joint.
- The stationary arm is aligned with a vertical passing through the long axis of the trunk.
- The movable arm is aligned with the middorsal surface of the thigh (femur).
- The entire lower extremity is abducted (Fig. 3.2).
- The angle formed by the leg with a vertical passing through the long axis of the trunk is recorded.

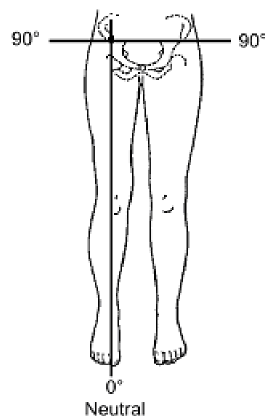


Figure 3.1. Zero starting position.
Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons, 1965. p. 62. [30]

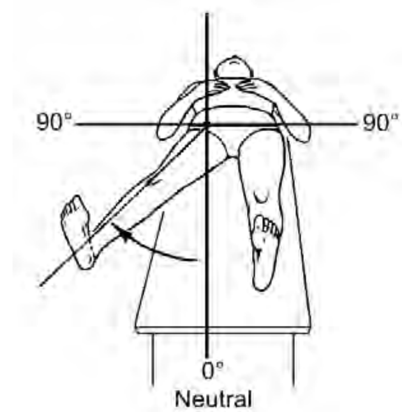


Figure 3.2. Clinical determination of hip abduction.
Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

Table 3.2. Ankle Dorsiflexion

Testing Condition

- The infant must be in an alert, non crying state at all times.

Testing Position

- Supine with hips and knees in available extension.

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the lateral malleolus.
- The stationary arm is aligned parallel to the lateral (fibular) aspect of the leg.
- The movable arm is parallel to the lateral border of the foot, along the fifth metatarsal.
- The ankle is gently moved in maximum dorsiflexion.
- The angle formed by the dorsum of the foot and the anterior aspect of the leg is recorded (Fig. 3.3).

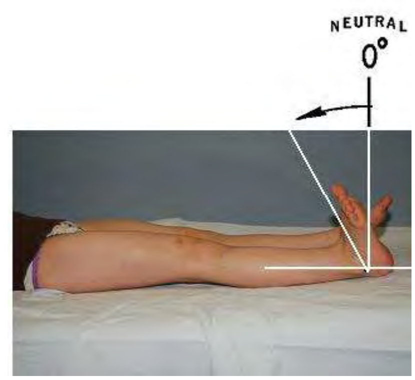


Figure 3.3. Ankle dorsiflexion.
(© IRDPQ-2011).

TABLE 3.3. ELBOW EXTENSION

Testing Condition

- The infant must be in an alert, non crying state at all times.

Testing Position

- Supine.

Goniometer Alignment and Measurements

- The axis of the goniometer is centered at the lateral aspect of the elbow.
- The stationary arm is aligned parallel to the lateral side of the arm (humerus).
- The movable arm is parallel to the lateral (radial) side of the forearm.
- The elbow is extended.
- The angle formed at the elbow is recorded (Fig. 3.4).

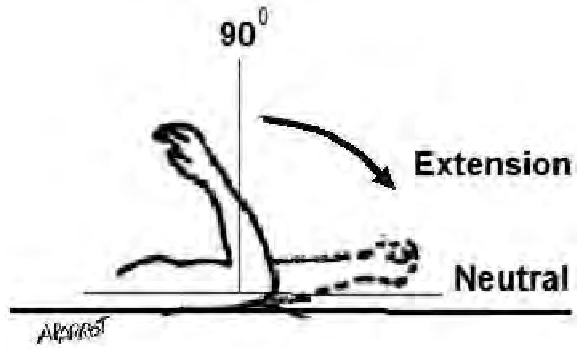


Figure 3.4. Elbow extension. (© IRDPQ-2011).

1.4 Normative Reference Values

TABLE 3.4. AVERAGE VALUE OF JOINT MEASUREMENTS AT BIRTH, 4, 8, AND 12 MONTHS IN PREMATURE INFANTS WITHOUT CNS PROBLEMS

Passive Joint Motion	Average Value and SD°	Birth*	4 mo	8 mo	12 mo
Hip abduction in extension	Mean°	63.4	59.4	60.6	71.7
	SD°	7.9	19.4	12	28.1
Ankle dorsiflexion	Mean°	37.6	36.7	37.7	28.2
	SD°	11.12	13.4	19.6	15.6
Elbow extension	Mean°	178.4	178.8	179.1	180
	SD°	3.6	4.4	1.17	0
Number of Subjects		*n* = 33	*n* = 29	*n* = 18	*n* = 11

***** *First testing performed at hospital discharge at mean gestational age of 37 weeks (SD = 2.13).*
Other measurements were taken at 4, 8, 12 months (mo) chronological age.
SD: Standard deviation. CNS: Central Nervous System. All measurements are in degrees°.

Adapted from: Harris, Simons, Ritchie, Mullett, and Myerberg, p. 188. [16]

1.5 Clinical Example

- 4-month-old premature child (chronological age).
- Elbow extension = 150°.
- The child lacks elbow extension. The angle value is not within two SD of the mean of his age group. This may suggest high muscle tone or an underlying medical problem.

1.6 Study Summary

Title: Joint Range of Motion Development in Premature Infants [16]	
Authors	Harris, M. B., Simons, C. J. R., Ritchie, S. K., Mullett, M. D., & Myerberg, D. Z.
Publication	Pediatric Physical Therapy, 1990, 2, 185-191.
Purpose of the Study	To document joint range of motion values for premature infants during the first year of life.
Type of Population	☐ Normal ☒ Other: Premature infants with and without central nervous system sequelae.
Clinical Relevance	Quantification of range of motion in hip flexion contracture, hip abduction, ankle dorsiflexion and elbow extension in premature infants.

Methods

Subjects

- The study sample consisted of 65 premature infants: (38 ♀; 27 ♂). USA.
- Age range: ~37 weeks (gestational age) to 12 months (chronological age).
- Infants were classified into two groups depending on common complications directly related to prematurity.
- Range of motion (ROM) was assessed at time of hospital discharge, at approaching term gestational age (~37 weeks, SD=2.13) and at 4, 8, 12 months. (Chronological age).
- If the child was not present at the clinic appointment, the subject was not represented in the data for that particular age.

Testing Procedures and Instrumentation

- Hip abduction, hip extension (hip flexion contracture), elbow extension, wrist extension, ankle dorsiflexion, the scarf sign and the popliteal angle (PA) were measured on both sides.
- Testing positions were standardized and based on the Amiel-Tison Neurological Evaluation[b] and the International SFTR Method of Measuring and Recording Joint Motion[c]. Testing was abandoned if infants were crying vigorously or were in a deep sleep.
- Instrumentation: Standard plastic goniometer (arms were shortened to accommodate limb segments). The larger angle was recorded to ensure reading in a standard fashion with the exception of hip abduction measurements.

Data Analysis

- Inter-rater reliability was established by having two examiners test the subjects independently in rapid succession. Reliability was obtained on six subjects, representing each age and each motion. Agreement between the examiners was calculated in two ways :
  1. One-way analysis of variance procedure producing an intra-class correlation coefficient (ICC);
  2. A ratio of agreement to total observations multiplied by 100 to obtain a percentage.
- Mean, range and standard deviation for each joint motion were calculated.

b) Amiel Tison neurological evaluation intends to establish the risk for later neurologic impairment. A recent study [9] tested the reliability of the revised Amiel Tison neurological evaluation at term. Kappa Coefficient Ranges for the scarf sign test was 0.82 and for the popliteal angle 0.78 which is excellent by authors ratings.

c) International SFTR Method of Measuring and Recording Joint Motion [14, 32] refers to the assessment of joint motion by using a standardized approach based on the international neutral zero method and different basic planes designation. SFTR: S = Sagittal; F = Frontal; T = Transverse; R = Rotation.

1.6 Study Summary (Continued)

Results

- **Psychometric Properties**

  Inter-rater reliability: ICC for:
  - Ankle dorsiflexion: 0.87.
  - Hip extension (hip flexion contracture): 0.72.
  - Hip abduction: 0.85.
  - Popliteal angle: 0.83.
  - The scarf sign: 0.84.
  - Wrist extension: 0.59.

  Perfect agreement was reported in elbow extension, hip extension and hip abduction (100%). Percentage of agreement for wrist extension was 92%; for ankle dorsiflexion, 75 %; for PA, 67%; and for the scarf sign, 75%.
- There was no difference in ROM between the two sides of the body. ROM of hip extension remained relatively constant over the 12 months. PA values decreased by 5° between the first and second test and then remained fairly constant. Over the first year, only ankle dorsiflexion showed a clear decrease of almost 10°.
- Premature infants who had CNS involvement had no change in ROM for hip abduction and had much lower ankle dorsiflexion values at 8 months than infants who had no CNS involvement.
- Premature infants who had no CNS involvement had an increase in abduction ROM. At 12 months of age, abduction ROM was much greater than in premature infants who had CNS involvement.
- Findings support results from other authors that premature infants never acquired the extreme postural flexion exhibited by term infants at birth.

Authors' Conclusion

- Pre-term infants have less flexion at term conceptional age than their full-term counterparts. This may support the concept that gross motor development in premature infants is qualitatively different from motor development in full-term children.

Comments

- Internal validity seems good. However, sample size is small in some age-categories (*n* =18 in the 8-months-group; *n* = 11 in the 12-months-group) and the use of results should be interpreted with caution. External validity in the other age groups (including sample size) seems good and the data can be used as a trend for clinical guidelines.
- Only the measurements presenting acceptable reliability with the goniometry technique were taking into account for this document. The scarf sign (no goniometer measurement) and wrist extension ROM (poor inter-rater reliability) were excluded.
- The PA measurements were excluded based on the testing position (hip maximally flexed on the abdomen) which is reported as being less accurate than when the hip is flexed at 90°, the latter being unaffected by abdominal bulk.[19, 22]

2. Passive Range of Motion of the Hip in the Newborn [12]

Age range: one to three days.

2.1 Clinical Use

- Quantification of hip ROM.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

2.2 Measurements

- Ending flexion (not shown, see note*).
- Medial rotation (Table 3.5).
- Lateral rotation (Table 3.5).
- Abduction in flexion: hip in 90° flexion with the knee flexed (not shown).
- Abduction in extension (Table 3.6).
- Adduction (Table 3.7).

2.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard plastic two-arm 360° goniometer. The arms are shortened to 2 inches in order to accommodate the limb segments of infants.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated:
  - Anterior superior iliac spine (ASIS);
  - Posterior superior iliac spine (PSIS);
  - Femoral greater trochanter;
  - Lateral epicondyle;
  - Anterior mid-patella;
  - Anterior mid-ankle (halfway between the two malleoli).

TEST

- All measurements were taken in supine. Testing position, goniometer alignment and measurements are presented in Tables 3.5 through 3.7.
- Results are compared to the normative reference values in Table 3.8.

***Note**: Ending flexion is measured with the contralateral leg in maximum hip and knee flexion to stabilize the pelvis. The tested hip is kept in neutral position and brought in flexion.The end range is determined when the pelvis begins to rock posteriorly.

TABLE 3.5. HIP MEDIAL AND LATERAL ROTATION

Testing Condition

- The infant must be in an alert-quiet, alert-active or drowsy-awake Brazelton states. Measurements were taken with the diaper off, the infant lying on a warmer bed in the nursery.
- An assistant gently holds the infant's head in midline to reduce effects of neonatal neck reflexes.

Testing Position

- Supine.
- The tested hip and knee are flexed to 90° and neutral with respect to abduction and adduction.
- The patella is directly over the hip joint axis.
- The opposite leg remains in a relaxed posture.

Goniometer Alignment and Measurements

- The axis of the goniometer is placed on the mid-patella landmark.
- The stationary arm is parallel to the right and left anterior superior iliac spines.
- The movable arm is aligned with the mid-patella and mid-ankle landmarks.
- The hip is moved in medial or lateral rotation (Fig. 3.5).

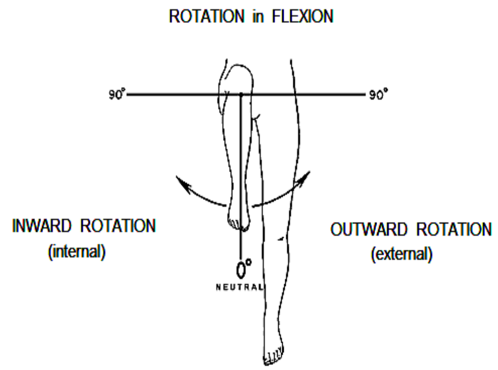


Figure 3.5. Clinical determination of hip rotation in flexion. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 60. [30]

TABLE 3.6: HIP ABDUCTION IN EXTENSION

Testing Condition

- Refer to Table 3.5.

Testing Position

- Supine.
- Hip and knee of tested leg are in maximum extension without being forced and in neutral position with respect to rotation (Fig. 3.6). Physiological hip and knee flexion will be present.

Goniometer Alignment and Measurements

- The axis of the goniometer is placed over the ASIS of the measured limb.
- The stationary arm is aligned with the contralateral ASIS.
- The movable arm is aligned with the mid-patella.
- The entire lower extremity is abducted (Fig. 3.7).

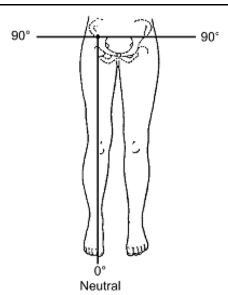


Figure 3.6. Zero starting position. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

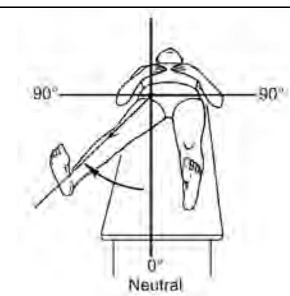
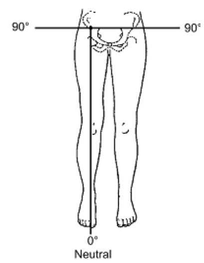
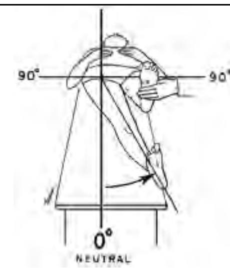


Figure 3.7. Clinical determination of hip abduction. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

TABLE 3.7. HIP ADDUCTION	
Testing Condition	
▪ Refer to Table 3.5.	
Testing Position	
▪ Supine. ▪ Pelvis is stabilized anteriorly across the abdomen and laterally at both iliac crests. ▪ Hip and knee of tested leg are in maximum extension without being forced (Fig. 3.8). Physiological hip and knee flexion will be present. ▪ The opposite leg is slightly flexed to allow maximum adduction of tested hip (Fig. 3.9).	
Goniometer Alignment and Measurements	
▪ The axis of the goniometer is over the ASIS of the measured limb. ▪ The stationary arm is aligned with the contralateral ASIS. ▪ The movable arm is aligned with the mid-patella. ▪ The entire lower extremity is adducted (Fig. 3.9).	
 **Figure 3.8. Zero starting position. Slightly flex the non tested leg to allow maximum adduction of tested hip.** Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]	 **Figure 3.9. Clinical determination of hip adduction.** Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

2.4 Normative Reference Values

Note

- Beginning flexion testing procedures are presented in Part 4, Table 4.3.
- n = 60. All measurements are in degrees.

TABLE 3.8. *Comprehensive data summary of seven hip joint movements*

Joint movement	Ranges	Mean	Median	SD	95% Normal ranges	95% CI
Beginning flexion	17–39	29.9	29.6	3.93	22.0–37.8	28.9–30.9
Ending flexion	112–141	127.5	127.1	4.84	117.8–137.2	126.2–128.7
Medial rotation	59–86	76.0	76.8	5.58	64.8–87.2	74.6–77.4
Lateral rotation	82–97	91.9	92.2	2.97	86.0–97.8	90.8–92.7
Abduction in flexion	63–86	79.3	79.9	4.34	70.6–88.0	78.2–80.4
Abduction in extension	27–58	38.9	38.5	5.11	28.7–49.1	37.6–40.2
Adduction	11–30	17.3	17.0	3.50	10.3–24.3	16.4–18.2

CI, confidence interval.

Reprinted from Journal of Pediatrics Orthopaedics, 9, Forero, Okamura, and Larson, Normal range of hip motion in neonates, p.393, (1989) with permission from LWW. [12]

2.5 Clinical Example

- Newborn child.
- PROM of hip abduction = 59°.
- The recorded value is not within the 95% of normal ranges and may indicate hypermobility or an underlying medical problem.

2.6 Study Summary

Title: Normal ranges of hip motion in neonates [12]	
Authors	Forero, N., Okamura, L. A., & Larson, M. A.
Publication	Journal of Pediatric Orthopedics, 1989, 9, 391-395.
Purpose of the Study	▪ To determine neonates passive range of motion (ROM) of the hip in using a clinically acceptable and accurate method of measurement. ▪ To confirm results of previous studies which found no significant differences between neonatal males and females.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of hip ROM in neonates.

Methods

Subjects

- The study sample consisted of 60 healthy, full-term neonates (26 ♀, 34 ♂). USA.
- Age range: One to three days.
- Mean gestational age: 40 weeks.
- Mean age: 1.45 days.
- Racial distribution: 70% Hispanic, 25% White, 5% Black individuals.

Testing Procedures and Instrumentation

- Joint motion measurements were taken when the child was in one of the three Brazelton's states of alertness. One clinician gently held the infant's head in midline to reduce any possible effects of neonatal neck reflexes on muscle tone. Testing positions were standardized in supine. The children were placed on a warmer bed in the nursery. Traditional landmarks were marked.
- Instrumentation: Standard two arm plastic 360° goniometer in 5° increments. The goniometer was calibrated against known angles of 0°, 45°, 90°, 135° and 180° before onset of the study.

Data Analysis

- Three measurements were taken for each joint motion of each infant and a mean value calculated. These values were then used to calculate a mean value, SD, median, 95% normal ranges, and 95% confidence intervals (CIs) of the means for each joint movement.
- Pearson correlation coefficients were calculated to determine possible relationships between each of the variables; *t* tests were used to determine if there exist significant differences between genders and racial characteristics. Mean, range and standard deviation (SD) were calculated for different variables (age, birth weight, etc.). Range and frequency were determined for sex and racial background.

2.6 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Goniometric measurements were performed by the therapist who had the higher intra-tester ($r = 0.999$; $p < 0.05$) and inter-tester reliabilities as compared with an experienced pediatric physical therapist ($r = 0.977$; $p < 0.05$). Results are in near to perfect agreement. ▪ Ranges, means, medians, SD, 95% normal ranges and 95% CIs of the means of joint motions are presented therein. ▪ The medians of all the movements were within 1° of the respective means indicating a near-normal distribution of the data. ▪ Genders and ethnicity: No significant differences were found between males and females in hip ROM. No significant differences were found between Hispanics and Caucasians in hip ROM. Findings are in agreement with other authors. ▪ Anthropometric and hip ROM measurements: All neonates lacked full hip extension. Lateral rotation was greater than medial rotation. Positive correlations, although not strong, were found between birth weight and birth length, abduction in flexion and medial rotation, and abduction in flexion and lateral rotation: Neonates with greater abduction in flexion tended to have greater medial rotation ($r = 0.44$; $p < 0.0005$) and greater lateral rotation ($r = 0.44$; $p < 0.0015$). Negative correlations, although weak, were found between birth weight and medial rotation, adduction and ending flexion, adduction and lateral rotation, and adduction and abduction in flexion: Neonates with greater adduction tended to have less ending flexion ($r = –0.34$; $p < 0.008$), less lateral rotation ($r = -0.43$; $p < 0.0006$) and less adduction in flexion ($r = –0.49$; $p < 0.0001$). ▪ Beginning flexion is within the range of other studies. Lateral rotation is within the maximum range reported by other studies and greater than in one study but not clinically significant. ▪ Medial rotation is within the range of other studies. Abduction in flexion is within the range of other studies. ▪ Abduction in extension was not measured in any other neonatal study reviewed. ▪ The presence of discrepancies with certain studies may be related to different landmarks, testing positions, the state of alertness of the child at the moment of measurement and the number of subjects.
Authors' Conclusion
▪ Passive ROM of seven hip joint movements was measured in 60 healthy, full-term neonates to determine 95% normal ranges. The method is comprehensive and detailed and thus provides accurate evaluative data. Results of the present data closely support results from other authors who used a similar method.

Comments
▪ The present study was selected among others, based on the quality of the analysis, intra-tester reliability was verified, and in the consistency in presenting the data. Also, the description of the standardized method is excellent. The study was carried out in a meticulous and methodological way. ▪ Internal and external validity (including sample size: $n = 60$) seems good and the use of results as a trend for clinical guidelines is appropriate. ▪ Another study (Schwarze et al. (1993)) had a much larger sample population (1000 infants), but the study was not retained due to the lack in the description of the method and results.

3. Passive Range of Motion of Hip Rotations in Prone Position in Infants [8]

Age range: 6 weeks, 3 months, 6 months.

3.1 Clinical Use

- Quantification of hip joint motions.
- To assess developmental changes in joint motion during the first six months of life.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

3.2 Measurements

- Internal rotation (Table 3.9).
- External rotation (Table 3.9).

3.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.
- Examination table.

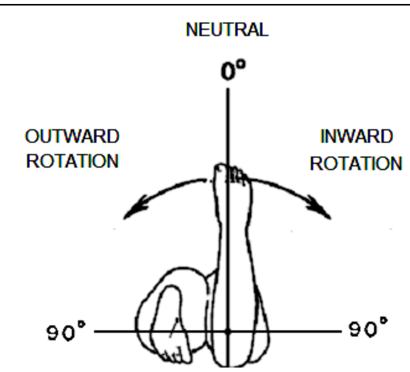
PRE-TEST

- Mark the following anatomical landmarks:
  - Tibial tuberosity;
  - Anterior mid-ankle joint (halfway between the two malleoli).

TEST

- Testing position, goniometer alignment and measurements are presented in Table 3.9.
- Results are compared to the normative reference values in Table 3.10.

TABLE 3.9. HIP INTERNAL AND EXTERNAL ROTATION

Testing Condition ▪ The infant has to be in a relaxed state. ▪ The head is gently held in midline to control effects of tonic neck reflexes on muscle tone. **Testing Position** ▪ Prone. ▪ Tested hip is in extension and neutral rotation. ▪ Knee is flexed to 90°. **Goniometer Alignment and Measurements** ▪ The axis of the goniometer is placed over the tibial tuberosity. ▪ The stationary arm is perpendicular to the table. ▪ The movable arm is aligned with the mid-ankle joint on the shaft of the tibia. ▪ The hip is moved in internal or external rotation (Fig. 3.10).	 **Figure 3.10. Method of positioning and clinical determination of hip rotation in extension.** Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965. p. 60. [30]

3.4 Normative Reference Values

Note: Flexion contracture testing procedures are presented in Part 4, Table 4.5.

Table 3.10. Mean, range and standard deviation of hip flexion contracture, internal rotation and external rotation at 6 weeks, 3 months and 6 months of age.

	6 WEEKS N=40	3 MONTHS N=40	6 MONTHS N=40
Flexion Contracture			
Mean	19°	7°	7°
Range	6°-32°	1°-18°	-1°-(+16°)
S.D.	6.0°	3.8°	4.2°
Internal Rotation			
Mean	24°	26°	21°
Range	16°-36°	15°-35°	15°-42°
S.D.	5.0°	3.4°	4.3°
External Rotation			
Mean	48°	45°	46°
Range	26°-73°	37°-60°	34°-61°
S.D.	11.0°	4.5°	4.8°

Reprinted with permission from Coon, Donato, Houser, and Bleck, Normal Ranges of Hip Motion in Infants Six Weeks, Three Months and Six Months of Age, Current Orthopaedic Practice – A Review and Research Journal. 110, p. 257. [8]

3.5 Study Summary

Title: Normal Ranges of Hip Motion in Infants Six Weeks, Three Months and Six Months of Age [8]	
Authors	Coon, V., Donato, G., Houser, C., & Bleck, E. E.
Publication	Clinical Orthopaedics and Related Research, 1975, 110, 256-260
Purpose of the Study	To establish mean values and normal ranges of hip flexion contracture and rotation in infants during the first six months of life.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hip flexion contracture, range of motion of hip rotations and changes in relation to age.

Methods

Subjects

- The study sample consisted of 80 healthy children (40 ♀, 40 ♂). USA.
- Age: 6 weeks, 3 months and 6 months.
- Subjects were divided into two age groups: Group 1 consisted of 40 children, assessed at 6 weeks and at 3 months of age. Group 2 was an independent sample of 40 children, assessed at 6 months of age.
- Measurements: Random selection for the tested leg. All measurements for hip external rotation (HER), hip internal rotation (HIR) and hip flexion contracture (HFC) were taken on the left leg. Three measurements for each ROM were taken by the same evaluator while another clinician stabilized other joints and posture. The child's head was held in midline to control for possible effects of neonatal reflexes.
- A Polaroid photograph was taken as a visual record of the child's ROM and position during testing.
- Testing position was standardized in supine and in prone.
- Instrumentation: Standard goniometer.
- Data analysis: Mean, range and standard deviations (SD) were calculated for each joint motion and for the three age groups. Match pair *t* test and Pearson Correlations were calculated.

Results

- **Psychometric Properties:** Non applicable.
- There were no statistically significant differences between genders. For all subjects, means for HLR were approximately two times greater than HMR.
- All three parameters were most variable at 6 weeks of age. HLR were more variable than HFC or HMR in each group.
- HFC: Matched paired t- test results indicated a decrease in HFC from 6 weeks to 3 months that is highly significant ($p<0.001$). Independent two samples mean *t*- test showed no significant decrease from 3 months to 6 months.
- Hip rotations: Matched paired *t*- test indicated no significant change in HLR and HMR between 6 weeks to 3 months. Independent two samples mean *t*- test showed a significant decrease in HMR from 3 months to 6 months ($p< 0.001$).
- Pearson Correlations on group 1 indicated that subjects who lost the greatest amount of flexion contracture between 6 weeks to 3 months tended to have a decrease in range of HMR ($r = +.44$, $p =0.005$). No other correlations were found to be significant.
- Results of no differences between genders are consistent with other studies. Decrease of HFC seems to decrease more slowly than what was reported by other authors. Hip rotations results are consistent with many other studies and in disagreement with two studies.
- The authors explain their results with a description of embryological development and in utero position.

3.5 Study Summary (Continued)

Authors' Conclusion
▪ In the present study: HFC, HMR and HLR data are reported in 40 infants at 6 weeks and 3 months and in an independent sample of 40 infants at 6 months of age. ▪ A mean HFC of 19° was present at 6 weeks of age decreasing to 7° by three months but still present at 6 months suggesting that forceful extension of the hip in infants may be contraindicated. ▪ HFC decreases from 6 weeks to 3 months. HLR is greater than HMR. It would appear that HMR greater than HLR, before the age of 6 months, is contrary to normal development and may indicate further examination to rule out abnormality. ▪ There is a significant decrease in medial rotation from 3 months to 6 months.

Comments
▪ Internal and external validity (including sample size: n = 40 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

4. Passive Range of Motion of the Ankle in the Newborn [27]

Age range: 6 to 65 hours.

4.1 Clinical use

- Quantification of ankle ROM.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

4.2 Measurements

- Ankle dorsiflexion (Table 3.11).
- Ankle plantar flexion (Table 3.12).

4.3 Testing Procedures

REQUIRED EQUIPMENT

- Clear plastic 360° goniometer with 5 degrees incre ments. The arms of the goniometer are shortened to 2 inches from the axis to the end of each arm.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.
- Examination table.

PRE-TEST

- Mark the following anatomical landmarks:
  - Lateral malleolus;
  - Lateral aspect of the fifth metatarsal;
  - Head of the fibula.

TEST

- Testing position, goniometer alignment and measurements are presented in Tables 3.11 and 3.12.
- Results are compared to the normative reference values in Table 3.13.

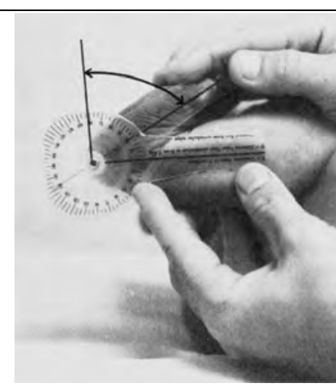
<table>
<tr><th colspan="2">TABLE 3.11. ANKLE DORSIFLEXION</th></tr>
<tr><td>Testing Condition</td><td rowspan="6">
Figure 3.11. Method of positioning and clinical determination of ankle dorsiflexion. Reprinted from Waugh, K., Minkel, J., Parker, R, and Coon, V, Measurement of Selected Hip, Knee and Ankle Joint Motions in Newborns, Physical Therapy, 1983, 63 p. 1617. [27]</td></tr>
<tr><td>▪ The infant has to be in a relaxed state. A bottle nipple in the infant’s mouth was used to maintain this state.
▪ The head is gently held in midline to control possible effects of tonic neck reflexes on muscle tone.</td></tr>
<tr><td>Testing Position</td></tr>
<tr><td>▪ Supine
▪ The hip and knee of the tested limb are maintained in maximum flexion and neutral rotation.</td></tr>
<tr><td>Goniometer Alignment and Measurements</td></tr>
<tr><td>▪ The axis of the goniometer is shifted distally from the lateral malleolus to allow the alignment of the movable arm along the lateral aspect of the fifth metatarsal.
▪ The stationary arm is aligned with the head of the fibula.
▪ The ankle is gently moved in dorsiflexion. It is maintained in neutral position by exerting pressure on the upper third of the sole of the foot (Fig. 3.11).</td></tr>
</table>

TABLE 3.12. ANKLE PLANTAR FLEXION

Testing Condition

- The infant has to be in a relaxed state. A bottle nipple in the infant's mouth was used to maintain this state.
- The head is gently held in midline to control possible effects of tonic neck reflexes on muscle tone.

Testing Position

- Supine.
- The hip and knee of the tested limb are maintained in maximum flexion and neutral rotation.

Goniometer Alignment and Measurements

- The axis of the goniometer is shifted distally from the lateral malleolus to allow the alignment of the movable arm along the lateral aspect of the fifth metatarsal.
- The stationary arm is aligned with the head of the fibula.
- The ankle is gently moved in plantar flexion by exerting pressure on the most proximal aspect of the dorsum of the foot while preventing inversion or eversion of the ankle (Fig. 3.12).

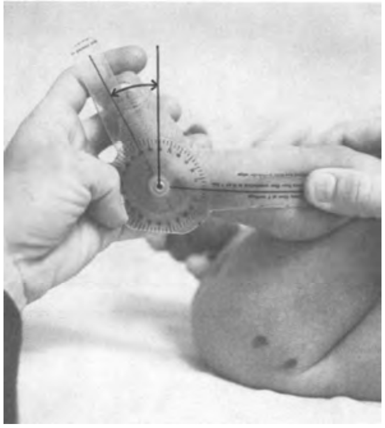


Figure 3.12. Method of positioning and clinical determination of ankle plantar flexion. Reprinted from Waugh, K., Minkel, J., Parker, R, and Coon, V, Measurement of Selected Hip, Knee and Ankle Joint Motions in Newborns, Physical Therapy, 1983, 63 p. 1618. [27]

4.4 Normative Reference Values

TABLE 3.13. MEAN AND STANDARD DEVIATION OF PASSIVE ANKLE DORSIFLEXION AND PLANTAR FLEXION IN NEWBORNS
AGE: 6 TO 65 HOURS

Passive Joint Motion	Mean°	SD°
Ankle dorsiflexion	58.9	7.9
Ankle plantar flexion	25.7	6.3

SD: Standard deviation. n = 40. All measurements are in degrees°.

Data from Waugh, K., Minkel, J., Parker, R, and Coon, V, Measurement of Selected Hip, Knee and Ankle Joint Motions in Newborns, Physical Therapy, 1983, 63, p.1619. [27]

4.5 Clinical Example

- Newborn child.
- Ankle dorsiflexion= 32°.
- Angle value is not within two SD of the mean and indicates possible joint motion limitation.

4.6 Study Summary

Title: Measurement of Selected Hip, Knee, and Ankle Joint Motions in Newborns	
Authors	Waugh, K. G., Minkel, J. L., Parker, R., & Coon, V. A. (1983)..
Publication	Physical Therapy, 1983, 63, 1616-1621
Purpose of the Study	▪ To provide clinically useful mean values in joint motions in healthy newborns. ▪ To determine if any relationships exist between different joint motions in the lower extremities.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion in the lower limbs.

Methods

Subjects

- The study sample consisted of 40 unimpaired, full-term newborns (22♀; 18 ♂). USA.
- Age range: 6 to 65 hours.

Testing Procedures and Instrumentation

- Passive range of motion (PROM) of hip extension, knee extension, ankle plantar flexion, ankle dorsiflexion and the popliteal angle (PA) were measured three times. Measurements were taken from the left leg since no significant differences between sides were reported in previous studies in the newborn infants. Testing position was standardized in supine. All measurements were taken by the same tester while another tester stabilized the child in each position. The head was held in midline to control for possible effects of neonatal reflexes.
- Instrumentation: Standard goniometer (modified to accommodate the short limbs of the infants).

Data Analysis

- Mean, standard deviation and range of motion were calculated from the three independent measurements of each motion. Pearson correlation coefficients were computed to examine potential relationships between each of the five motions. Results were judged to be significant when $p \leq .05$.

Results

Psychometric Properties: Non applicable.

- All the values obtained from the three independent measurements of each motion were within ± 5 degrees of each other. Norms (mean and standard deviation) of lower extremity motions ($n = 40$) are presented therein.
- All subjects lacked complete hip extension. The PA showed the greatest amount of variation. All subjects, except one, had some degree of knee extension limitation and greater range of dorsiflexion than plantar flexion. In 75% of the subjects, dorsiflexion was twice as great as plantar flexion.
- Findings for hip flexion contracture are in disagreement with other studies and might have been caused by variations in positioning techniques and in the interpretation of the end range.
- Findings for knee extension limitation, and for plantar and dorsiflexion are consistent with other reports.

4.6 Study Summary (Continued)

Authors' Conclusion
▪ Every infant, except one, lacked full extension in hip and knee and will gain in amplitude with neuro-developmental maturation. Plantar flexion was generally limited, but dorsiflexion was unlimited. ▪ Pearson correlation coefficients indicated that infants with greater dorsiflexion tended to have less plantar flexion, and infants with a greater limitation of knee extension measured with the hip extended tended to have a smaller PA.

Comments
▪ Internal and external validity (including sample size, *n* = 40) seems good and the use of results as a trend for clinical guidelines is appropriate. ▪ From the present study, the normative data for ROM of the ankle and knee extension limitation were selected but not for the hip. Another study (Forero et al. – 1989)[12] was selected since it had a larger sample size (*n* = 60). ▪ The PA measurements were also excluded based on the testing position (hip maximally flexed on the abdomen) which is reported as being less accurate than when the hip is flexed at 90°, the latter being unaffected by abdominal bulk.[19, 22]

5. Active Range of Motion in the Upper Extremities in Male Subjects [6]

Age range: 18 months to 19 years.

5.1 Clinical Use

- Quantification of ROM in the upper extremities.
- To screen children who are at risk for neurological or musculoskeletal disorders.

5.2 Measurements

- Shoulder
  - Horizontal flexion.
  - Horizontal extension.
  - Neutral abduction.
  - Forward flexion.
  - Backward extension.
  - Inward rotation.
  - Outward rotation.
- Elbow
  - Flexion.
  - Extension.
- Forearm
  - Pronation.
  - Supination.
- Wrist
  - Flexion.
  - Extension.
  - Radial deviation.
  - Ulnar deviation.

5.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated.

TEST

- Testing positions:
  - Shoulder extension: Prone.
  - All other measurements: Supine.
- Method: The technique of measurement is based on the American Academy of Orthopaedic Surgeons method which refers to the neutral zero procedure. [30]
- Results are compared to the normative reference values in Table 3.14, for the upper extremities in subjects under 19 yrs (third column).

5.4 Normative Reference Values

TABLE 3.14

COMPARISON OF ESTIMATED RANGES OF MOTION *(Degrees)*

Joint	AAOS Average Ranges of Joint Motion*	This Study†‡ (N = 109)	This Study ≤ 19 Yrs.†‡ (N = 53)	This Study > 19 Yrs.†‡ (N = 56)
Shoulder				
Horizontal flexion	135	140.7 ± 5.9	140.8 ± 6.8	140.7 ± 4.9
Horizontal extension	—	45.4 ± 6.2	47.3 ± 6.1§	43.7 ± 5.8§
Neutral abduction	170	184.0 ± 7.0	185.4 ± 3.6	182.7 ± 9.0
Forward flexion	158	166.7 ± 4.7	168.4 ± 3.7§	165.0 ± 5.0§
Backward extension	53	62.3 ± 9.5	67.5 ± 8.0§	57.3 ± 8.1§
Inward rotation	70	68.8 ± 4.6	70.5 ± 4.5§	67.1 ± 4.1§
Outward rotation	90	103.7 ± 8.5	108.0 ± 7.2§	99.6 ± 7.6§
Elbow				
Flexion	146	142.9 ± 5.6	145.4 ± 5.3§	140.5 ± 4.9§
Extension	0	0.6 ± 3.1	0.8 ± 3.5	0.3 ± 2.7
Forearm				
Pronation	71	75.8 ± 5.1	76.7 ± 4.8	75.0 ± 5.3
Supination	84	82.1 ± 3.8	83.1 ± 3.4§	81.1 ± 4.0§
Wrist				
Flexion	73	76.4 ± 6.3	78.2 ± 5.5§	74.8 ± 6.6§
Extension	71	74.9 ± 6.4	75.8 ± 6.1§	74.0 ± 6.6§
Radial deviation	19	21.5 ± 4.0	21.8 ± 4.0	21.1 ± 4.0
Ulnar deviation	33	36.0 ± 3.8	36.7 ± 3.7	35.3 ± 3.8
Hip				
Beginning position flexion	—	2.1 ± 3.6	3.5 ± 4.3§	0.7 ± 2.1§
Flexion	113	122.3 ± 6.1	123.4 ± 5.6	121.3 ± 6.4
Extension	28	9.8 ± 6.8	7.4 ± 7.3§	12.1 ± 5.4§
Abduction	48	45.9 ± 9.3	51.7 ± 8.8§	40.5 ± 6.0§
Adduction	31	26.9 ± 4.1	28.3 ± 4.1§	25.6 ± 3.6§
Inward rotation	45	47.3 ± 6.0	50.3 ± 6.1§	44.4 ± 4.3§
Outward rotation	45	47.2 ± 6.3	50.5 ± 6.1§	44.2 ± 4.8§
Knee				
Beginning position flexion	—	1.6 ± 2.7	2.1 ± 3.2§	1.1 ± 2.0§
Flexion	134	142.5 ± 5.4	143.8 ± 5.1§	141.2 ± 5.3§
Ankle				
Flexion (plantar)	48	56.2 ± 6.1	58.2 ± 6.1§	54.3 ± 5.9§
Extension (dorsiflexion)	18	12.6 ± 4.4	13.0 ± 4.7	12.2 ± 4.1
Fore part of the foot				
Inversion	33	36.8 ± 4.5	37.5 ± 4.7§	36.2 ± 4.2§
Eversion	18	20.7 ± 5.0	22.3 ± 4.6§	19.2 ± 4.9§

* Averages of estimates from four sources used by The American Academy of Orthopaedic Surgeons.

† Mean ± one standard deviation.

‡ Average age (± S.D.) = 22.4 ± 2.7, 9.2 ± 1.7, and 34.9 ± 3.4 years, respectively; average leg length (± S.D.) = 81.2 ± 5.6, 68.7 ± 7.1, and 93.1 ± 3.6 centimeters, respectively.

§ Significance differences, $p < 0.01$

Reprinted with permission from Boone, D and Azen, S. Normal range of Motion of Joints in Male Subjects, The Journal of Bone and Joint Surgery, Am., July 1979, 61, p.757. [6] http://www.jbjs.org/

5.5 Study Summary

Title: Normal Range of Motion of Joints in Male Subjects	
Authors	Boone D. C. & Azen S.P.
Publication	The Journal of Bone and Joint Surgery, Am., 1979, 61, 756-759.
Purpose of the Study	▪ To determine the amplitudes of active joint motion of the extremities of male subjects. ▪ To analyse the influence of age in these motions.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion of the extremities.

Methods

Subjects

- The study sample consisted of 109 healthy male subjects. USA.
- Age range: 18 months to 54 years.
- Racial population: The majority of subjects were white Americans, 15 were Hispanic, 12 Black and 3 were Oriental.
- Subjects were initially divided into six age groups composed of seventeen to nineteen individuals each. From these six age groups, two age groupings were determined: the younger group (*n* = 53) aged 1 to 19 years and the older group (*n* = 58), aged 20 to 54 years.

Testing Procedures and Instrumentation

- Active motion of the shoulder, elbow, forearm, wrist, hip, knee, ankle and foot, and beginning and ending position were measured by one tester, on both sides in the basic planes. The method was based on the techniques of the American Academy of Orthopaedic Surgeons.
- Instrumentation: Standard goniometer.

Data Analysis

- Average intra-tester reliability was determined as measured by the SD of measurements at 4 weekly sessions. Mean and standard deviation (SD) were calculated. Initially, analyses was performed separately for the six age groups: one to five-years old, six to twelve, thirteen to nineteen, twenty to twenty-nine, thirty to thirty-nine, and forty-two to fifty-four years old. Paired t tests were used to compare the motions between the left and right sides. Finally, two sample t tests were performed for two age groupings: one to nineteen and twenty to fifty-four -years old. The 0.01 level (or below) was selected as the criterion of statistical significance.

Results

- **Psychometric Properties**: Non applicable.
- Average intra-tester reliability had a mean SD of 1.0 degree for all joint motions.
- The SD of measurement error attributable to the goniometer was 3.7 degrees.

Comparison of ROM Between Sides

Few motions showed significant differences between left and right sides :

- In the 6 to 12 years old: shoulder horizontal flexion on the right side was greater than on the left ($p< 0.001$); backward extension was greater on the left side than on the right ($p< 0.01$);
- In the 20 to 29 years old: shoulder backward extension and elbow flexion were greater on the left side ($p< 0.01$). Foot eversion was greater on the left side ($p< 0.001$);
- No consistent pattern was noted, thus left and right motions were averaged for analysis.

5.5 Study Summary (Continued)

Results (Continued)

Differences Between ROM and Age

Since the study is based on cross-sectional data from groups of subjects of various ages, the authors report that they can only infer that differences in motions between children and adults are related to age. Analyses of variance revealed significant differences between the two age groups for most motions ($p < 0.01$):

- Shoulder joint motion: the greatest difference was backward extension and outward rotation;
- Elbow joint motion: hyperextension was possible for younger subjects and gradually decreased with age. ROM in elbow flexion and supination was less in the older age group;
- The inability to assume a zero starting position of knee flexion (complete extension) was present in the younger subjects;
- The inability to assume a zero starting position of hip flexion (complete extension) was present in the younger subjects and evident in some of the adults;
- The amplitudes of most hip motions are markedly different between the younger and the older groups;
- The findings are consistent with other studies.

Authors' Conclusion

- The amplitudes of motion of the left and right joints were consistently similar, therefore the healthy limb can be routinely used for means of comparison.
- Normal limits for ROM of the extremities were calculated in two age groups for male subjects and will be helpful when a bilateral deficit is present or suspected.

Comments

- Internal and external validity seems good and the use of results as a trend for clinical guidelines is appropriate. However, the number of subjects per age-groups is small (n = 17 to 19) and data should be interpreted with caution.
- Generalization of the results for female subjects may be challenged.
- There is a paucity of research concerning the normal ROM in the pediatric population. To the best of our knowledge, the present study is the only one that reports normative values for mostly all active motions in all joints for the pediatric population. However, the age range for the pediatric population is wide (1 to 19 years) making the data maybe less discriminant for the very young individuals.

6. Active Range of Motion in the Upper Extremities [10]

Mean age: 12.8 years (SD: 3.3 years): Primary school prepubertal pupils and secondary school adolescents.

6.1 Clinical Use

- Quantification of ROM in the upper extremities.

6.2 Measurements

- Shoulder anteflexion.
- Elbow flexion.
- Elbow extension.
- Wrist palmar flexion.
- Wrist dorsal flexion.

6.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated.

TEST

- Method: ROMs are measured by using standard techniques based on the anatomical landmarks and alignment of the goniometer. Angle value is recorded to the nearest 5°.
- Results are compared to the normative reference values in Table 3.15 for the upper extremities in the reference group.

6.4 Normative Reference Values

TABLE 3.15. Maximal Active Joint Motion, Left and Right Extremities Combined (mean [SD]; range) in Degrees in Children With SGH Compared With a Reference Group

Joints	Children With SGH (n = 19)			Reference Group (n = 274)			P Value
	Mean	SD	Range	Mean	SD	Range	
Shoulder anteflexion	156	10	140–170	157	11	130–185	NS
Elbow flexion	146	5	135–153	146	5	130–160	NS
Elbow extension	−1	7	−10–10	4	6	−10–20	**<0.001**
Wrist palmar flexion	61	6	40–70	73	8	45–95	**<0.001**
Wrist dorsal flexion	59	11	40–70	74	8	50–100	**<0.001**
Hip flexion	114	9	95–130	117	8	95–150	NS
Hip extension	−13	5	−20 to −5	−10	5	−25–0	**0.01**
Knee flexion	142	6	130–150	147	6	130–165	**<0.001**
Knee extension	−7	5	−15–5	0	5	−13–13	**<0.001**
Ankle plantar flexion	52	8	40–70	57	8	40–80	**0.02**
Ankle dorsal flexion	2	10	−30–15	8	6	−5–23	**<0.001**

NS indicates not significant.
Statistically significant differences are given in bold face.

Reprinted with permission from: Engelbert, R. Uiterwaal, C., van de Putte, E, Helders, P., Sakkers, R., van Tintelen, P. & Bank, R., Pediatric Generalized Joint Hypomobility and Musculoskeletal Complaints: A New Entity? Clinical, Biochemical, and Osseal Characteristics, Pediatrics, 2004, 113, p.716. [10]

6.5 Study Summary

Title: Pediatric Generalized Joint Hypomobility and Musculoskeletal Complaints: a New Entity? Clinical, Biochemical, and Osseal Characteristics [10]	
Authors	Engelbert, R. H. H., Uiterwaal, C. S. P. M., Van De Putte, E., Helders, P. J. M., Sakkers, R. J. B., Van Tintelen, P., & Bank, R A
Publication	Pediatrics, 2004, 113, p. 714-719.
Purpose of the Study	To describe clinical features, osseal characteristics and collagen biochemistry in children with symptomatic generalized hypomobility.
Type of Population	☒ Normal ☒ Other: children with symptomatic generalized hypomobility (SGH).
Clinical Relevance	Quantification of range of motion in the upper extremities.

Methods

Subjects

The study sample consisted of:

1) 284 children with no disabilities (118 ♂, 166 ♀). Mean age 12.8 years (SD: 3.3). The Netherlands;
2) 19 children with SGH (68% boys). Mean age: 11.6 (SD: 2.7) years. The Netherlands.

Testing Procedures and Instrumentation

- Anthropometric variables (weight, height), active ROM of different joints and strength of different muscle groups were measured bilaterally by the first author.
- Active ROM of each joint was measured by using the anatomic landmarks technique. Instrumentation: standard 360° goniometer, hand-hel d myometer.
- With the SGH children, additional measurements were taken: Exercise tolerances, motor development, quantitative ultrasound measurements of bone and degradation products of collagen in urine were studied. Collagen modifications were determined in skin biopsies of three children and in hypertrophic scar tissue of another child.

Data Analysis

- Central estimators were calculated as means (standard error of the mean) or medians (min, max).
- Results are presented as linear regression coefficients of the group indicator representing mean group differences with their 95% CIs. Statistical significance was considered to have been reached when 95% CIs did not include a null value.
- Mean values and SD are presented for active ROM in healthy children.

Results

- **Psychometric Properties:** Prior to the study, the reliability of ROM of all joints of 16 healthy children was examined. Pearson correlation coefficient between testers' measurements was 0.69 (P = 0.003). Mean difference between 2 measurements was 2.4 degrees (SD: 4.6), indicating that 95% confidence interval (CI) was < 9.2 degrees.
- No significant differences were found between the left and right side therefore, mean range of joint motion was calculated.
- ROM significantly decreased in almost all joints of all 19 SGH children and was significantly lower compared to the reference group (-108.3 degrees; 95% CI: -136.9 to -79.8). Mean, SD and range for healthy and SGH subjects are presented therein.
- Quantitative ultrasound measurements as well as urinary pyridinoline cross-link levels were, after adjustment for possible confounders, significantly lower in SGH children. Results and the summary of the characteristics of the hypomobile children compared to the reference group are presented therein.

6.5 Study Summary (Continued)

Authors' Conclusion
▪ SGH in children is considered a new clinical entity with specific clinical characteristics that might be related to an increased stiffness of connective tissue as a result of higher amounts of collagen with increased cross-linking.

Comments
▪ Limit of the study: The number of SGH children is small (n =19) compared to the reference group (n=274), thus 95% CI are large. Clinical use of the data for ROM in the SGH group becomes precarious since it is possible that an important limitation of the ROM may be in the limits of the norms, (within the IC limits). ▪ To the best of our knowledge, there is no other study that reports normative values for active ROM in such a large sample of healthy children in that specific age range. ▪ Internal and external validity (including sample size: *n*=284 healthy children) seems good and the use of results as a trend for clinical guidelines in this population is appropriate.

7. Active and Passive Range of Motion in the Shoulder [2]

Age range: 4 years to 70 years

7.1 Clinical Use

- Quantification of ROM in the shoulder, dominant and non dominant side, in males and females.

7.2 Measurements

- Forward elevation.
- Abduction.
- Internal rotation at 90° of abduction.
- External rotation at 90° of abduction.
- External rotation with the arm adducted.
- Extension.

7.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated.

TEST

- Testing position:
  - Prone for shoulder extension;
  - Supine for all other joint motions. The subject flexes his hips and knees so that the feet are flat on the table to prevent arching of the back.

- Method:
  - ROMs are measured by using standard techniques based on the anatomical landmarks and alignment of the goniometer; [30]
  - Maximum forward elevation is recorded. Motion of internal rotation is considered complete when the spine of the scapulae begins to lift off the examination table;
  - Results are compared to the normative reference values in Table 3.16, per gender.

7.4 Normative Reference Values

TABLE 3.16 Mean active and passive motion

	Female subjects		Male subjects	
	Dominant	**Nondominant**	**Dominant**	**Nondominant**
Active ROM				
Forward elevation	176.7 ± 5.5	176.2 ± 5.9	173.6 ± 8.0	173.5 ± 7.6
Abduction	187.6 ± 16.1	188.6 ± 15.4	180.1 ± 18.2	181.8 ± 17.1
IR-90°	47.5 ± 11.2	54.5 ± 11.3	41.2 ± 9.3	50.1 ± 10.2
ER-90°	104.9 ± 12.0	97.3 ± 11.3	101.2 ± 11.6	91.1 ± 12.0
ER-adduction	81.4 ± 13.0	77.2 ± 12.1	78.3 ± 10.6	73.7 ± 11.7
Extension	67.3 ± 8.7	68.7 ± 9.3	64.6 ± 9.6	67.3 ± 9.2
Passive ROM				
Forward elevation	178.7 ± 3.5	178.3 ± 4.4	176.2 ± 7.4	176.1 ± 6.6
Abduction	194.6 ± 16.5	195.0 ± 16.6	187.4 ± 18.9	189.0 ± 18.3
IR-90°	57.5 ± 12.3	65.4 ± 12.2	48.6 ± 7.0	63.5 ± 8.2
ER-90°	118.0 ± 15.5	110.2 ± 15.1	113.8 ± 15.7	101.9 ± 15.5
ER-adduction	92.3 ± 13.2	87.3 ± 12.5	87.2 ± 12.9	82.2 ± 13.4
Extension	83.2 ± 11.2	84.6 ± 11.3	77.4 ± 11.8	80.0 ± 10.1

ER, External rotation; *IR*, internal rotation.

Reprinted from Journal of Shoulder and Elbow Surgery, 10, Barnes, J., Van Steyn, S. & Fischer, R. The Effects of Age, Sex, and Shoulder Dominance on Range of Motion of the Shoulder, p. 244, (2001) [2], with permission from Elsevier.

7.5 Study Summary

Title: The Effects of Age, Sex, and Shoulder Dominance on Range of Motion of the Shoulder [2]	
Authors	Barnes, C. J., Van Steyn, S. J., & Fischer, R. A.
Publication	Journal of Shoulder and Elbow Surgery, 2001, 10, 242-246
Purpose of the Study	To determine the effects of age, sex, and arm dominance on shoulder range of motion.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of active and passive ROM of the shoulder.

Methods

Subjects

- The study sample consisted of 280 healthy subjects (140 ♀ and 140 ♂) with no history of shoulder trouble. 254 were right arm dominant and 26 were left arm dominant. USA.
- Racial population: The majority of the subjects were white (*n* = 258). Few subjects were African-American (*n* =13) and Asian (*n* = 9).
- Subjects were divided into six age groups based on chronological age in years. Each group consisted of 40 subjects (20 ♀ and 20 ♂):
    - Group 1: 0 – 10 years
    - Group 2: 11 – 20 years
    - Group 3: 21 – 30 years
    - Group 4: 31 – 40 years
    - Group 5: 41 – 50 years
    - Group 6: 51 – 60 years

Testing Procedures and Instrumentation

- Active ROM (AROM) and passive ROM (PROM) of shoulder forward elevation (FE), abduction (ABD), internal rotation (IR) and external rotation (ER) at 90° of abduction, ER with the arm adducted, and extension (EXT) were measured bilaterally with standardized procedures. Arm dominance and non dominance were evaluated.
- Instrumentation: 360° standard goniometer with 10 inches movable arms.

Data Analysis

- All measurements were done by one author to eliminate inter-observer error. Mean and standard deviations (SD) were calculated for all motions for dominant and non dominant shoulders in AROM and PROM.
- Linear regression analyses for all motions were calculated except for FE because most subjects in the younger groups were able to achieve complete motion (180°). FE was evaluated with three-way analysis of variance. Separate analyses of variance were performed and significance was defined at ($p < 0.05$).

7.5 Study Summary (Continued)

Results
Psychometric Properties: Non applicable. **Age** ▪ Age had a statistically significant effect on all motions ($p < 0.01$). All motions decreased with age except IR that increased with age. This was mostly observed between the 4- and 10- year olds. In children older than 11, increase of IR was relatively small. Findings are in agreement with another study and not with others. In the age group 4 years to 10 years 11 months, the non dominant shoulder had greater active and passive IR. The dominant shoulder had greater active and passive ER. However, no statistical significance was observed when this group was analyzed alone. **Gender** ▪ Females, for all motions, except active EXT, had a significantly greater ROM than males ($p < 0.01$). **Dominant / Non Dominant Arm** ▪ The non dominant shoulder had greater IR and EXT than the dominant side. The dominant shoulder had greater ER than the non dominant side. ▪ No significant differences were found between the dominant and the non dominant sides for FE or ABD. ▪ Results indicate that the differences between the dominant and the non dominant shoulder for IR and ER motions are of sufficient magnitude that comparisons between sides may be misleading in all ages.
Authors' Conclusion
▪ The authors report normative data for shoulder motion that, to their knowledge, was analyzed on the largest cohort of North American individuals. ▪ The influence of arm dominance should be considered, particularly when assessing shoulder rotation.

Comments
▪ Internal and external validity (including sample size, n =40 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

8. Active Range of Motion in the Lower Extremities in Male Subjects [6]

Age range: 18 months to 19 years.

8.1 Clinical Use

- Quantification of ROM in the lower extremities.
- To screen children who are at risk for neurological or musculoskeletal disorders.

8.2 Measurements

- Hip
  - Beginning position flexion.
  - Flexion.
  - Extension.
  - Abduction.
  - Adduction.
  - Inward rotation.
  - Outward rotation.
- Knee
  - Beginning position flexion.
  - Flexion.
- Ankle
  - Flexion (plantar).
  - Extension (dorsiflexion).
- Fore part of the foot
  - Inversion.
  - Eversion.

8.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated.

TEST

- Testing positions:
  - Hip rotations: seated;
  - Hip extension: prone;
  - All other measurements: supine.
- Method: the technique of measurement is based on the American Academy of Orthopaedic Surgeons method which refers to the neutral zero procedure. [30]

Results are compared to the mean values in Table 3.17.

8.4 Mean values

Note: Complete data (mean and standard deviations) for ROMs in the lower extremities are presented in table 3.14, in subjects under 19 years (third colomn).

TABLE 3.17. MEAN VALUES FOR ACTIVE JOINT MOTION IN THE LOWER EXTREMITIES IN MALE SUBJECTS AGE: 18 MONTHS TO 19 YEARS

Active Joint Motion		Mean°
Hip	Beginning position flexion	3.5
	Flexion	123.4
	Extension	7.4
	Abduction	51.7
	Adduction	28.3
	Inward rotation	50.3
	Outward rotation	50.5
	Beginning position flexion	2.1
Knee	Flexion	143.8
Ankle	Plantar flexion	58.2
	Dorsiflexion	13.0
Forepart of the foot	Inversion	37.5
	Eversion	22.3

SD: Standard deviation. All measurements are in degrees°. n = 53.

§ Significant differences between age groups, p < 0.01

Data from Boone, D and Azen, S. Normal range of Motion of Joints in Male Subjects, The Journal of Bone and Joint Surgery, Am., July 1979, 61, p.757. [6]

8.5 Study Summary

Title: Normal Range of Motion of Joints in Male Subjects [6]	
Authors	Boone D.C, & Azen S.P.
Publication	The Journal of Bone and Joint Surgery, 1979, 61, 756-759.
Purpose of the Study	▪ To determine the amplitudes of active joint motion of the extremities of male subjects. ▪ To analyse the influence of age in these motions.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion of the extremities.

Methods

Subjects

- The study sample consisted of 109 healthy male subjects. USA.
- Age range: 18 months to 54 years.
- Racial population: The majority of subjects were white Americans, 15 were Hispanic, 12 Black and 3 were Oriental.
- Subjects were initially divided into six age groups composed of seventeen to nineteen individuals each. From these six age groups, two age groupings were determined: the younger group (*n* = 53) aged 1 to 19 years and the older group (*n* = 58), aged 20 to 54 years.

Testing Procedures and Instrumentation

- Active motion of the shoulder, elbow, forearm, wrist, hip, knee, ankle and foot, and beginning and ending position were measured by one tester, on both sides in the basic planes. The method was based on the techniques of the American Academy of Orthopaedic Surgeons.
- Instrumentation: Standard goniometer.

Data Analysis

- Average intra-tester reliability was determined as measured by the SD of measurements at 4 weekly sessions. Mean and standard deviation (SD) were calculated. Initially, analyses was performed separately for the six age groups: one to five-years old, six to twelve, thirteen to nineteen, twenty to twenty-nine, thirty to thirty-nine, and forty-two to fifty-four years old. Paired t tests were used to compare the motions between the left and right sides. Finally, two sample t tests were performed for two age groupings: one to nineteen and twenty to fifty-four -years old. The 0.01 level (or below) was selected as the criterion of statistical significance.

Results

- **Psychometric properties**: Non applicable.
- Average intra-tester reliability had a mean SD of 1.0 degree for all joint motions.
- The SD of measurement error attributable to the goniometer was 3.7 degrees.

Comparison of ROM between sides

Few motions showed significant differences between left and right sides:

- In the 6- to 12-year olds: shoulder horizontal flexion on the right side was greater than on the left ($p < 0.001$); backward extension was greater on the left side than on the right ($p < 0.01$);
- In the 20- to 29- year olds: shoulder backward extension and elbow flexion were greater on the left side ($p < 0.01$). Foot eversion was greater on the left side ($p < 0.001$);
- No consistent pattern was noted, thus left and right motions were averaged for analysis.

8.5 Study Summary (Continued)

Results (Continued)
Differences between ROM and Age Since the study is based on cross-sectional data from groups of subjects of various ages, the authors report that they can only infer that differences in motions between children and adults are related to age. Analyses of variance revealed significant differences between the two age groups for most motions ($p < 0.01$): ▪ Shoulder joint motion: the greatest difference was backward extension and outward rotation. ▪ Elbow joint motion: hyperextension was possible for younger subjects and gradually decreased with age. ROM in elbow flexion and supination was less in the older age group. ▪ The inability to assume a zero starting position of knee flexion (complete extension) was present in the younger subjects. ▪ The inability to assume a zero starting position of hip flexion (complete extension) was present in the younger subjects and evident in some of the adults; ▪ The amplitudes of most hip motions are markedly different between the younger and the older groups. ▪ The findings are consistent with other studies.
Authors' Conclusion
▪ The amplitudes of motion of the left and right joints were consistently similar, therefore the healthy limb can be routinely used for means of comparison. ▪ Normal limits for ROM of the extremities were calculated in two age groups for male subjects and will be helpful when a bilateral deficit is present or suspected.

Comments
▪ Internal and external validity seems good and the use of results as a trend for clinical guidelines is appropriate. However, the number of subjects per age-groups is small (n = 17 to 19) and the data should be interpreted with caution. ▪ Generalization of the results for female subjects may be challenged. ▪ There is a paucity of research concerning the normal ROM in the pediatric population. To the best of our knowledge, the present study is the only one that reports normative values for mostly all active motions in all joints for the pediatric population. However, the age range for the pediatric population is wide (1 to 19 years) making the data maybe less discriminant for the very young individuals.

9. Active Range of Motion in the Lower Extremities [10]

Mean age: 12.8 years (SD: 3.3 years) : Primary school prepubertal pupils and secondary school adolescents.

9.1 Clinical Use

- Quantification of AROM in the lower extremities.

9.2 Measurements espace

- Hip: Flexion and extension.
- Knee: Flexion and extension.
- Ankle: Plantar flexion and dorsal flexion.

9.3 Testing Procedures espace

REQUIRED EQUIPMENT

- Standard two-arm 360° goniometer with 5 degrees in crements.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated.

TEST

- Method: ROMs are measured by using standard techniques based on the anatomical landmarks and alignment of the goniometer.
- Angle value is recorded to the nearest 5 degrees.
- Results are compared to the mean values in Table 3.18.

9.4 Mean values

Note: Complete data (range and standard deviation) are presented in Table 3.15 for the lower extremities, in the reference group section.

Table 3.18. Mean values for Maximal Active Joint motion in the Lower Extremities in Normal Children. Mean Age: 12.8 Years (SD: 3.3 Years)

Active Joint Motion	Mean°
Hip flexion	117
Hip extension	–10
Knee flexion	147
Knee extension	0
Ankle plantar flexion	57
Ankle dorsal flexion	8

SD: Standard deviation. All measurements are in degrees°. n = 274.

Data from Engelbert, R. Uiterwaal, C., van de Putte, E, Helders, P., Sakkers, R., van Tintelen, P. & Bank, R., Pediatric Generalized Joint Hypomobility and Musculoskeletal Complaints: A New Entity? Clinical, Biochemical, and Osseal Characteristics, Pediatrics, 2004, 113, p.716. [10]

9.5 Study Summary

Title: Pediatric Generalized Joint Hypomobility and Musculoskeletal Complaints: a New Entity? Clinical, Biochemical, and Osseal Characteristics [10]	
Authors	Engelbert, R. H. H., Uiterwaal, C. S. P. M., Van De Putte, E., Helders, P. J. M., Sakkers, R. J. B., Van Tintelen, P., & Bank, R A
Publication	Pediatrics, 2004, 113, 714-719.
Purpose of the Study	To describe clinical features, osseal characteristics and collagen biochemistry in children with symptomatic generalized hypomobility.
Type of Population	☒ Normal ☒ Other: children with symptomatic generalized hypomobility (SGH).
Clinical Relevance	Quantification of range of motion in the upper extremities.

Methods

Subjects

The study sample consisted of:

1) 284 children with no disabilities (118 ♂, 166 ♀). Mean age 12.8 years (SD: 3.3). The Netherlands;
2) 19 children with SGH (68% boys). Mean age: 11.6 (SD: 2.7) years. The Netherlands.

Testing Procedures and Instrumentation

- Anthropometric variables (weight, height), active ROM of different joints and strength of different muscle groups were measured bilaterally by the first author.
- Active ROM of each joint was measured by using the anatomic landmarks technique. Instrumentation: standard 360° goniometer, hand-held myometer.
- With the SGH children, additional measurements were taken: Exercise tolerances, motor development, quantitative ultrasound measurements of bone and degradation products of collagen in urine were studied. Collagen modifications were determined in skin biopsies of three children and in hypertrophic scar tissue of another child.

Data Analysis

- Prior to the study, the reliability of ROM of all joints of 16 healthy children was examined. Pearson correlation coefficient between testers' measurements was .69 (P = .003). Mean difference between 2 measurements was 2.4 degrees (SD: 4.6), indicating that 95% confidence interval (CI) was < 9.2 degrees.
- Central estimators were calculated as means (standard error of the mean) or medians (min, max).
- Results are presented as linear regression coefficients of the group indicator representing mean group differences with their 95% CIs. Statistical significance was considered to have been reached when 95% CIs did not include a null value.
- Mean values and SD are presented for active ROM in healthy children.

Results

- **Psychometric Properties:** reliability is presented in the data analysis section.
- No significant differences were found between the left and right side therefore, mean range of joint motion was calculated.
- ROM significantly decreased in almost all joints of all 19 SGH children and was significantly lower compared to the reference group (-108.3 degrees; 95% CI: -136.9 to -79.8). Mean, SD and range for healthy and SGH subjects are presented therein.
- Quantitative ultrasound measurements as well as urinary pyridinoline cross-link levels were, after adjustment for possible confounders, significantly lower in SGH children. Results and the summary of the characteristics of the hypomobile children compared to the reference group are presented therein.

9.5 Study Summary (Continued)

Authors' Conclusion
▪ SGH in children is considered a new clinical entity with specific clinical characteristics that might be related to an increased stiffness of connective tissue as a result of higher amounts of collagen with increased cross-linking.

Comments
▪ Limit of the study: The number of SGH children is small (n =19) compared to the reference group (n=274), thus 95% CI are large. Clinical use of the data for ROM in the SGH group becomes precarious since it is possible that an important limitation of the ROM may be in the limits of the norms, (within the IC limits). ▪ To the best of our knowledge, there is no other study that reports normative values for active ROM in such a large sample of healthy children in that specific age range. ▪ Internal and external validity, (including sample size *n*=284 healthy children), seems good and the use of results as a trend for clinical guidelines in this population is appropriate.

10. Passive Range of Motion in the Lower Extremities [33]

Age range: 1 year to 7 years.

10.1 Clinical Use

- Quantification of ROM in the lower extremities.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

10.2 Measurements

- Hip internal rotation (Table 3.19).
- Hip external rotation (Table 3.20).
- Hip abduction (Table 3.21).
- Hip adduction (Table 3.22).
- Knee extension (Table 3.23).
- Ankle dorsiflexion (Table 3.24).

10.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks according to the joint being evaluated :
  - Anterior superior iliac spines (ASIS);
  - Femoral greater trochanter;
  - Longitudinal axis of the femur;
  - Lateral femoral condyle;
  - Tibial tuberosity;
  - Midpoint of the lateral knee-joint line;
  - Head of the fibula;
  - Lateral malleolus;
  - Lateral aspect of the fifth metatarsal.

TEST

- Testing position, goniometer alignment and measurements are presented in Tables 3.19 through 3.24.
- Results are compared to the normative reference values in Figures 3.22 through 3.27.

TABLE 3.19. HIP INTERNAL ROTATION

Testing Condition

- The child has to be in a relaxed state.

Testing Position

- Prone.
- The knee is flexed and the leg is perpendicular to the table top.
- An assistant stabilizes the pelvis while the tester rotates the hip.

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the tibial tuberosity.
- The stationary arm is perpendicular to the table top.
- The movable arm is aligned with the shaft of the tibia.
- The hip is moved in medial rotation (Fig. 3.13).

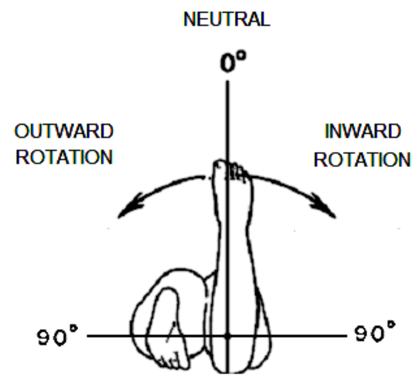


Figure 3.13. Method of positioning and clinical determination of hip rotation in extension. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons, 1965, p. 60. [30]

TABLE 3.20. HIP LATERAL ROTATION

Testing Condition

- The child has to be in a relaxed state.

Testing Position

- Prone.
- The knee is flexed and the leg perpendicular to the table top.
- An assistant stabilizes the pelvis.

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the tibial tuberosity.
- The stationary arm is perpendicular to the table top.
- The movable arm is on the shaft of the tibia.
- The hip is moved in lateral rotation (Fig. 3.14).

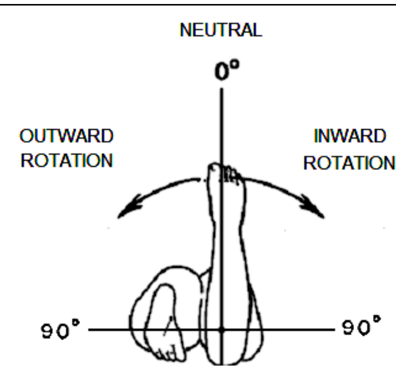


Figure 3.14. Method of positioning and clinical determination of hip rotation in extension Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 60. [30]

TABLE 3.21. HIP ABDUCTION

Testing Condition

- The child has to be in a relaxed state.

Testing Position

- Supine.
- Hips and knees are extended parallel with the midline axis of the body (Fig. 3.15).

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the ASIS of the tested hip.
- The stationary arm is aligned with the contralateral ASIS.
- The movable arm is along the longitudinal axis of the femur.
- The hip is moved in abduction (Fig. 3.16).

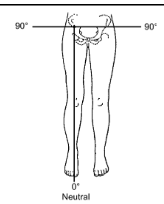


Figure 3.15. Zero starting position. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

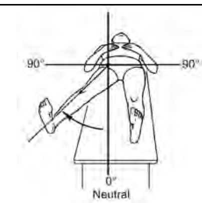


Figure 3.16. Clinical determination of hip abduction. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

TABLE 3.22. HIP ADDUCTION

Testing Condition

- The child has to be in a relaxed state.

Testing Position

- Supine.
- Hips are in extension and neutral rotation.
- The contralateral hip is abducted.
- Knees are in extension.
- The opposite leg is slightly flexed to allow maximum adduction of tested hip (Fig. 3.17).

Goniometer Alignment and Measurements

- The axis of the goniometer is centered over the ASIS of the tested hip.
- The stationary arm is aligned with the contralateral ASIS.
- The movable arm is along the longitudinal axis of the femur.
- The tested hip is moved in adduction (Fig. 3.18).

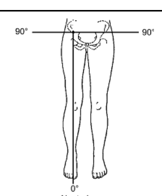


Figure 3.17. Zero starting position. Slightly flex the non tested leg to allow maximum adduction of tested hip. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

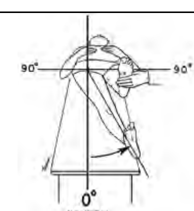


Figure 3.18. Clinical determination of hip adduction. Reprinted with permission from Joint Motion Method of Measuring and Recording. Rosemont, IL., American Academy of Orthopaedic Surgeons,1965, p. 62. [30]

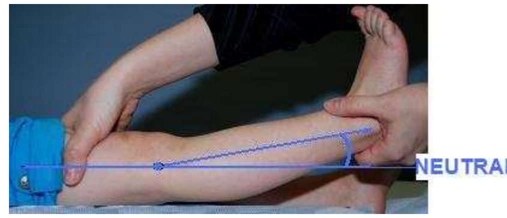
<table>
<tr><th colspan="2">Table 3.23. Knee Extension</th></tr>
<tr><td>Testing Condition</td><td rowspan="6">

Figure 3.19. Clinical determination of passive knee extension. Subject shows knee hyperextension. (© IRDPQ-2011).</td></tr>
<tr><td>The child has to be in a relaxed state.</td></tr>
<tr><td>Testing Position</td></tr>
<tr><td>▪ Supine.
▪ The hips are extended and kept in neutral rotation.</td></tr>
<tr><td>Goniometer Alignment and Measurements</td></tr>
<tr><td>▪ The axis of the goniometer is centered over the midpoint of the lateral knee-joint line.
▪ The stationary arm is aligned with the greater trochanter of the femur.
▪ The movable arm is aligned with the lateral malleolus of the fibula.
▪ The knee is moved in extension (Fig.3.19).
▪ Lack of full extension (knee flexion contracture) is expressed as negative values.
▪ Hyperextension is expressed as positive values.</td></tr>
</table>

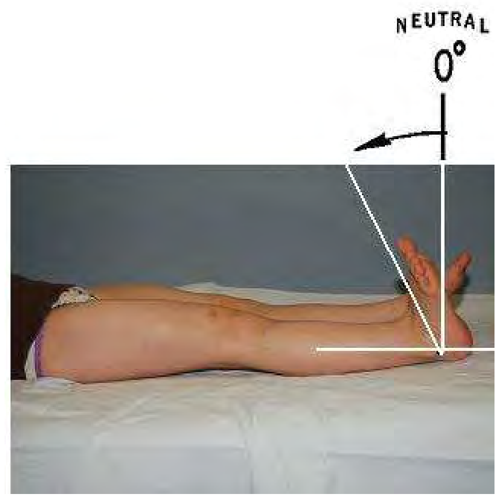
<table>
<tr><th colspan="2">Table 3.24. Ankle Dorsiflexion</th></tr>
<tr><td>Testing Condition</td><td rowspan="6">

Figure 3.20. Ankle dorsiflexion. (© IRDPQ-2011).</td></tr>
<tr><td>▪ The child has to be in a relaxed state.</td></tr>
<tr><td>Testing Position</td></tr>
<tr><td>▪ Supine.
▪ Hip in neutral rotation and knee in extension.
▪ Ankle in neutral position (eversion and inversion are restricted).</td></tr>
<tr><td>Goniometer Alignment and Measurements</td></tr>
<tr><td>▪ The axis of the goniometer is centered over the lateral ankle joint.
▪ The stationary arm is aligned along the shaft of the fibula.
▪ The movable arm is parallel with the fifth metatarsal.
▪ The ankle is moved in dorsiflexion (Fig. 3.20).
▪ Right-angle is designated as neutral dorsiflexion alignment (0°).
▪ Dorsiflexion above neutral position is expressed as positive values.
▪ Dorsiflexion under neutral position is expressed as negative values</td></tr>
</table>

10.4 Normative Reference Values

- Hip internal rotation (Fig. 3.22).
- Hip external rotation (Fig. 3.23).
- Hip abduction (Fig. 3.24).
- Hip adduction (Fig. 3.25).
- Knee extension (Fig. 3.26).
- Ankle dorsiflexion (Fig. 3.27).

INTERPRETATION OF RESULTS

The normative data in the following figures, for each range of motion, should be read as presented in Figure 3.21. [33]

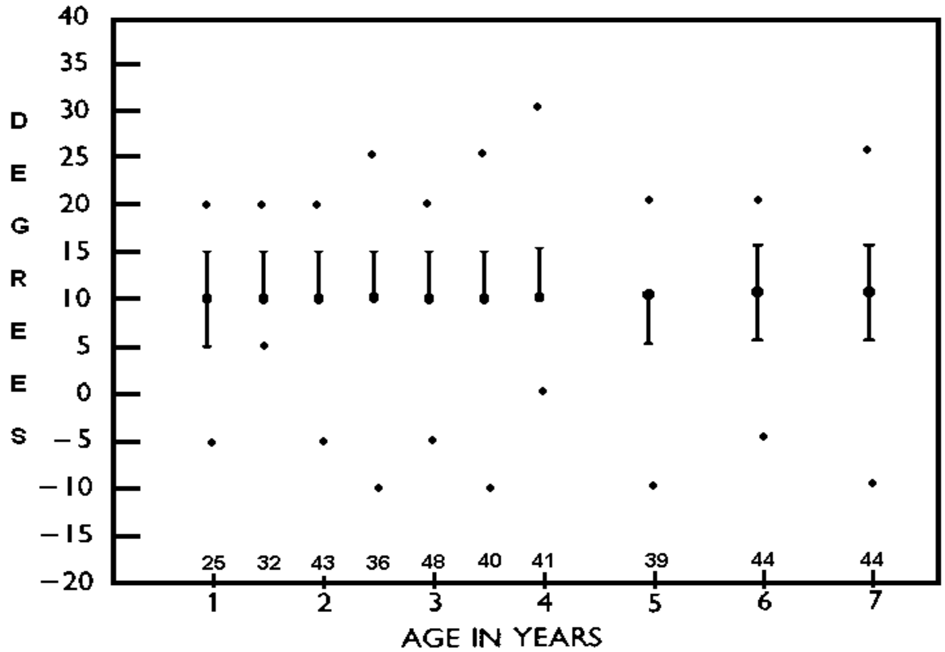


Figure 3.21. Interpretation of results:

- The vertical bar encompasses the middle 50% of subjects.
- The box indicates the median.
- The upper and lower markers show respectively the greatest and least value recorded.
- The number of subjects is given along the horizontal axis with each year.

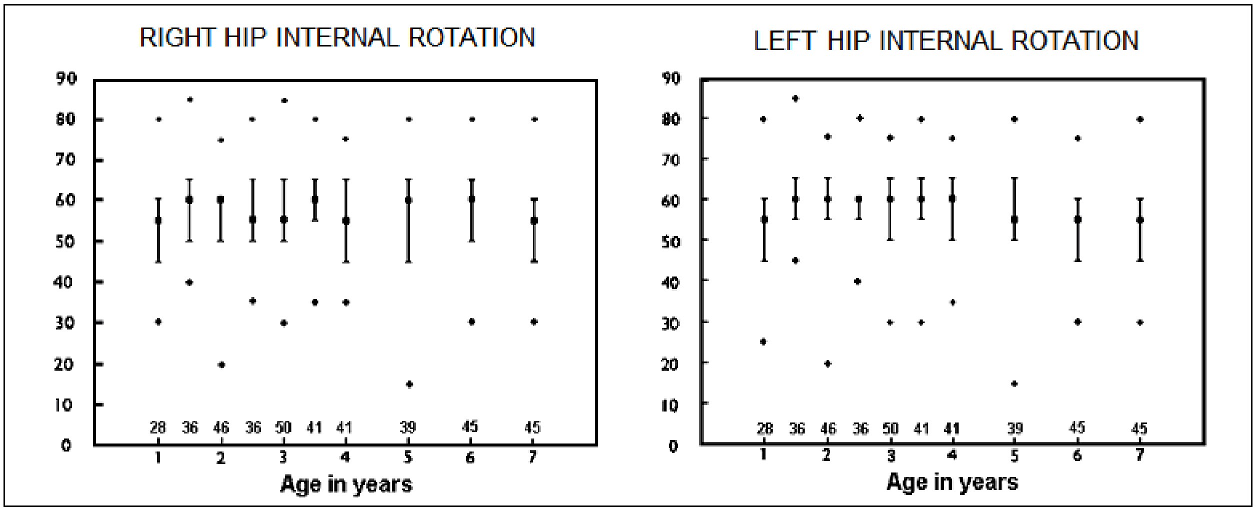


Figure 3.22. Range of passive internal rotation of the hip (degrees) – versus age (*n* = 407).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 38.[33]

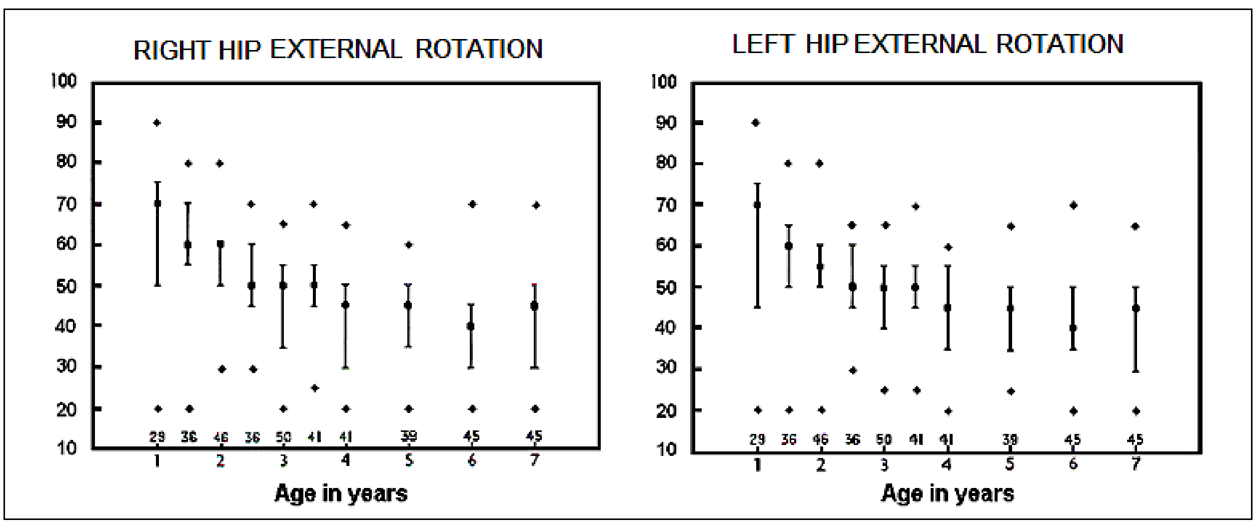


Figure 3.23. Range of passive external rotation of the hip (degrees) – versus age (*n* = 408).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 38.[33]

- **Clinical Practice Guidelines** [33]
  - At 1 year, median range of hip external rotation = 65°.
  - At 7 years, median range of hip external rotation has gradually diminished to 45°.
  - Greatest change occurs between 1 and 2 ½ years.

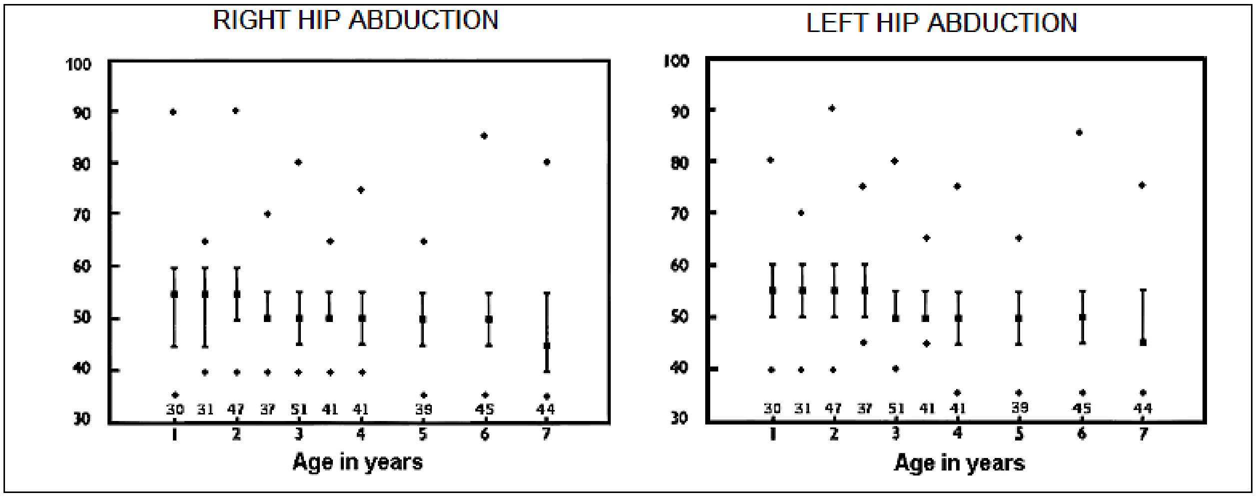


Figure 3.24. Range of passive abduction of the hip (degrees) – versus age (*n* = 406).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 39. [33]

- **Clinical Practice Guidelines** [33]
  - At 1 year, median abduction range is 55°.
  - Abduction gradually diminishes to 45° at 7 years.

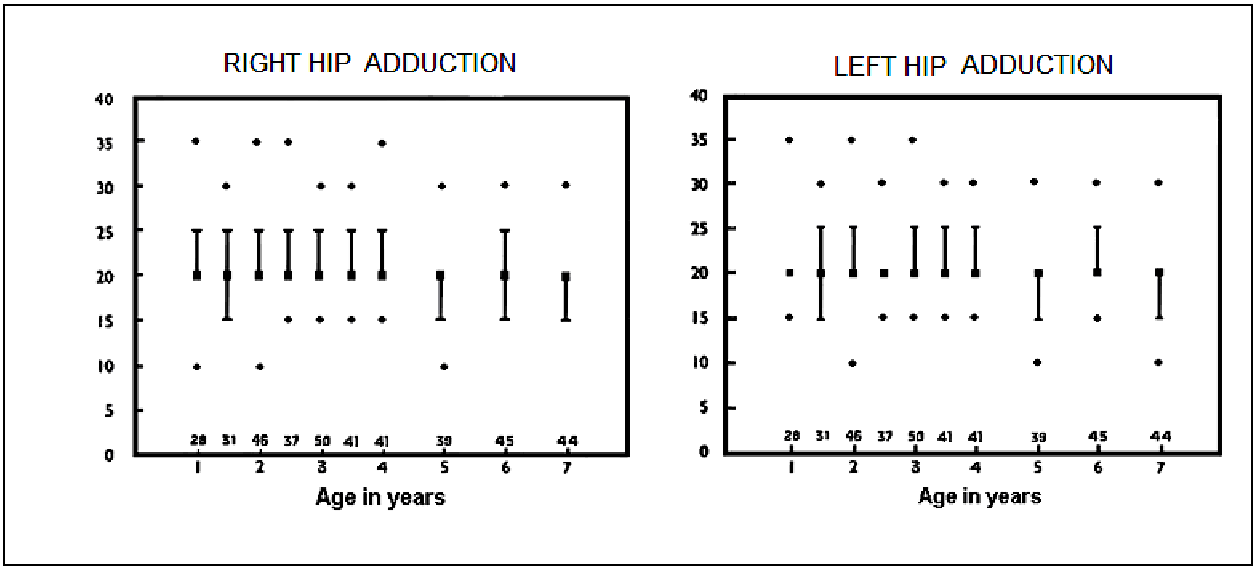


Figure 3.25. Range of passive adduction of the hip (degrees) – versus age (*n* = 402).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 39. [33]

- **Clinical Practice Guidelines** [33]
  - The median value in all age groups was 20° and litt le change is seen with age.

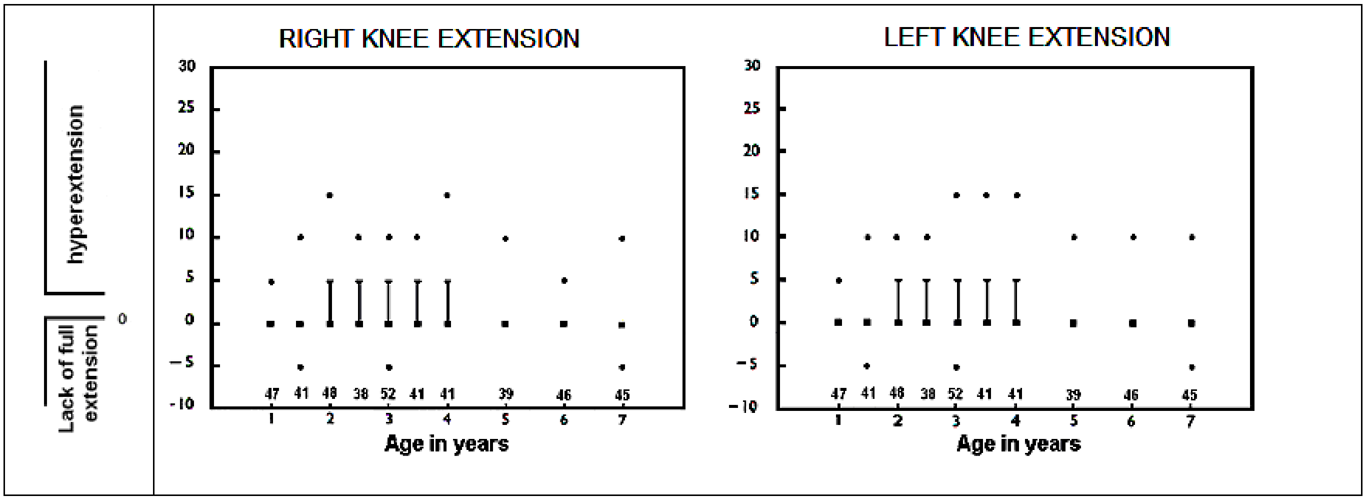


Figure 3.26. Range of passive knee extension (degrees) – versus age (n = 438).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 40. [33]

- **Clinical Practice Guidelines** [33]
  - Throughout all the age groups, the range between the 25th and 75th percentiles is only 5° with a median of 0°.
  - Many children showed passive hyperextension to 10°.
  - Knee flexion contracture of 5° was observed in the 1½-, 3- and 7-year-age-groups.

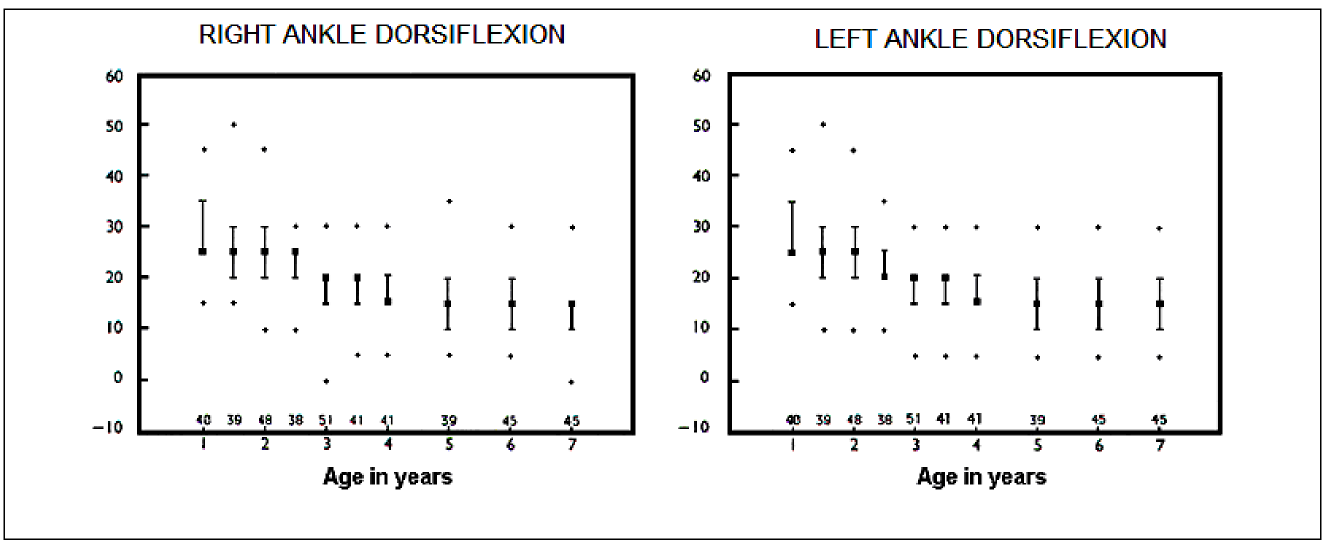


Figure 3.27. Range of passive ankle dorsiflexion (degrees) – versus age (n = 427).
© Sutherland, Olshen, Biden and Wyatt (1988), p. 41. [33]

- **Clinical Practice Guidelines** [33]
  - Significant decline in ankle dorsiflexion is observed with increasing age, the greatest change being between one and 4 years.

10.5 Study Summary

Title: The Development of Mature Walking[33]	
Author	Sutherland, David H.
Publication	(1988). London: Mac Keith Press.
Purpose of the Study	▪ To outline changes in gait from the ages of first walking to 7 years. ▪ To define mature gait in terms of specific gait parameters. ▪ To provide substantial basis for comparing children with possible gait problems with normal children of the same age.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of gait velocity and different spatial parameters on a short walkway in a therapeutic setting.

Methods

Subjects

- The study sample consisted of 309 healthy children. Mostly Caucasians. USA.
- Age range: 1 year to 7 years.
- Subjects were divided into ten age groups based on chronological age in years within 6 months intervals. For gait analysis, each group consisted of 36 to 49 subjects.

Testing Procedures and Instrumentation

- Various gait parameters were assessed and analyzed in a laboratory setting.
- Different anthropometric variables and range of motion in the lower extremities were measured. For range of motion analysis, 392 to 438 measurements were performed in each group.
- Instrumentation: Gait analysis laboratory and various measuring devices were used depending of the variables analyzed. Testing was done in different standardized positions.

Data Analysis

- Motion data was subjected to Fourier analysis to determine mean rotations across the gait cycle.
- Prediction regions, defining boundaries within 95% of normal children, were calculated using the resultant Fourier coefficients. Details are available therein.

Results

Due to the vast amount of information presented in this study, only the data concerning the variables that were used for this document are presented.
Psychometric Properties: Non applicable.

Gait

- Normative data for gait parameters are presented therein.
- Walking velocity increases with age in a linear manner from 1 to 3 years at a rate of about 11 cm/sec per year. From 4 to 7 years, the rate of change diminishes to 4.5 cm/sec.
- Cadence in the 1-year-old subjects was ~ 22.5% more than of the 7-year-olds. The main reduction occurs between 1 and 2 years of age. Cadence in the 7 -year-olds is ~ 26% more than the normal adult's mean.

Musculoskeletal Variables

- Mean values for range of motions are presented therein for the left and right sides. There was no significant difference between sides ($p < 0.01$) for any age groups and for either sex.
- Hip internal rotation has a substantial variability throughout 1 to 7 years of age. Median range of passive hip internal rotation varies between 53° and 60°.

10.5 Study Summary (Continued)

Results (Continued)
▪ Median range of hip adduction throughout 1 year to 7 years was 20°. ▪ Hip abduction at 1 year shows a median range of passive hip abduction of 55°. At 7 years, the median range of passive hip abduction has gradually diminished to 45°. ▪ At 7 years, the straight leg raise test exceeded range of motion of most adults. ▪ Ankle dorsiflexion, straight leg raise test, hip abduction and external rotation gradually decreased with age. Dorsiflexion, from 1 year to 7 years, shows a significant decline with increasing age, from 25° at 1 year to 15° at 7 years. At 1 year, hip ext ernal rotation is greater than hip internal rotation. At 2 ½ years, hip internal rotation is greater than hip external rotation. ▪ Complete extension of the hip to 10° across all ag e-groups is in disagreement with other authors. ▪ The greatest spread of data in normal children for femoro-tibial alignment was in the direction of valgus. Results show similar trends as other studies but with greater variability and may be due to different measurement methods such as X rays versus clinical measurements. ▪ Findings are consistent with other studies but some discrepancy exists with others which may be explained by the much larger sample size of the present study, the use of a permanent laboratory setting and in the assessment of free-speed gait.
Authors' Conclusion
Normative data for gait parameters, anthropometric and musculoskeletal measurements are available for normal children aged from 1 to 7 years. The ranges of motion are to be used as guidelines. The authors report that it would be unwise to label a child abnormal if he shows minor deviations from the presented values.

Comments
Internal and external validity (including sample size, *n* = 309) seems good and the use of results as a trend in clinical guidelines is appropriate.

11. Passive Range of Motion of the Ankle [1]

Age range: 7.4 to 13.9 years.

11.1 Clinical Use

- Quantification of ROM of dorsiflexion and plantar flexion.

11.2 Measurements

- Dorsiflexion with knee in extension in prone (Fig. 3.28).
- Dorsiflexion with knee in flexion in prone (Fig. 3.29).
- Plantar flexion in supine (Fig. 3.30).

Note: In this study, other ankle motions were measured (see Table 3.28). To obtain information about these measurements, the clinician will have to order the research study of Alanen et al. (2001). [1]

11.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks:
  - Head of the fibula;
  - Lateral malleolus;
  - Lateral aspect of the fifth metatarsal.

TEST

- Testing position, goniometer alignment and measurements are presented in Tables 3.25 and 3.26.
- Results are compared to the normative reference values in Table 3.27.

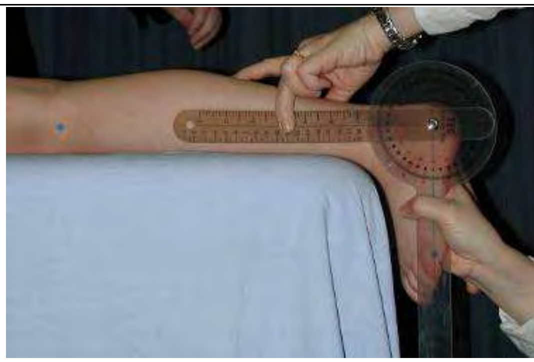
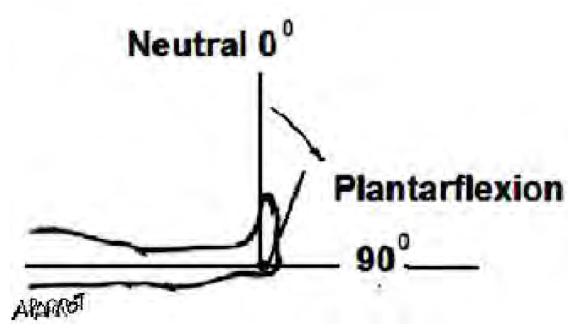
TABLE 3.25.	
Testing Position, in Extension	**Testing Position, in Flexion**
▪ Prone, the knee in extension, the feet extending over the edge of the examination table. ▪ The ankle is kept in neutral position.	▪ Prone, the knee in flexion. ▪ The ankle is kept in neutral position.
 **Figure 3.28. Method of positioning and clinical determination of ankle dorsiflexion, in extension.** (© IRDPQ-2008).	 **Figure 3.29. Method of positioning and clinical determination of ankle dorsiflexion, in flexion.** (© IRDPQ-2008).
Goniometer Alignment and Measurements	
▪ The stationary arm is placed directly parallel to the fibula with the head of the fibula as reference point. ▪ The movable arm is placed on the lateral side of the foot along the 5^{th} metatarsal bone. ▪ The ankle is moved in maximal dorsiflexion.	

Table 3.26. Ankle Plantar-Flexion	
Testing Position	 **Figure 3.30. Ankle plantarflexion.**(© IRDPQ-2011).
▪ Supine, knee in extension. ▪ The ankle is kept in neutral position. ▪ An assistant stabilizes the leg against the examination table.	
Goniometer Alignment and Measurements	
▪ The stationary arm is placed directly parallel to the fibula with the head of the fibula as reference point. ▪ The movable arm is placed on the lateral side of the foot along the 5^{th} metatarsal bone. ▪ The ankle is firmly pushed from the dorsum of the foot to maximal plantar-flexion, avoiding forefoot valgus and varus.	

11.4 Normative Reference Values

Table 3.27 *Means, standard deviations, and ranges of mobility of the ankle joint complex*

			Boys			Girls		
	P value	95% CI	Mean	SD	Range	Mean	SD	Range
Passive maximal inversion								
Left ankle	0.138	−2.6 to 0.4	31°	5.7	19–50°	32°	5.9	17–48°
Right ankle*	0.024	−3.2 to −0.3	31°	5.6	19–47°	33°	6.1	17–46°
Passive maximal eversion								
Left ankle	0.660	−0.9 to 1.4	12°	4.6	5–24°	12°	4.6	0–28°
Right ankle	0.271	−0.7 to 2.3	13°	6.1	1–30°	12°	5.3	2–27°
Passive maximal dorsiflexion								
Left (knee ext.)	0.325	−2.7 to 0.9	27°	6.6	14–45°	28°	7.4	12–50°
Right (knee ext.)	0.838	−2.0 to 1.6	24°	6.7	5–46°	25°	7.2	8–46°
Left (knee 90° fl.)	0.137	−0.5 to 3.4	42°	7.6	26–56°	41°	7.6	21–61°
Right (knee 90° fl.)*	0.011	0.6 to 4.2	41°	7.0	27–59°	38°	7.3	18–56°
Passive maximal plantarflexion								
Left ankle*	0.004	−4.6 to −0.9	52°	8.1	30–74°	54°	5.7	41–71°
Right ankle*	<0.001	−4.9 to −1.2	54°	7.5	35–73°	57°	6.8	39–80°
Loaded maximal dorsiflexion								
Left ankle	0.147	−3.5 to −0.6	40°	8.5	20–61°	41°	7.1	22–60°
Right ankle	0.143	−3.3 to −0.5	40°	7.8	22–60°	41°	7.0	26–61°
β angle								
Left (normal)	0.101	−0.2 to 2.2	188°	5.0	177–200°	187°	4.2	176–198°
Right (normal)*	0.004	0.5 to 3.1	188°	5.3	179–201°	186°	4.4	176–198°
Left (knee 45° fl.)*	0.022	0.2 to 2.5	190°	4.8	177–205°	189°	4.3	179–203°
Right (knee 45° fl.)*	0.004	0.7 to 3.4	189°	6.0	179–203°	187°	4.6	177–201°
γ angle								
Left (normal)	0.797	−0.8 to 1.1	88°	3.8	76–95°	88°	3.6	77–96°
Right (normal)*	0.022	−2.0 to −0.1	87°	3.9	77–95°	88°	3.4	80–97°
Left (knees 45° fl.)	0.069	−0.1 to 1.8	86°	3.7	77–93°	85°	3.6	73–93°
Right (knees 45° fl.)	0.179	−1.7 to 0.3	84°	4.4	73–95°	84°	3.6	77–92°

P values and 95% confidence intervals (95% CI) refer to differences of means between boys and girls. SD, standard deviation.
* $P < 0.05$.

11.5 Study Summary

Title: Ankle Joint Complex Mobility of Children 7 to 14 Years Old [1]	
Authors	Alanen, J. T., Levola, J. V., Helenius, H. Y., & Kvist, M. H.
Publication	Journal of Pediatric Orthopedics, 2001, 21, 731-737
Purpose of the Study	To examine the mobility of the ankle joint complex in healthy children and reliability of measurement.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of PROM of ankle dorsiflexion and plantar-flexion.

Methods

Subjects

- The study sample consisted of 245 unimpaired children; (141 ♀, 104 ♂). Finland.
- Age range = 7.4 years to 13.9 years (mean: 10.2 years).
- Caucasian subjects.

Testing Procedures and Instrumentation

- PROM of the ankle joint complex and loaded maximal dorsiflexion of the ankle were measured bilaterally. Testing positions were standardized in prone, in supine and in standing.
- Instrumentation: standard goniometer. Translucent paper was used for eversion and inversion and photographs for loaded maximal dorsiflexion.

Data Analysis

- Comparison of variances and normality of distribution were checked before analyses. Paired *t*-test was used to evaluate side differences: $p < 0.05$ was interpreted as significant and 95% confidence intervals were calculated.
- 27 children were studied twice by the same physician and retest was carried out 3 to 6 days after the first test. The intra-class correlation coefficients were calculated to test intra-tester reliability.

Results

- **Psychometric Properties:** The range of intra-class correlation coefficients varied between 0.51 and 0.88. Intra-tester reliability was considered fair to good. Inversion of the left ankle was an exception with an intra-class correlation coefficient of 0.40.
- Variations of PROM of the ankle joint complex were large in healthy children aged 7 years to 14 years. In the present study, the values between the 2.5 and the 97.5 percentiles were regarded as being within the reference range.
- The largest gender-related difference was in girls where plantar-flexion ROM was greater than in boys. Other statistically significant gender differences do exist, but were small and, as mentioned by the authors, probably lack clinical meaning.
- 29% of the children had a left-right side difference of > 5° and 5% to 10% had a left-right side difference of > 10° in many of the measurements. Values for passive dorsiflexion, knee in flexion, averaged 15° larger (SD: 5.7, range: 0 to 33°) than dorsiflexion with knee in extension.

Authors' Conclusion

- There is a wide range of motions of the ankle joint complex. Gender difference exists in childhood but is minute and probably has no clinical meaning.
- Many healthy children had a difference in PROM of > 5° and even > 10° between the left and right sides. Therefore, the "healthy ankle" cannot necessarily be used in clinical practice as a reference when evaluating, for example, treatments of foot and ankle injuries in children.

Comments

- Internal and external validity (including sample size, *n* =141 girls and 104 boys) seems good and the use of results as a trend for clinical guidelines is appropriate.

12. Passive Range of Motion of Ankle Dorsiflexion in Adolescent Athletes [25]

Age range: 14 to 17 years.

12.1 Clinical Use

- To identify if ankle joint motion in young athletes is different from a non-athletic population.
- To obtain normative data that are more representative for this type of children.

12.2 Measurements

- Dorsiflexion, knee in extension (Fig. 3.31).
- Dorsiflexion, knee in flexion.

12.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 3.28 and 3.29.
- Results are compared to the normative reference values in Table 3.30.

TABLE 3.28. ANKLE DORSIFLEXION, KNEE IN EXTENSION

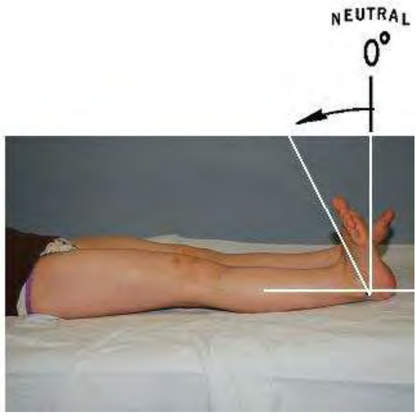
Testing Position	
▪ Supine. ▪ The foot and the ankle are held in neutral position.	
Goniometer Alignment and Measurements	
▪ The stationary arm is placed parallel to the fibula. ▪ The movable arm is placed on the lateral side of the foot along the 5th metatarsal bone. ▪ The ankle is moved in dorsiflexion with the knee in extension (Fig. 3.31). ▪ 0° is defined as 90° relationship between the lateral border of the foot and the long axis of the leg. ▪ A negative value indicates that the foot is relatively plantar flexed in relation to the leg.	**Figure 3.31. Dorsiflexion, knee in extension.** (© IRDPQ-2011).

TABLE 3.29. ANKLE DORSIFLEXION, KNEE IN FLEXION
Testing Position
▪ Supine, tested knee in 90° flexion. ▪ The foot and ankle are held in neutral position.
Goniometer Alignment and Measurements
▪ Similar to Table 3.28. ▪ The ankle is moved in dorsiflexion with the knee in flexion.

12.4 Normative Reference Values

TABLE 3.30. MEAN VALUES AND STANDARD DEVIATION OF ANKLE DORSIFLEXION IN ADOLESCENT ATHLETES AGE: 14 YEARS TO 17 YEARS			
Passive Ankle Dorsiflexion		Mean °	SD °
Right ankle	Knee in extension	0.35	2.2
	Knee in flexion	4.88	3.23
Left ankle	Knee in extension	–0.6	2.09
	Knee in flexion	4.68	3.33
SD: Standard deviation. All measurements are in degrees°. n = 40.			

Data from: Saxena and Kim, p.313. [25]

12.5 Study Summary

Title: Ankle Dorsiflexion in Adolescent Athletes	
Authors	Saxena A. & Kim W.
Publication	Journal of the American Podiatric Medical Association, 2003, 93, 312-314
Purpose of the Study	To establish standard values for ankle dorsiflexion in adolescent athletes.
Type of Population	☒ Normal ☒ Other: Adolescent athletes
Clinical Relevance	Quantification of dorsiflexion in athletic teenagers.

Methods

Subjects

- Subjects were asked to volunteer for the study during a preseason health screening.
- The study sample consisted of 40 healthy high-school athletes (16 ♀, 24 ♂) without a history of ankle injury. USA.
- Age range: 14 years to 17 years.

Testing Procedures and Instrumentation

- Measurements were recorded bilaterally by an experienced evaluator for ankle dorsiflexion with the knee extended and the knee flexed. Testing position was standardized in supine.
- Instrumentation: standard goniometer.

Data Analysis

- Statistical significance using the student *t* test was set at ($p< .05$). Mean and standard deviations (SD) were calculated.

Results

- **Psychometric Properties**: Non applicable.
- For the group, knee in extension, the mean dorsiflexion (± SD) for the right ankle was 0.35° (± 2.2), and with the knee in flexion, 4.88° (± 3.2 3). Mean dorsiflexion (± SD) for the left ankle was – 0.6° (± 2.09), knee extended and 4.68° (± 3.33) w ith the knee flexed.
- There were no statistically significant differences between limbs, and within the groups, and between genders.
- Ankle dorsiflexion in asymptomatic adolescent athletes is approximately 0° with the knee extended and just less than 5° with the knee flexed. Compare d to a study with adults, values are lower and may be due to different testing procedures and non-athletic subjects were not excluded if they had had an ankle injury.
- Authors report two principal limitations to the study:
  a) The amount of force applied when measuring dorsiflexion may be a variable but, by having an experienced clinician do all the measurements, variables were kept to a minimum;
  b) The use of a goniometer instead of an equinometer.
- Sample size may be considered small and is related to the fact that it was difficult to find athletes who had never had an ankle injury.
- The findings are consistent with other authors in the definition of gastrocnemius equines which is reported as < 5° of maximal ankle dorsiflexion with knee extended and < 10° with the knee flexed, perhaps suggesting that adolescent athletes have a component of gastrocnemius equinus or that the baseline values differ from a non-athletic healthy population.

Authors' Conclusion

- The authors obtained baseline values that have not been, to their knowledge, reported in the literature. Values obtained in this study are lower than some reported in previous studies but may indicate that some degree of equinus is normal in adolescent athletes.
- There is a possible contribution of less dorsiflexion to injuries or, if it is a beneficial trait, remains to be investigated.

Comments

- Internal and external validity (including sample size, $n = 40$) seems good and the use of results as a trend for clinical guidelines is appropriate.

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Soucie J. M , Wang C , Forsyth, A, Funk, S., Denney, M., Roach, K. E., Boone, D., and the Hemophilia Treatment Center Network. (2010) Range of motion measurements: reference values and a database for comparison studies. *Haemophilia,* 17, 500-507, doi: 10.1111/j.1365-2516.2010.02399.x	Passive joint ROM measurements were obtained on a total of 674 normal subjects aged 2-69. Female subjects had greater joint mobility in all age groups in nearly all joints. Range of motion average values for all joints decreased with advancing age for both men and women and, in most cases were significantly different than most commonly used normative values. Our study of ROM measurements taken by trained physical therapists on a large sample of healthy individuals revealed significant gender- and age-related variation that may be an important consideration in patient assessment. **Note**: The authors have established a public database of joint ROM measures, with methods, materials, description and sample tables. Data can be consulted at the Centers for Disease and Control Prevention Web site in the Normal Joint Range of Motion Study. http://www.cdc.gov/ncbddd/jointROM/index.html Data was accessed on October 1, 2011.
Ohman AM, Beckung ER. (2008) Reference values for range of motion and muscle function of the neck in infants. *Pediatr Phys Ther*. Spring; 20 (1): 53-8.	ROM was measured, and muscle function was estimated in 38 infants at the ages of 2, 4, 6, and 10 months. For rotation the mean ROM was 110 degrees and for lateral flexion it was 70 degrees. Infants of 2 months of age had a median muscle function score of 1 (interquartile range, 1-2). Muscle function increased to score 3 to 4 by 10 months. Infants below 1 year of age have good ROM in rotation (> or = 100 degrees) and lateral flexion (> or = 65 degrees) of the neck. These reference values for passive ROM and muscle function of the neck may have clinical utility in assessing and documenting the initial evaluation and progress of infants with congenital muscular torticollis.

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Glanzman, A. M., Swenson, A. E., & Kim, H. (2008). Intra-rater range of motion reliability in cerebral palsy: a comparison of assessment methods. *Pediatric Physical Therapy*. Winter; *20*, 369-372.	Intrarater reliability of goniometry performed with and without an assistant and the reliability of the Staheli and Thomas tests of hip extension were measured. Visual estimation was also evaluated as a method of range of motion assessment.Goniometry with 1 and 2 assessors both produced ICCs in the excellent range as did the Staheli and Thomas test measurements of hip extension. The use of an assistant did not provide additional benefit. Visual estimation showed excellent correlation with goniometry.
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Mutlu, A., Livanelioglu, A. & Gunel, M. K. (2007) Reliability of goniometric measurements in children with spastic cerebral palsy. *Medical Science Monitor*, 13, CR323-329.	Intra-testing reliability and inter-test reliability scores were high.
Owen, J., Stephens, D. & Wright J. G. (2007) Reliability of hip range of motion using goniometry in pediatric femur shaft fractures. *Canadian Journal of Surgery,* 50, 251-255.	Most ICCs for the different aspects of hip range were between 0.2 and 0.5, indicating slight agreement. Goniometric measurement, using standardized protocols for the hip, has low reliability.
Golden DW, Jhee JT, Gilpin SP, Sawyer JR.(2007) Elbow range of motion and clinical carrying angle in a healthy pediatric population.*J Pediatr Orthop* B. Mar;16(2):144-9.	Cross-sectional clinical measurement of 600 elbows (300 patients) range of motion and carrying angle in normal children. Significant increase was found in range of motion and carrying angle with age (P<0.01) and significantly increased range of motion and carrying angle in females as compared with males (P<0.01). In conclusion, elbow joint range of motion and carrying angle increase with age. This is the first cross-sectional analysis of range of motion and carrying angle to our knowledge in the pediatric population. Increased elbow extension may contribute to the increased carrying angle seen in females compared with males.
Arbogast KB, Gholve PA, Friedman JE, Maltese MR, Tomasello MF, Dormans JP. Normal cervical spine range of motion in children 3-12 years old. (2007) *Spine* (Phila Pa 1976). May 1;32(10):E309-15.	A total of 67 children, (3 age groups : 3-5 years, 6-8 years, 9-12 years), were tested in flexion/extension, lateral bending, and horizontal rotation with ROM instrument and videography. This study contributes valuable normative data for pediatric cervical spine ROM in children that can be used as a clinical reference and for biomechanical applications. In children 3-12 years of age, both flexion and rotation increased slightly with age. Of interest, there were no differences in ROM with gender, which contradicts adult literature where females have been shown to have more cervical spine ROM than males.
McWhirk, L. B. & Glanzman, A. M. (2006) Within-session inter-rater realiability of goniometric measures in patients with spastic cerebral palsy. *Pediatric Physical Therapy*.18(4), 262-265.	Interclass correlation coefficients ranged from 0.582 (hip extension) to 0.929 (popliteal angle).

Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

Part 4

Specific Tests

Complete document :

www.irdpq.qc.ca/communication/publications

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Part 4

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Hip Flexion Contracture

Summary

Measurement of hip joint range of motion is used clinically to assess joint disability or various medical conditions (orthopedic, neurological or musculoskeletal disorders). Research findings indicate that the ROM of joints is different in neonates, children, and adults without significant differences between sexes. [9, 14, 19, 20] To assess if there is joint motion limitation, the comparison between sides is usually appropriate. [49]

Limitation of hip extension is physiologically normal in infants and children [9, 14, 20, 31, 44] and the term that is often used to describe this condition is hip flexion contracture (HFC). However, the term "contracture" usually refers to a pathological condition, which is not the case in the pediatric population when limitation of hip extension is within the normal ranges. Since the term "contracture" is often used in the literature to describe hip extension limitation, the same term will be used throughout this chapter for purposes of consistency. A common test used to detect HFC is the Thomas maneuver.

VALIDITY AND RELIABILITY OF THE THOMAS MANEUVER

- Inter-rater reliability had high scores in premature infants. [20]
- Compared to other measurements taken in children (unimpaired and mild spastic diplegia), the Thomas test was reported as presenting the most reliable inter-sessional measures (along with knee extension measurements) and mostly when limitation was present in small degrees. [24]
- For additional information on hip measurements, refer to the ''up to date'' pages, at the end of the references pages.

Four studies were selected to document HFC with the Thomas maneuver in:

- The premature child - Harris et al.-1990; [20]
- Newborns - Forero et al. -1989; [14]
- Infants - Coon et al.-1975; [9]
- Children - Boone et al. -1979. [5]

1. Hip Flexion Contracture in the Premature Child [20]

Age range: Newborns (~37 weeks gestational age), 4, 8 and 12 months (chronological age).

1.1 Clinical Use

- To measure neonatal passive ROM of hip extension limitation and to document age-related changes in the premature child.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

1.2 Measurements

- Hip flexion contracture (Fig. 4.1).

1.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm goniometer. The arms were shortened to accommodate the limb segments of infants.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks:
  - Lateral aspect of the hip joint;
  - Lateral aspect of the femur.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.1.
- Method: International SFTR[a] Method of Measuring and Recording Joint Motion. This method refers to the neutral zero procedure.[16, 51] Thomas maneuver is used to detect hip flexion contracture.
- Results are compared to the normative reference values in Table 4.2

---

[a] International SFTR Method of Measuring and Recording Joint Motion [14, 32] refers to the assessment of joint motion by using a standardized approach based on the international neutral zero method and different basic planes designation. SFTR: S = Sagittal; F = Frontal; T = Transverse; R = Rotation.

TABLE 4.1. HIP FLEXION CONTRACTURE

Testing Condition

- The infant must be in an alert, non crying state. The head is gently held in midline to control effects of tonic neck reflexes on muscle tone.

Testing Position

- Standard Thomas test.
- The contralateral hip and knee are flexed to the chest. The test leg is allowed to drop into extension.

Figure 4.1. Method of positioning and clinical determination of hip flexion contracture (© IRDPQ – 2011).

- **Goniometer Alignment and Measurements**

- The axis of the goniometer is centered over the lateral aspect of the hip joint.
- The stationary arm rests on the table top.
- The movable arm is parallel to the lateral aspect of the femur.
- The angle formed by the leg aligned with the surface on which the infant is lying is recorded (Fig. 4.1).

1.4 Normative Reference Values

TABLE 4.2. AVERAGE VALUE OF HIP FLEXION CONTRACTURE AT BIRTH, 4, 8, AND 12 MONTHS FOR PREMATURE INFANTS WITHOUT CNS PROBLEMS

Passive Joint Motion		Birth*	4 Months	8 Months	12 Months
HFC	Mean°	13.7	19.5	16.2	16.6
	SD°	5.5	8.4	15.9	25.9
Number of Subjects		*n* = 33	*n* = 29	*n* = 18	*n* = 11

** First testing performed at hospital discharge at mean gestational age of 37 weeks (SD=2.13). Other measurements were taken at 4, 8, 12 months chronological age. SD: Standard deviation. HFC: Hip flexion contracture. All measurements are in degrees°. CSN: Central nervous system.*

Data from : Harris, Simons, Ritchie, Mullett, and Myerberg, (1990), p. 188. [20]

1.5 Study Summary

Title: Joint Range of Motion Development in Premature Infants [20]	
Authors	Harris, M. B., Simons, C. J. R., Ritchie, S. K., Mullett, M. D., & Myerberg, D. Z.
Publication	Pediatric Physical Therapy, 1990, 2, 185-191.
Purpose of the Study	To document joint range of motion values for premature infants during the first year of life.
Type of Population	☐ Normal ☒ Other: Premature infants with and without central nervous system sequelae.
Clinical Relevance	Quantification of range of motion in hip flexion contracture, hip abduction, ankle dorsiflexion and elbow extension in premature infants.

Methods

Subjects
- The study sample consisted of 65 premature infants: (38 ♀; 27 ♂). USA.
- Age range: ~37 weeks (gestational age) to 12 months (chronological age).
- Infants were classified into two groups depending on common complications directly related to prematurity.
- Range of motion (ROM) was assessed at time of hospital discharge, at approaching term gestational age (~37 weeks, SD=2.13) and at 4, 8, 12 months chronological age.
- If the child was not present at the clinic appointment, the subject was not represented in the data for that particular age. The number of children without central nervous system complications (CNS) was at initial examination: 33; at four months, 29; at eight months,18 and at twelve months, 11.

Testing Procedures and Instrumentation
- Hip abduction, hip extension (hip flexion contracture), elbow extension, wrist extension, ankle dorsiflexion, the scarf sign and the popliteal angle (PA) were measured on both sides.
- Testing positions were standardized and based on the [b]Amiel-Tison Neurological Evaluation and the [c] International SFTR Method of Measuring and Recording Joint Motion. Testing was abandoned if infants were crying vigorously or were in a deep sleep.
- Instrumentation: Standard plastic goniometer (arms were shortened to accommodate limb segments). The larger angle was recorded to ensure reading in a standard fashion with the exception of hip abduction measurements.

Data Analysis
- Inter-rater reliability was established by having two examiners test the subjects independently in rapid succession. Reliability was obtained on six subjects, representing each age and each motion. Agreement between the examiners was calculated in two ways:
  1. One-way analysis of variance procedure producing an intra-class correlation coefficient (ICC);
  2. A ratio of agreement to total observations multiplied by 100 to obtain a percentage.
- Mean, range and standard deviation for each joint motion was calculated.

---

b) Amiel Tison neurological evaluation intends to establish the risk for later neurologic impairment. A recent study [9] tested the reliability of the revised Amiel Tison neurological evaluation at term. Kappa Coefficient Ranges for the scarf sign test was 0.82 and for the popliteal angle 0.78 which is excellent by authors ratings.

c) International SFTR Method of Measuring and Recording Joint Motion [14, 32] refers to the assessment of joint motion by using a standardized approach based on the international neutral zero method and different basic planes designation. SFTR: S = Sagittal; F = Frontal; T = Transverse; R = Rotation.

1.5 Study Summary (Continued)

Results

- **Psychometric Properties**
  - Inter-rater reliability: ICC for ankle dorsiflexion: 0.87.
    - Hip extension (hip flexion contracture): 0.72.
    - Hip abduction: 0.85.
    - Popliteal angle: 0.83.
    - The scarf sign: 0.84.
    - Wrist extension: 0.59.
  - Perfect agreement was reported in elbow extension, hip extension and hip abduction (100%). Percentage of agreement for wrist extension was 92%; for ankle dorsiflexion, 75 %; for PA, 67%; and for the scarf sign, 75%.
- There was no difference in ROM between the two sides of the body. ROM of hip extension remained relatively constant over the 12 months. PA values decreased by 5° between the first and second test and then remained fairly constant. Over the first year, only ankle dorsiflexion showed a clear decrease of almost 10°.
- Premature infants who had CNS involvement had no change in ROM for hip abduction and had much lower ankle dorsiflexion values at 8 months than infants who had no CNS involvement.
- Premature infants who had no CNS involvement had an increase in abduction ROM. At 12 months of age, abduction ROM was much greater than in premature infants who had CNS involvement.
- Findings support results from other authors that premature infants never acquired the extreme postural flexion exhibited by term infants at birth.

Authors' Conclusion

- Pre-term infants have less flexion at term conceptional age than their full-term counterparts. This may support the concept that gross motor development in premature infants is qualitatively different from motor development in full-term children.

Comments

- Internal validity seems good. However, sample size is small in some age-categories (*n* =18 in the 8-months-group; *n* = 11 in the 12-months-group) and the use of results must be interpreted with caution. External validity in the other age groups (including sample size) seems good and the data can be used as a trend for clinical guidelines.
- Only the measurements presenting acceptable reliability with the goniometry technique were taking into account for this document. The scarf sign (no goniometer measurement) and wrist extension ROM (poor inter-rater reliability) were excluded.
- The PA measurements were excluded based on the testing position (hip maximally flexed on the abdomen) which is reported as being less accurate than when the hip is flexed at 90°, the latter being unaffected by abdominal bulk.[19, 22]

2. Hip Flexion Contracture in the Newborn [14]

Age range: One to three days.

2.1 Clinical Use

- To measure neonatal passive ROM of hip extension limitation.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

2.2 Measurements

- Hip flexion contracture (Fig. 4.2).

2.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard two-arm 360° goniometer.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks:
  - Anterior superior iliac spine (ASIS);
  - Posterior superior iliac spine (PSIS);
  - Femoral greater trochanter;
  - Femoral lateral epicondyle;
  - On the tested limb, a line is drawn between the anterior and posterior superior iliac spines and a line perpendicular to it from the greater trochanter.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.3.
- Results are compared to the normative reference values in Table 4.4

TABLE 4.3. HIP FLEXION CONTRACTURE

Testing Condition

- The infant must be in an alert-quiet, alert-active or drowsy-awake Brazelton states. Measurements were taken with the diaper off, the infant lying on a warmer bed in the nursery.
- The infant's head is gently held in midline to reduce effects of neonatal neck reflexes.

Testing Position

- Standard Thomas test.
- The contralateral leg is placed in maximum hip and knee flexion to stabilize the pelvis.
- The tested hip is kept in neutral position and brought in extension.
- The end range of beginning flexion is determined when the pelvis begins to rock anteriorly.

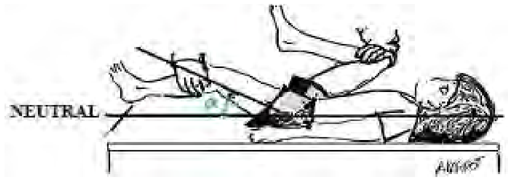


Figure 4.2. Method of positioning and clinical determination of hip flexion contracture. (© IRDPQ – 2011).

Goniometer Alignment and Measurements

- The axis of the goniometer is placed over the greater trochanter.
- The stationary arm is aligned with the perpendicular line described previously in the pre-test section.
- The movable arm is aligned with a line of the femoral lateral epicondyle along the midline of the femur.
- The angle formed by the leg aligned with the surface on which the infant is lying is recorded (Fig. 4.2).

2.4 Normative Reference Values

TABLE 4.4. DATA SUMMARY OF HIP FLEXION CONTRACTURE IN NEONATES
AGE: ONE TO THREE DAYS

Passive Joint Motion	Mean°	SD°	95% Normal Ranges°
HFC	29.9	3.93	22.0 - 37.8

SD: Standard deviation. HFC: Hip flexion contracture. All measurements are in degrees°. n: 60.

Data from: Forero, Okamura, and Larson, (1989), p.393. [14]

2.5 Study Summary

Title: Normal Ranges of Hip Motion in Neonates [14]	
Authors	Forero, N., Okamura, L. A., & Larson, M. A.
Publication	Journal of Pediatric Orthopedics, 1989, 9, 391-5.
Purpose of the Study	▪ To determine neonatal passive range of motion (ROM) of the hip joint using a clinically acceptable and accurate method of measurement. ▪ To confirm results of previous studies which found no significant differences between neonatal males and females.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of hip ROM in neonates.

Methods

Subjects

- The study sample consisted of 60 healthy, full-term neonates (26 ♀, 34 ♂). USA.
- Age range: One to three days.
- Mean gestational age: 40 weeks.
- Mean age: 1.45 days.
- Racial distribution: 70% Hispanic, 25% White, 5% Black individuals.

Testing Procedures and Instrumentation

- Joint motion measurements were taken when the child was in one of the three Brazelton's states of alertness. One clinician gently held the infant's head in midline to reduce any possible effects of neonatal neck reflexes on muscle tone. Testing positions were standardized in supine. The children were placed on a warmer bed in the nursery. Traditional landmarks were marked.
- Instrumentation: Standard two arm plastic 360° goniometer in 5° increments. The goniometer was calibrated against known angles of 0°, 45°, 90°, 135° and 180° before onset of the study.

Data Analysis

- Three measurements were taken for each joint motion of each infant and a mean value calculated. These values were then used to calculate a mean value, SD, median, 95% normal ranges, and 95% confidence intervals (CIs) of the means for each joint movement.
- Pearson correlation coefficients were calculated to determine possible relationships between each of the variables; *t* tests were used to determine if there exist significant differences between genders and racial characteristics. Mean, range and standard deviation (SD) were calculated for different variables (age, birth weight, etc.). Range and frequency were determined for sex and racial background.

2.5 Study Summary (Continued)

Results
▪ **Psychometric Properties:** Goniometric measurements were performed by the therapist who had the higher intra-tester (r = 0.999; p< 0.05) and inter-tester reliabilities as compared with an experienced pediatric physical therapist (r = 0.977; p< 0.05). Results are in near to perfect agreement. ▪ Ranges, means, medians, SD, 95% normal ranges and 95% CIs of the means of joint motions are presented therein. ▪ The medians of all the movements were within 1° of the respective means indicating a near-normal distribution of the data. ▪ Genders and ethnicity: No significant differences were found between males and females in hip ROM. No significant differences were found between Hispanics and Caucasians in hip ROM. Findings are in agreement with other authors. ▪ Anthropometric and hip ROM measurements: All neonates lacked full hip extension. Lateral rotation was greater than medial rotation. Positive correlations, although not strong, were found between birth weight and birth length, abduction in flexion and medial rotation, and abduction in flexion and lateral rotation: Neonates with greater abduction in flexion tended to have greater medial rotation (r = 0.44; p< 0.0005) and greater lateral rotation (r = 0.44; p< 0.0015). Negative correlations, although weak, were found between birth weight and medial rotation, adduction and ending flexion, adduction and lateral rotation, and adduction and abduction in flexion: Neonates with greater adduction tended to have less ending flexion (r = –0.34; p< 0.008), less lateral rotation (r = -0.43; p< 0.0006) and less adduction in flexion (r = –0.49; p< 0.0001). ▪ Beginning flexion is within the range of other studies. Lateral rotation is within the maximum range reported by other studies and greater than in one study but not clinically significant. ▪ Medial rotation is within the range of other studies. Abduction in flexion is within the range of other studies. ▪ Abduction in extension was not measured in any other neonatal study reviewed. The presence of discrepancies with certain studies may be related to different landmarks, testing positions, the state of alertness of the child at the moment of measurement and the number of subjects.
Authors' Conclusion
▪ Passive ROM of seven hip joint movements was measured in 60 healthy, full-term neonates to determine 95% normal ranges. The method is comprehensive and detailed and thus provides accurate evaluative data. Results of the present data closely support results from other authors who used a similar method.

Comments
▪ The present study was selected among others, based on the quality of the analysis, intra-tester reliability was verified, and in the consistency in presenting the data. Also, the description of the standardized method is excellent. The study was carried out in a meticulous and methodological way. ▪ Internal and external validity (including sample size: *n* = 60) seems good and the use of results as a trend for clinical guidelines is appropriate. ▪ Another study (Schwarze et al. (1993)[35] had a much larger sample population (1000 infants), but the study was not retained due to the lack in the description of the method and results.

3. Hip Flexion Contracture in Infants [9]

Age range: 6 weeks, 3 months and 6 months.

3.1 Clinical Use

- To measure neonatal passive ROM of hip extension limitation and to document age-related changes in the premature child.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

3.2 Measurements

- Hip flexion contracture (Fig. 4.3).

3.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks with the leg in extension:
  - The femoral greater trochanter;
  - The lateral condyle of the femur.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.5.
- Results are compared to the normative reference values in Table 4.6, for flexion contracture.

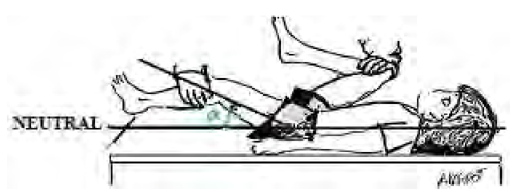
<table>
<tr><th colspan="2">TABLE 4.5. HIP FLEXION CONTRACTURE</th></tr>
<tr><td>Testing Condition</td><td rowspan="4">

Figure 4.3. Method of positioning and clinical determination of hip flexion contracture. (© IRDPQ – 2011).</td></tr>
<tr><td>▪ The child's head is gently held in midline to reduce effects of neonatal reflexes on muscle tone.</td></tr>
<tr><td>Testing Position</td></tr>
<tr><td>▪ Standard Thomas test (Fig. 4.3).
▪ The contralateral hip and knee are flexed to prevent lumbar lordosis.
▪ The tested hip is extended in neutral position.</td></tr>
<tr><td colspan="2">Goniometer Alignment and Measurements</td></tr>
<tr><td colspan="2">▪ The axis of the goniometer is placed on the greater trochanter.
▪ The stationary arm is aligned parallel to the table.
▪ The movable arm is aligned with the lateral condyle of the femur.
▪ The angle formed by the leg aligned with the surface on which the infant is lying is recorded.</td></tr>
</table>

3.4 Normative Reference Values

TABLE 4.6. Mean, range and standard deviation of hip flexion contracture, internal rotation and external rotation at 6 weeks, 3 months and 6 months of age.

	6 WEEKS N=40	3 MONTHS N=40	6 MONTHS N=40
Flexion Contracture			
Mean	19°	7°	7°
Range	6°-32°	1°-18°	-1°-(+16°)
S.D.	6.0°	3.8°	4.2°
Internal Rotation			
Mean	24°	26°	21°
Range	16°-36°	15°-35°	15°-42°
S.D.	5.0°	3.4°	4.3°
External Rotation			
Mean	48°	45°	46°
Range	26°-73°	37°-60°	34°-61°
S.D.	11.0°	4.5°	4.8°

Reprinted with permission from LWW from Coon, V., Donato, G., Houser, C. and Bleck, (1975) Normal Ranges of Hip Motion in Infants Six Weeks, Three Months and Six Months of Age. Clinical Orthopaedic and Related Research, 110, p.257. [9]

3.5 Study Summary

Title: Normal Ranges of Hip Motion in Infants Six Weeks, Three Months and Six Months of Age [9]	
Authors	Coon, V., Donato, G., Houser, C., & Bleck, E. E.
Publication	Clinical Orthopaedics & Related Research, 1975, 110, 256-60.
Purpose of the Study	To establish mean values and normal ranges of hip flexion contracture and rotation in infants during the first six months of life.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hip flexion contracture, range of motion of hip rotations and changes in relation to age.

Methods

Subjects

- The study sample consisted of 80 healthy children (40 ♀, 40 ♂). USA.
- Age: 6 weeks, 3 months and 6 months.
- Subjects were divided into two age groups: Group 1 consisted of 40 children, (19 ♀, 25 ♂), assessed at 6 weeks and at 3 months of age. Group 2 was an independent sample of 40 children, (21 ♀, 19 ♂) assessed at 6 months of age.

Measurements

- All measurements were taken on the left leg based on the fact that there is no difference in joint range between sides in newborns. The head was held in midline to control for possible effects of neonatal reflexes. Three parameters were assessed: ROM of hip lateral rotations (HLR), hip medial rotations (HMR) and hip flexion contracture (HFC). Three measurements for each ROM were taken by the same evaluator while another clinician stabilized other joints and posture.
- In addition, a Polaroid photograph was taken as a visual record of the measurements.
- Testing position was standardized in supine and in prone.
- Instrumentation: Standard goniometer.

Data Analysis

- Mean, range and standard deviations (SD) were calculated for each joint motion and for the three age groups. Match pair *t* test and Pearson Correlations were calculated.

Results

Psychometric Properties: Non applicable.

- There were no statistically significant differences between genders. For all subjects, mean values for HLR were twice greater than HMR.
- All three parameters were most variable at 6 weeks of age. HLR were more variable than HFC or HMR in each group.

3.5 Study Summary (Continued)

Results
HFC ▪ Matched paired *t*- test results indicated a decrease in HFC from 6 weeks to 3 months that is highly significant (p<0.001). Independent two sample mean *t*- test showed no significant decrease from 3 months to 6 months. **Hip Rotations** ▪ Matched paired *t*- test indicated no significant change in HLR and HMR between 6 weeks to 3 months. Independent two samples mean *t*- test showed a significant decrease in HMR from 3 months to 6 months (p< 0.001). ▪ Pearson Correlations on group 1 indicated that subjects who lost the greatest amount of flexion contracture between 6 weeks to 3 months tended to have a decrease in range of HMR (r = +.44, p =0.005). No other correlations were found to be significant. ▪ Results of no differences between genders are consistent with other studies. Decrease of HFC seems to decrease more slowly than what was reported by other authors. Hip rotations results are consistent with many other studies and in disagreement with two studies. Authors explain their results with description of embryological development and in utero position.

Authors' Conclusion
▪ In the present study: HFC, HMR and HLR data are reported in 40 infants at 6 weeks and 3 months and in an independent sample of 40 infants at 6 months of age. ▪ A mean HFC of 19° was present at 6 weeks of age de creasing to 7° by 3 months but still present at 6 months suggesting that forceful extension of the hip in infants may be contraindicated. ▪ HFC decreases from 6 weeks to 3 months. HLR is greater than HMR. It would appear that HMR greater than HLR, before the age of 6 months, is contrary to normal development and may indicate further examination to rule out abnormality. ▪ There is a significant decrease in medial rotation from 3 months to 6 months.

Comments
Internal and external validity (including sample size: n = 40 in each group) seems good and the use of results as a trend for clinical guidelines is appropriate.

4. Hip Flexion Contracture in Children [5]

Age range: 18 months to 19 years (male subjects).

4.1 Clinical Use

- To measure neonatal passive ROM of hip extension limitation and to document age-related changes.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

4.2 Measurements

- Hip flexion contracture.

4.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the traditional anatomical landmarks:
  - The femoral greater trochanter;
  - The lateral epicondyle of the femur.

TEST

- Method: American Academy of Orthopaedic Surgeons method which refers to the neutral zero procedure. [51]
  - Zero starting position in supine (Fig. 4.4).
  - Both lower extremities are brought in flexion (Fig. 4.5).
  - The tested hip is allowed to drop in extension. The angle formed by the leg aligned with the surface on which the infant is lying is recorded (Fig. 4.6).

- Results are compared to the normative reference values in Table 4.7.

Figure 4.4. Zero starting position: Non tested hip held in full flexion. (© IRDPQ – 2011).
This flattens the lumbar spine and indicates a flexion deformity, if present.

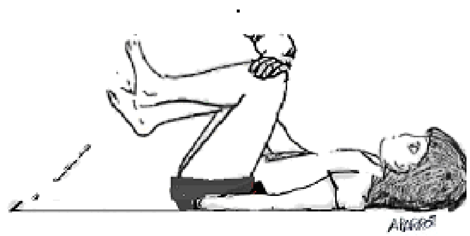


Figure 4.5. Both lower extremities are brought in flexion. (© IRDPQ – 2011).
The tester places one hand on the iliac crest to feel the point where the pelvis begins to rotate.

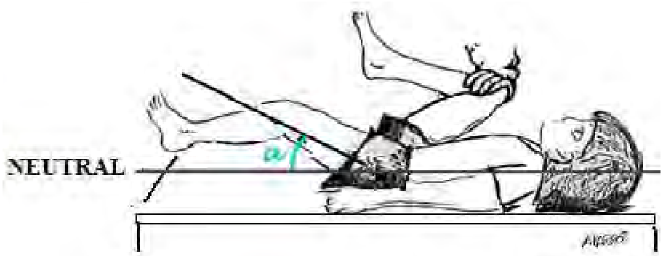


Figure 4.6. Clinical determination of hip flexion contracture.(© IRDPQ – 2011).

4.4 Normative Reference Values

TABLE 4.7. MEAN AND STANDARD DEVIATION OF HIP FLEXION CONTRACTURE IN MALE SUBJECTS AGE: 18 MONTHS TO 19 YEARS		
Passive Joint motion	**Mean°**	**SD°**
HFC	3.5	4.3§
§ Significant differences $p < 0.01$: The amount of limited hip extension was greater for children younger than six years compared to older subjects. SD Standard deviation. HFC: Hip flexion contracture. n = 53. All measurements are in degrees°.		

Data from : Boone, D and Azen, S. Normal Range of Motion of Joints in Male Subjects, The Journal of Bone and Joint Surgery, Am., 1979, 61, p.757. [5]

4.5 Medical Guidelines

The presence of hip flexion contracture is physiologically normal in the young child and when values are within the normal ranges, no stretching exercises should be applied or prescribed.

4.6 Study Summary

Title: Normal Range of Motion of Joints in Male Subjects [5]	
Authors	Boone, D. C., & Azen, S. P.
Publication	The Journal of Bone and Joint Surgery, Am. 1979, 61, 756-9.
Purpose of the Study	▪ To determine the amplitudes of active joint motion of the extremities of male subjects. ▪ To analyse the influence of age in these motions.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion of the extremities.

Methods

Subjects

- The study sample consisted of 109 healthy male subjects. USA.
- Age range: 18 months to 54 years.
- Racial population: The majority of subjects were white Americans, 15 were Hispanic, 12 Black and 3 were Oriental.
- Subjects were initially divided into six age groups composed of seventeen to nineteen individuals each. From these six age groups, two age groupings were determined: the younger group (*n* = 53) aged 1 to 19 years and the older group (*n* = 58), aged 20 to 54 years.

Testing Procedures and Instrumentation

- Active motion of the shoulder, elbow, forearm, wrist, hip, knee, ankle and foot, and beginning and ending position were measured by one tester, on both sides in the basic planes. The method was based on the techniques of the American Academy of Orthopaedic Surgeons.
- Instrumentation: Standard goniometer.

Data Analysis

- Average intra-tester reliability was determined as measured by the SD of measurements at 4 weekly sessions. Mean and standard deviation (SD) were calculated. Initially, analyses was performed separately for the six age groups: one to five-years old, six to twelve, thirteen to nineteen, twenty to twenty-nine, thirty to thirty-nine, and forty-two to fifty-four years old. Paired t tests were used to compare the motions between the left and right sides. Finally, two sample t tests were performed for two age groupings: one to nineteen and twenty to fifty-four -years old. The 0.01 level (or below) was selected as the criterion of statistical significance.

Results

- **Psychometric Properties**: Non applicable.
- Average intra-tester reliability had a mean SD of 1.0 degree for all joint motions.
- The SD of measurement error attributable to the goniometer was 3.7 degrees.

Comparison of ROM Between Sides

Few motions showed significant differences between left and right sides :

- In the 6 to 12 years old: shoulder horizontal flexion on the right side was greater than on the left ($p < 0.001$); backward extension was greater on the left side than on the right ($p < 0.01$);
- In the 20 to 29 years old: shoulder backward extension and elbow flexion were greater on the left side ($p < 0.01$). Foot eversion was greater on the left side ($p < 0.001$);
- No consistent pattern was noted, thus left and right motions were averaged for analysis.

4.6 Study Summary (Continued)

Results
Differences Between ROM and Age
Since the study is based on cross-sectional data from groups of subjects of various ages, the authors report that they can only infer that differences in motions between children and adults are related to age. Analyses of variance revealed significant differences between the two age groups for most motions ($p < 0.01$):
▪ Shoulder joint motion: the greatest difference was backward extension and outward rotation;
▪ Elbow joint motion: hyperextension was possible for younger subjects and gradually decreased with age. ROM in elbow flexion and supination was less in the older age group;
▪ The inability to assume a zero starting position of knee flexion (complete extension) was present in the younger subjects;
▪ The inability to assume a zero starting position of hip flexion (complete extension) was present in the younger subjects and evident in some of the adults;
▪ The amplitudes of most hip motions are markedly different between the younger and the older groups;
▪ The findings are consistent with other studies.
Authors' Conclusion
▪ The amplitudes of motion of the left and right joints were consistently similar, therefore the healthy limb can be routinely used for means of comparison.
▪ Normal limits for ROM of the extremities were calculated in two age groups for male subjects and will be helpful when a bilateral deficit is present or suspected.

Comments
▪ Internal and external validity seems good and the use of results as a trend for clinical guidelines is appropriate. However, the number of subjects per age-groups is small (n = 17 to 19) and data should be interpreted with caution.
▪ Generalization of the results for female subjects may be challenged.
▪ There is a paucity of research concerning the normal ROM in the pediatric population. To the best of our knowledge, the present study is the only one that reports normative values for mostly all active motions in all joints for the pediatric population. However, the age range for the pediatric population is wide (1 to 19 years) making the data maybe less discriminant for the very young individuals.

Knee Flexion Contracture

Summary

Measurement of the knee joint motion is used clinically to assess joint disability or various medical conditions (neuromuscular diseases, postural abnormalities…) [24, 44] and, to assess if there is joint motion limitation, the comparison between sides is usually appropriate. [49]

Limitation of knee extension is physiologically normal in infants and children. [44 32] This limitation is greater in newborns with increased gestational age, the greatest limitation being noted in the full-term neonates. [32] In children without disabilities, it is observed that the range of motion gradually increases during the first six months. [24]

As mentioned previously, the term “contracture” usually refers to a pathological condition, which is not the case in children [9] when limitation of knee extension is within the normal limits. Since the term “contracture” is often used in the literature to describe knee flexion contracture (KFC), the same term will be used throughout this chapter for purposes of consistency.

KFC angle is usually measured by calculating the amount of knee extension limitation, with the hip extended. Compared to other measurements in children (unimpaired and mild spastic diplegia), knee extension measurement was reported as presenting the most reliable inter-sessional measures (along with the Thomas test) in both populations and mostly when limitation was present in small degrees. [24]

Three studies were selected to document KFC in:

- Newborns - Waugh et al.-1983; [44]
- Newborns and Infants - Reade et al.-1984; [32]
- Children - Boone et al. -1979. [5]

The first two studies [44, 32] use the same testing position but differ slightly in the alignment of the goniometer. The population sample is larger in the former study (n = 40) [44] compared to the latter (n = 10) [32] in each age group. Testing procedures and sample size may explain the difference in the data when comparing the normative reference values.

5. Knee Flexion Contracture in the Newborn [44]

Age range: 6 to 65 hours.

5.1 Clinical Use

- To measure neonatal passive ROM of knee extension limitation.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

5.2 Measurements

- Knee flexion contracture (Fig. 4.7).

5.3 Testing Procedures

REQUIRED EQUIPMENT

- Clear plastic 360° goniometer. Arms are shortened to 2 inches (5 cm).
- In the present study, a warm examination table was used.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

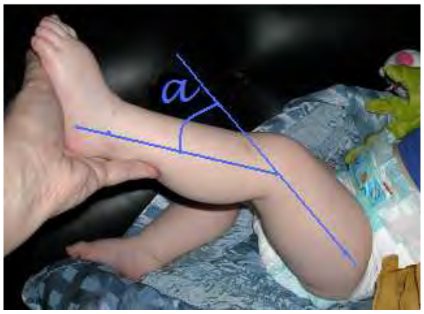
PRE-TEST

- Mark the following anatomical landmarks:
  - The femoral greater trochanter;
  - The lateral femoral condyle;
  - The lateral malleolus.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.8.
- Results are compared to the normative reference values in Table 4.9.

TABLE 4.8. KNEE FLEXION CONTRACTURE

Testing Condition	 **Figure 4.7. Knee extension limitation with hip in available extension.** (© IRDPQ – 2011).
▪ The child must be kept in a relaxed state. ▪ The head is gently held in midline to reduce effects of neonatal reflexes on muscle tone.	
Testing Position	
▪ Supine ▪ The tested hip is maintained in maximum extension and neutral position. The knee is passively extended.	
Goniometer Alignment and Measurements	
▪ The axis is placed at the lateral femoral condyle. ▪ The stationary arm is aligned with the greater trochanter of the femur. ▪ The movable arm is aligned with the lateral malleolus of the fibula. ▪ The angle (the lack of full passive knee extension with the hip in available extension) is recorded (Fig. 4.7).	

5.4 Normative Reference Values

TABLE 4.9. MEAN AND STANDARD DEVIATION OF KNEE FLEXION CONTRACTURE§ IN NEWBORNS AGE: 6 TO 65 HOURS		
Passive Joint Motion	**Mean°**	**SD°**
KFC	15.3§	9.9
§: Values represent the lack of full passive knee extension with the hip in available extension (Fig. 4.7). SD: Standard deviation. KFC: Knee flexion contracture. n = 40. All measurements are in degrees°.		

Data from: Waugh, Minkel, Parker, and Coon, (1989) p. 1619. [44]

5.5 Study Summary

Title: Measurement of Selected Hip, Knee and Ankle Joint Motions in Newborns [44]	
Authors	Waugh, K. G., Minkel, J. L., Parker, R., & Coon, V. A.
Publication	Physical Therapy, 1983, 63, 1616-21.
Purpose of the Study	To provide clinically useful mean values in joint motions in healthy newborns. To determine if any relationships exist between different joint motions in the lower extremities.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion in the lower limbs.

Methods

Participants
The study sample consisted of 40 unimpaired, full-term newborns (22♀; 18 ♂). USA.
Age range: 6 to 65 hours.

Testing Procedures and Instrumentation

- Passive range of motion (PROM) of hip extension, knee extension, ankle plantar flexion, ankle dorsiflexion and the popliteal angle (PA) were measured 3 times.
- Measurements were taken from the left leg since no significant differences between sides were reported in previous studies in newborn infants. Testing position was standardized in supine. All measurements were taken by the same tester while another stabilized the child in each position. The head was held in midline to control for possible effects of neonatal reflexes.
- Instrumentation: Standard goniometer (modified to accommodate the short limbs of the infants).

Data Analysis

- Mean, standard deviation and range of motion were calculated from the 3 independent measurements of each motion. Pearson correlation coefficients were computed to examine potential relationships between each of the five motions. Results were judged to be significant when $p \leq .05$.

Results

Psychometric Properties: Non applicable.

- All the values obtained from the three independent measurements of each motion were within ± 5 degrees of each other. Norms (mean and standard deviation) of lower extremity motions (n = 40) are presented therein. All subjects lacked complete hip extension. The PA showed the greater amount of variation. All subjects, except one, had some degree of knee extension limitation and greater range of dorsiflexion than plantar flexion. In 75% of the subjects, dorsiflexion was twice as great as plantar flexion.
- Authors report that the results in hip flexion contracture are in disagreement with other studies and might have been caused by variations in positioning techniques and in the interpretation of the end range.
- Results are consistent with other reports for knee extension limitation and for plantar and dorsiflexion ROM.

5.5 Study Summary (Continued)

Authors' Conclusion
▪ Every infant, except one, lacked full extension at both the hip and the knee. PROM will gain in amplitude with neuro-developmental maturation. Plantar flexion was generally limited, but dorsiflexion was unlimited. ▪ Pearson correlation coefficients indicated that infants with greater dorsiflexion tended to have less plantar flexion, and infants with a greater limitation of knee extension measured with the hip extended tended also to have a smaller PA.

Comments
▪ Internal and external validity (including sample size, *n* = 40) seems good and the use of results as a trend for clinical guidelines is appropriate. ▪ Reference values for knee extension limitation and PROM of the ankle were selected. For hip ROM, another study (Forero et al. - 1989) was selected since it presented a larger sample size. The PA measurements were excluded, based on the testing position used, in which the hip was maximally flexed on the abdomen. It is reported that the testing position with the hip flexed at 90° is more accurate since it is not affected by abdominal bulk. [26, 32]

6. Knee Flexion Contracture in Newborns and Infants [32]

Age range: Newborns (1-2 or 3 days after birth) and from 1 to 12 months.

6.1 Clinical Use

- To measure infants' passive ROM of knee extension limitation annd document age-related changes.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

6.2 Measurements

In the present study, the amount of knee extension limitation with the hip extended is defined as the ''Heke (**H**ip **e**xtension, **k**nee **e**xtension) angle'' and indicates capsular joint restrictions. [32]

6.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard 360° goniometer.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

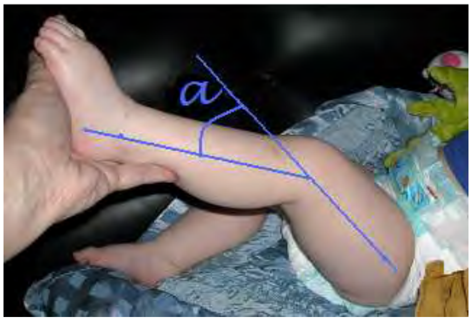
PRE-TEST

- Mark the following anatomical landmarks:
  - The femoral greater trochanter;
  - The lateral side of the knee joint;
  - The lateral malleolus of the fibula.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.10.
- Results are compared to the mean values in Table 4.11 for the HEKE angle.

TABLE 4.10. KNEE FLEXION CONTRACTURE

Testing Condition	 **Figure 4.8. Knee extension limitation with hip in available extension (HEKE angle).** (© IRDPQ – 2011).
▪ The child must be kept in a relaxed awake state. Clothing is removed from the lower extremities.	
Testing Position	
▪ Supine. ▪ The non tested limb is allowed to rest unrestricted on the table. ▪ The pelvis is stabilized. ▪ The hip of the tested limb is maintained in available extension and neutral position. ▪ The knee is passively extended until firm resistance is met. Hold for a few seconds to allow the muscles to accommodate to the stretch then gently extend further and record the angle value.	
Goniometer Alignment and Measurements	
▪ The axis is placed at the knee joint. ▪ The stationary arm is aligned with the greater trochanter of the femur. ▪ The movable arm is aligned with the lateral malleolus of the fibula. The angle (knee extension lacking with the hip extended) is recorded. Fig. 4.8.	

6.4 Mean Values

Note: To obtain complete data (range and standard deviations), the clinician will have to order the article of Reade & al. (1984). [32]

TABLE 4.11. Mean Values° for the Heke Angle in Newborns and in Infants.

Newborn	21.5°
Age in Months	HEKE Mean Angle
1	16.5°
2	15.5°
3	13.5°
4	11.5°
5	8.0°
6	6.0°
7	5.0°
8	0.5°
9	0.5°
10	0.5°
11	0.0°
12	0.0°

n = 10 /each age-group

Data from: Reade E., Hom L., Hallum A. & Lopopolo R. (1984) p. 777. [32]

6.5 Study Summary

Title: Changes in Popliteal Angle Measurement in Infants up to One Year of Age [32]	
Authors	Reade, E., Hom, L., Hallum, A., & Lopopolo, R.
Publication	Developmental Medicine and Child Neurology, 1984, 26, 774-80
Purpose of the Study	To determine trends in the changes of the popliteal angle (PA) in normal infants up to the age of 12 months.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of knee extension limitation.

Methods

Participants
- The study sample consisted of 130 infants (61♀, 69♂). USA.
- Infants were grouped by monthly age into 13 groups consisted of 10 subjects in each group.
- Newborns were tested at 1-2 or 3 days after birth. The other children were assessed on their monthly anniversary.
- Age range:1 day to 12 months.

Testing Procedures and Instrumentation
- Angle measurements were taken on the left lower extremity (arbitrarily selected). Popliteal angle (PA) and Heke angle (HA) were measured by the same examiner. The PA measures hamstring tightness and the HA measures capsular joint restrictions.
- Data was collected by two testers. One performed all measurements and the other extended the knee and assured stabilization techniques.
- Testing position was standardized in supine.
- Instrumentation: Goniometer. A positioning apparatus was used to maintain hip flexed at 90°.

Data Analysis
- Mean, standard deviation and range of the HA and PA were calculated.
- Linear regression analysis was used to test the significance of the correlation between age and mean HA and PA.

Results

- **Psychometric Properties:** Non applicable.
- There was a highly significant negative correlation between age and the PA and the HA.
- Mean and standard deviations for PA and HA were calculated in 130 children up to one year of age.
- PA: 90% of all infants between 8 and 12 months had no hamstring tightness. PA decreases with age and is not seen in most infants by 8 months of age.
- HA: 94% of all infants between 8 and 12 months had a Heke angle of 0 degree. HA decreases in a similar pattern.

Authors' Conclusion

- There is a gradual decline in limitation of knee extension by 8 months of age. Continued resistance to knee extension could indicate an underlying medical disorder.
- Results of this study provide normative data that will be helpful to clinicians when assessing knee joint limitation in the screening of possible neuromuscular problems.

Comments

Internal validity seems good. However sample size is small in each age group (n =10) and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution.

7. Knee Flexion Contracture in Children [5]

Age range: 18 months to 19 years (male subjects).

7.1 Clinical Use

- To measure infants' passive ROM of knee extension limitation.
- To screen infants who are at risk for neurological or musculoskeletal disorders.

7.2 Measurements

- Knee flexion contracture.

7.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following traditional anatomical landmarks:
  - The femoral greater trochanter;
  - The knee joint;
  - The lateral malleolus of the fibula.

TEST

- Method: American Academy of Orthopaedic Surgeons method which refers to the neutral zero procedure[51]. The child lies supine, the tested hip extended in available extension (Fig. 4.8).
- Results are compared to the normative reference values in Table 4.12.

7.4 Normative Reference Values

TABLE 4.12. MEAN AND STANDARD DEVIATION OF KNEE FLEXION CONTRACTURE IN MALE SUBJECTS AGE: 18 MONTHS TO 19 YEARS

Passive Joint Motion	Mean°	SD°
KFC	2.1	3.2§

§ Significant differences $p < 0.01$: The amount of limited knee extension was greater for children younger than six years compared to older subjects. SD: Standard deviation. KFC: Knee flexion contracture . All measurements are in degrees°: n = 53.

Date from : Boone, D and Azen, S. (1979) Normal Range of Motion of Joints in Male Subjects, The Journal of Bone and Joint Surgery, Am., 61, p.757. [5]

7.5 Medical Guidelines

- The presence of knee flexion contracture is physiologically normal in the young child and when values are within the normal ranges, no stretching exercises should be applied or prescribed.

7.6 Study Summary

Title: Normal Range of Motion of Joints in Male Subjects [5]	
Authors	Boone, D. C., & Azen, S. P.
Publication	The Journal of Bone and Joint Surgery, Am., 1979, 61, 756-9.
Purpose of the Study	▪ To determine the amplitudes of active joint motion of the extremities of male subjects. ▪ To analyse the influence of age in these motions.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Quantification of range of motion of the extremities.

Methods

Subjects

- The study sample consisted of 109 healthy male subjects. USA.
- Age range: 18 months to 54 years.
- Racial population: The majority of subjects were white Americans, 15 were Hispanic, 12 Black and 3 were Oriental.
- Subjects were initially divided into six age groups composed of seventeen to nineteen individuals each. From these six age groups, two age groupings were determined: the younger group (*n* = 53) aged 1 to 19 years and the older group (*n* = 58), aged 20 to 54 years.

Testing Procedures and Instrumentation

- Active motion of the shoulder, elbow, forearm, wrist, hip, knee, ankle and foot, and beginning and ending position were measured by one tester, on both sides in the basic planes. The method was based on the techniques of the American Academy of Orthopaedic Surgeons.
- Instrumentation: Standard goniometer.

Data Analysis

- Average intra-tester reliability was determined as measured by the SD of measurements at 4 weekly sessions. Mean and standard deviation (SD) were calculated. Initially, analyses was performed separately for the six age groups: one to five-years old, six to twelve, thirteen to nineteen, twenty to twenty-nine, thirty to thirty-nine, and forty-two to fifty-four years old. Paired t tests were used to compare the motions between the left and right sides. Finally, two sample t tests were performed for two age groupings: one to nineteen and twenty to fifty-four -years old. The 0.01 level (or below) was selected as the criterion of statistical significance.

Results

- **Psychometric Properties**: Non applicable.
- Average intra-tester reliability had a mean SD of 1.0 degree for all joint motions.
- The SD of measurement error attributable to the goniometer was 3.7 degrees.

Comparison of ROM Between Sides

Few motions showed significant differences between left and right sides :

- In the 6 to 12 years old: shoulder horizontal flexion on the right side was greater than on the left ($p < 0.001$); backward extension was greater on the left side than on the right ($p < 0.01$);
- In the 20 to 29 years old: shoulder backward extension and elbow flexion were greater on the left side ($p < 0.01$). Foot eversion was greater on the left side ($p < 0.001$);
- No consistent pattern was noted, thus left and right motions were averaged for analysis.

7.6 Study Summary (Continued)

Results (Continued)
Differences Between ROM and Age Since the study is based on cross-sectional data from groups of subjects of various ages, the authors report that they can only infer that differences in motions between children and adults are related to age. Analyses of variance revealed significant differences between the two age groups for most motions ($p < 0.01$): ▪ Shoulder joint motion: the greatest difference was backward extension and outward rotation; ▪ Elbow joint motion: hyperextension was possible for younger subjects and gradually decreased with age. ROM in elbow flexion and supination was less in the older age group; ▪ The inability to assume a zero starting position of knee flexion (complete extension) was present in the younger subjects; ▪ The inability to assume a zero starting position of hip flexion (complete extension) was present in the younger subjects and evident in some of the adults; ▪ The amplitudes of most hip motions are markedly different between the younger and the older groups; ▪ The findings are consistent with other studies.
Authors' Conclusion
▪ The amplitudes of motion of the left and right joints were consistently similar, therefore the healthy limb can be routinely used for means of comparison. ▪ Normal limits for ROM of the extremities were calculated in two age groups for male subjects and will be helpful when a bilateral deficit is present or suspected.

Comments
▪ Internal and external validity seems good and the use of results as a trend for clinical guidelines is appropriate. However, the number of subjects per age-groups is small (n = 17 to 19) and data should be interpreted with caution. ▪ Generalization of the results for female subjects may be challenged. ▪ There is a paucity of research concerning the normal ROM in the pediatric population. To the best of our knowledge, the present study is the only one that reports normative values for mostly all active motions in all joints for the pediatric population. However, the age range for the pediatric population is wide (1 to 19 years) making the data maybe less discriminant for the very young individuals.

Hamstring Tightness Assessment

Summary

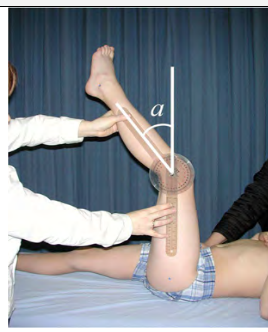
Different tests are clinically used to assess hamstring tightness in children: The popliteal angle (PA), the popliteal complementary angle (PCA) and the straight leg raise (SLR) test.

THE POPLITEAL ANGLE AND THE POPLITEAL COMPLEMENTARY ANGLE

Both measurements are clinical indicators of gestational maturity in the neonatal period [23, 26] and are considered to be a red flag for neuromuscular implications in the presence of excessive tightness. [26,32] Clinically, the PA is among one of the most popular methods for assessing hamstring tightness in children. [23, 26, 32]

RELIABILITY

Reliability scores differ between studies. A summary of selected studies is presented in the ''up to date'' section at the end of the references' pages.
Difficulties can arise when consulting data in the literature since the definition of the PA differs between studies. The meaning of the terms used in this chapter is presented in Table 4.13. Knowledge of these differences is important when the results are compared to the normative values.

TABLE 4.13. DEFINITION OF THE POPLITEAL ANGLE AND THE POPLITEAL COMPLEMENTARY ANGLE			
The PA is the measurement of the angle that the tibia subtends with the extended line of the femur when the hip is flexed and the knee extended. The degree of lack of full knee extension is the PA. [23, 32]	 **Figure 4.9. The popliteal angle.** (© IRDPQ-2008).	The PCA is the measurement of the angle subtended of the popliteal surface by the long axis of the tibia with the femur, when the hip is flexed and the knee extended.	 **Figure 4.10. The popliteal complementary angle.** (© IRDPQ-2008).

Two studies using the PA were selected to document hamstring tightness in:

- Infants - Reade et al. (1984); [32]
- Children, 1 year to 10 years - Katz et al. (1992). [23]

One study [26] using the PCA was selected to document hamstring tightness,(though the authors of the study refer to this angle as the PA). Kuo et al (1997) [26] present normative data in infants and children, 2 weeks to 16 years.

All three studies [23, 26, 32] measure hamstring tightness in the positioning of the pelvo-femoral angle to 90° (Figures 4.9 and 4.10). This position is reported to be a more accurate method than others since measurements are not affected by abdominal bulk. [26, 32]

THE STRAIGHT LEG RAISE TEST

The SLR test in this work is used to assess hamstring tightness and no other medical conditions. It is considered a sensitive test during the child's growth and minimal difference between sides would suggest further investigation. [26]
One study using the SLR test was selected to document hamstring tightness in infants and children, 2 weeks to 16 years - Kuo et al. (1997). [26]

8. The Popliteal Angle

Age range:

- Newborns to 12 months; [32]
- 1 year to 10 years. [23]

8.1 Clinical Use

- In infants, the popliteal angle (PA) is an indicator of gestational age. [23, 26, 32]
- In children with cerebral palsy the PA is used to assess high muscle tone in the hamstring muscle and contracture. [23, 32]
- Hamstring tightness in a "healthy" child might be an indication to observe the child for other signs of neuromuscular pathology. [32]

8.2 Measurements

- The degree of lack of full knee extension is measured in the positioning of the pelvo-femoral angle to 90° (Fig. 4.11).

8.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks:
  - Axis of the knee joint;
  - Greater trochanter;
  - Lateral malleolus.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.14.
- Results are compared to:
  - **A.** The mean values in in Table 4.15 for newborns and infants; [32]
  - **B.** The normative reference values in Figure 4.14 for children 1 year to 10 years. [23]

TABLE 4.14. POPLITEAL ANGLE

Testing Condition

- The child has to be in a relaxed awake state.
- Two testers are needed: One tester takes the measurements and the other extends the knee and assures standard stabilization techniques (not shown).

Testing Position

- Supine, the pelvis is stabilized.
- The contraleteral limb rests unrestricted on the table. [23, 32]
- The tested hip and knee are flexed to 90° in neutr al position (Fig. 4.11).

Goniometer Alignment and Measurements

- The axis is centered over the knee joint.
- The stationary arm is aligned with the greater trochanter.
- The movable arm is aligned with the lateral malleolus.
- The hip must be kept at an angle of 90°. To avoid stretch reflex response [23], slowly extend the knee to point of mild resistance:
  - For the age range from birth to 12 months, the authors held the position a few seconds to allow the muscle to accommodate to the stretch, and then gently extended the knee further, without causing pain; [32]
  - For the age range 1 year to 10 years, the authors did not further extend the knee, to avoid producing pain. [23]
- The angle is recorded as shown in Figure 4.12.

Figure 4.11. Starting position and goniometer alignment. (© IRDPQ - 2008).

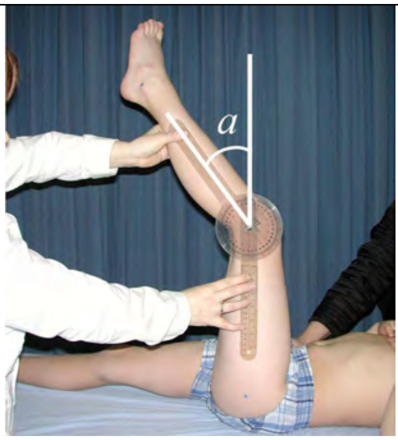


Figure 4.12. End position and clinical determination of the PA. (© IRDPQ - 2008).

8.4 - A . Mean Values (newborn to 12 months)

Note: To obtain complete data (range and standard deviations), the clinician will have to order the article of Reade et al.-1984. [32]

TABLE 4.15 MEAN VALUES° FOR THE PA IN NEWBORNS AND IN INFANTS.

Newborn	27.0°
Age in months	Mean angle
1	24.5°
2	23.5°
3	18.0°
4	19.0°
5	15.0°
6	10.5°
7	6.5°
8	1.5°
9	1.5°
10	0.5°
11	0.0°
12	0.0°
n = 10 /each age-group.	

Data from : Reade E, Hom L, Hallum A, Lopopolo R. p. 777. [32]

Figure 4.13. Clinical determination of the PA. *a* = the degree of lack of full knee extension.
(© IRDPQ - 2008).

8.4 – B. Normative reference values (1 year to 10 years)

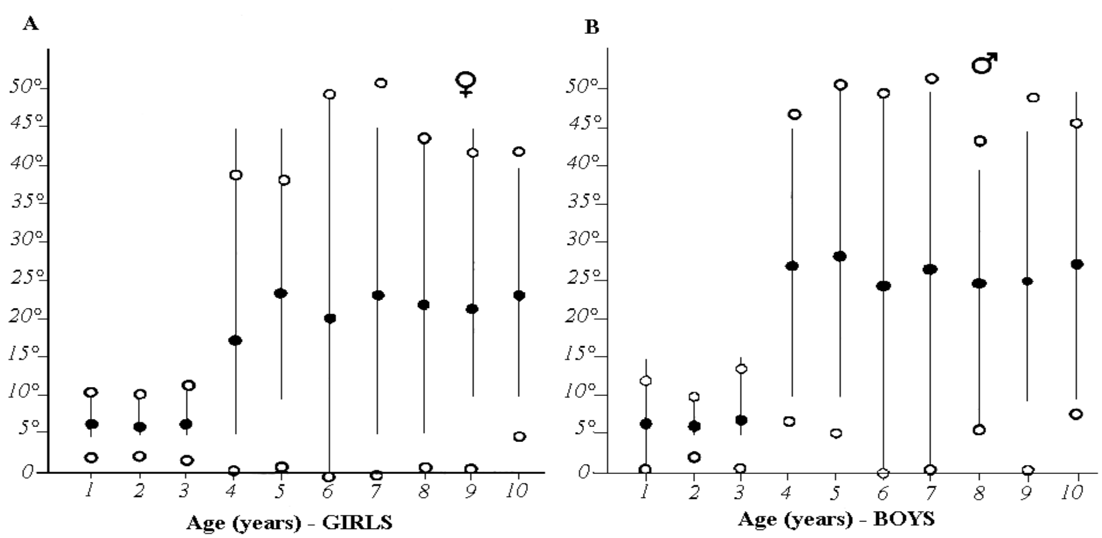


Figure 4.14. The measurements of popliteal angles are plotted as the mean values plus or minus two standard deviations for each age groups.
The solid lines show ranges, the solid circles the mean, and the open circles, plus or minus two standard deviations.. A: girls; B: boys. Total sample: 482 healthy children

Reprinted with permission from LWW from Katz K, Rosenthal A, Yosipovitch Z. Normal Ranges of Popliteal Angle in Children, Journal of Pediatric Orthopaedics, 1992, 12, p. 230. [23]

8.5 Clinical Practice Guidelines

- In children aged 12 months or less: [32]
  - There is a highly significant relationship between age and degree of limitation of knee extension in "normal" children.
- In children aged between 1 year and 10 years: [23]
  - A popliteal angle < 50° does not interfere with nor mal gait and should be regarded as a normal angle in children;
  - A popliteal angle ≥ 50° indicates a significant hamstring shortening.

8.6 Study Summary

Title Changes in Popliteal Angle Measurement in Infants up to One Year of Age [32]	
Authors	Reade, E., Hom, L., Hallum, A., & Lopopolo, R.
Publication	Developmental Medicine and Child Neurology, 1984, 26, 774-80
Purpose of the Study	To determine trends in the changes of the popliteal angle (PA) in normal infants up to the age of 12 months.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Hamstring tightness assessment.

Methods

Subjects
- The study sample consisted of 130 infants (61♀, 69♂). USA.
- Age range: 1 day to 12 months.
- Infants were grouped by monthly age into 13 groups. Number of subjects per age group was 10. Newborns were tested at 1-2 or 3 days after birth. The other children were assessed on their monthly anniversary.

Testing Procedures and Instrumentation
- Angle measurements were taken on the left lower extremity (arbitrarily selected).
- Popliteal angle (PA) and Heke angle (HA) were measured by the same examiner. The PA measures hamstring tightness and the HA measures capsular joint restrictions.
- Data was collected by two testers: One performed all measurements and the other extended the knee and assured stabilization techniques.
- Testing position was standardized in supine.
- Instrumentation: Goniometer. A positioning apparatus was used to maintain the hip flexed at 90°.

Data Analysis
- Mean, standard deviation and range of the HA and PA were calculated.
- Linear regression analysis was used to test the significance of the correlation between age and mean HA and PA.

Results

- **Psychometric Properties:** Non applicable.
- There was a highly significant negative correlation between age and the PA and the HA.
- Mean and standard deviations for PA and HA were calculated in 130 children up to one year of age.
- PA: 90% of all infants between 8 and 12 months had no hamstring tightness. PA decreases with age and is not seen in most infants by 8 months of age.
- HA: 94% of all infants between 8 and 12 months had a Heke angle of 0 degree. HA decreases in a similar pattern.

Authors' Conclusion

There is a gradual decline in limitation of knee extension by 8 months of age. Continued resistance to knee extension could indicate an underlying medical disorder.
Results of this study provide normative data that will be helpful to clinicians when assessing knee joint limitation in the screening of possible neuromuscular problems.

Comments

Internal validity seems good. However sample size is small in each age group (n =10 per age group) and the use of results as a trend for clinical guidelines is appropriate but must be interpreted with caution.

8.7 Study Summary

Title: Normal Ranges of Popliteal Angle in Children [23]	
Authors	Katz, K., Rosenthal, A., & Yosipovitch, Z.
Publication	Journal of Pediatric Orthopaedics, 1992, 12, 229-31.
Purpose of the Study	To investigate the range of the popliteal angle in children.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hamstring tightness.

Methods

Subjects

- The study sample consisted of 482 healthy children (211♀, 271♂). Israël.
- Age range: 1 year to 10 years.
- Children were divided into 10 groups based on chronological age. Each group consisted of 22 to 76 children.

Testing Procedures and Instrumentation

- For each child, the average Popliteal angle (PA) was measured for both limbs and testing position was standardized in supine.
- Instrumentation: Standard goniometer.

Data Analysis

- Mean and two standard deviations (SD) were calculated for each group. Statistical analysis was performed using the Student *t* test.
- Intra- and inter-examiner variability was assessed according to another study's method for means of comparison.
- Intra-examiner variability was assessed by one author by measuring the PA in three children of various ages, on three separate occasions over a two-week period.
- Inter-examiner variability was assessed by six medical professionals. The PA was measured on the same three children.

Results

- **Psychometric Properties:** Non applicable.
- Intra and inter-examiner variabilities were similar to values reported in other reliability studies. Intra-examiner variability*: Average standard deviations: 2.63°, mean error 1.07°. Inter-examiner variability*: Average standard deviations: 3.16°, mean error 1.29°.
- Mean values and ranges of the PA are age-dependent:
  - In children 1- 3 year olds, mean angle = 6°;
  - In 4 year olds, mean angle = 24° and then the PA remained stable up to 10 years.
- There was no significant difference between boys and girls until the age of 4.
  - At four, there was an abrupt increase in the PA difference between genders ($p < 0.001$) (girls mean PA = 17°, boys mean PA = 27°);
  - At ≥ 5 years, the mean was ~26° with little change up to 10 years of age.

* Intra and inter-examiner variability is not to be interpreted as intra-examiner reliability

8.7 Study Summary (Continued)

Authors' Conclusion
▪ Tightness of hamstring muscles < 50° as expressed by a PA does not interfere with normal gait and an angle < 50° should be considered normal. ▪ Findings of the study support the recommendation that a PA > 40°- 45° is an indication for hamstring lengthening in children with cerebral palsy who have sitting or gait disturbance.

Comments
▪ Internal and external validity, including sample size, seems good and the use of results as a trend for clinical guidelines is appropriate.

9. The Popliteal Complimentary Angle [26]

Age range: 2 weeks to 16 years.

9.1 Clinical Use

- To assess hamstring tightness.
- Hamstring tightness in a "healthy" child might be an indication to observe the child for other signs of neuromuscular pathology. [32]

9.2 Measurements

- The angle subtended of the popliteal surface by the long axis of the tibia with the femur represents the PCA (Fig. 4.17).
- **Note** : in the present study, the authors used the term popliteal angle but, as defined in this document, measured the PCA. The reported angle value will thus be higher.

9.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.

PRE-TEST

- Mark the following anatomical landmarks:
  - Axis of the knee joint;
  - Greater trochanter;
  - Lateral malleolus.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.16.
- Results are compared to the normative reference values in Figure 4.18.

<table>
<tr><th colspan="2">TABLE 4.16. POPLITEAL COMPLIMENTARY ANGLE</th></tr>
<tr><td colspan="2">Testing Condition</td></tr>
<tr><td colspan="2">▪ The child has to be in a relaxed awake state.</td></tr>
<tr><td colspan="2">Testing Position</td></tr>
<tr><td colspan="2">▪ The contralateral leg is held extended on the table.
▪ Neonates and infants with temporary knee flexion contracture are placed at the end of the examination table so that the contralateral hip can extend fully.
▪ The tested hip and knee are flexed to 90° in neutral position (Fig. 4.15).</td></tr>
<tr><td colspan="2">Goniometer Alignment and Measurements</td></tr>
<tr><td colspan="2">▪ The axis is centered over the knee joint.
▪ The stationary arm is aligned with the greater trochanter.
▪ The movable arm is aligned with the lateral malleolus.
▪ The hip must be kept at an angle of 90°.
▪ The knee is extended passively until moderate resistance is met.
▪ The angle subtended on the popliteal surface by the long axis of the tibia with the femur is the PCA (Fig. 4.16).
▪ Two testers are needed: One tester takes the measurements and the other extends the knee and assures standard stabilization techniques (not shown).</td></tr>
<tr><td>
Figure 4.15. Starting position and goniometer alignment. (© IRDPQ - 2008).</td><td>

Figure 4.16. End position and clinical determination of the PCA. (© IRDPQ - 2008).</td></tr>
</table>

9.4 Normative Reference Values

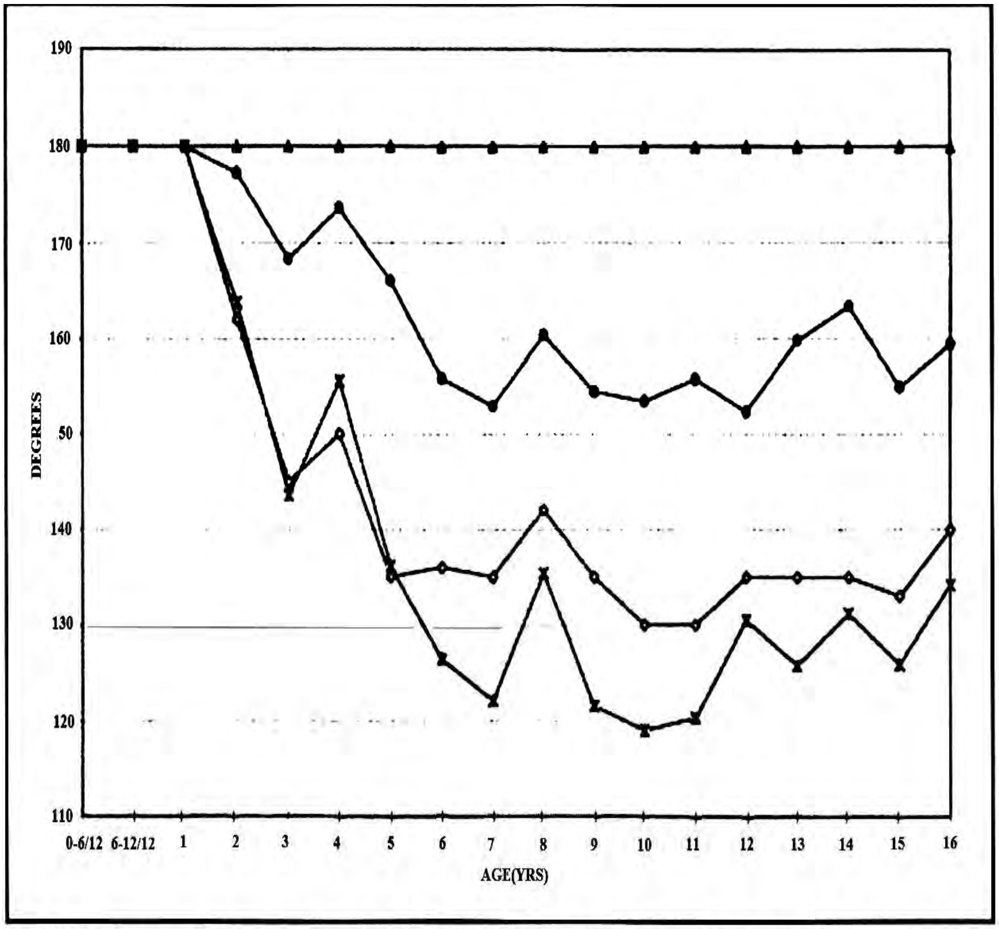


FIG. 4.18.Age versus popliteal angle. • , mean; x, -2SD;[diamond operator],lower range;[black up pointing small triangle], upper range.

Figure 4.17. Clinical determination of the PCA. ***a*** **= the angle subtended of the popliteal surface by the long axis of the tibia with the femur.** (© IRDPQ - 2008).

Reprinted with permission from Kuo., L.,Chung, W., Bates, E. and Stephen, J. (1997) The Hamstring Index. Journal of Pediatric Orthopaedics, 17, p. 6. [26]

Note : * This angle, as defined in this document, is considered the popliteal complimentary angle.

9.5 Clinical Practice Guidelines

- Girls show more flexibility than boys and mean values may be 5° to 10° higher. [26, 32]

9.6 Study Summary

Title: The Hamstring Index [26]	
Authors	Kuo, L., Chung, W., Bates, E., & Stephen, J.
Publication	Journal of Pediatric Orthopaedics, 17, 78-88.
Purpose of the Study	To assess the limits of hamstring tightness by using three common tests. To examine variations between sides, gender, age and puberty. To assess the sensitivity and usefulness of the three methods.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hamstring tightness.

Methods

Subjects

- The study sample consisted of 369 children, (182♀, 187 ♂). Australia.
- Age range: 2 weeks to 16 years.
- Children were divided into 18 groups according to age. Number of subjects varied from 20 to 26 in each age group.
- A total of 738 lower limbs were examined.

Testing Procedures and Instrumentation

- Weight and height, straight leg raise (SLR) test, popliteal angle (PA), toe-touching test (TTT) were measured by the senior author, in standardized positions.
- Instrumentation: Standard goniometer.

Data Analysis

- Intra-tester error, as described in other studies, was measured by performing each test on three subjects on three different occasions.
- The average value of both limbs was used in all measurements.
- Mean, standard deviation and range were calculated for each age group and gender.
- Hamstring tightness was defined when values were > 2 SD from the mean.

Results

Psychometric Properties: Non applicable
The mean intra-examiner error* was < 4° for the PA and SLR. Results are presented therein for each test, according to age.

SLR: From birth to 6 months: Average angle was 100°. Followed an increase to a peak of 110° over the next 12-18 months. SLR then decreased rapidly within 3 years to almost 80° at age 5-6 years, and then remained constant until skeletal maturity.
The 95% confidence limits indicate that children < 2 years with an SLR angle < 80° have excessively tight hamstrings. Left- and right- sided variations are minimal. Girls have more flexibility than boys in all age groups, except in year one. On average, SLR was 5 -10° greater in girls.

PA**= 180° in all children aged < 2 years. Over the next 3- to 4-year period, the mean value decreased, to plateau at 155° by the age of 6 years. Girls have more flexibility than boys with a PA averaging between 5° and 10° in each age group.

TTT: The mean varied little between age groups, staying around 0 cm. But the range and 95% confidence limits varied widely particularly as age increased. Values extended between + 20 cm and - 20 cm in older children. Girls have more flexibility than boys with the increased reach varying between 2 and 4 cm. At puberty, in children between 10-16 years, there was little change in hamstring tightness during adolescence despite rapid growth and hormonal changes.

---

* Intra-examiner variability is not to be interpreted as intra-examiner reliability.
** The definition of the PA in the present study refers to the popliteal complimentary angle.

9.6 Study Summary (Continued)

Authors' Conclusion
▪ SLR and PA are passive tests that are more sensitive of hamstring tightness allowing better examiner control. ▪ TTT is an active test subject to great variability and is not a pure test of hamstring tightness. It is not reliable in children < 3 years and results show wide SD making the test less discriminative. ▪ Girls have less hamstring tightness than boys.

Comments
▪ Internal and external validity, including sample size, (*n* =20 to 26 in each age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

10. Straight Leg Raise Test [26]

Age range: 2 weeks to 16 years.

10.1 Clinical Use

- The straight leg raise (SLR) test is used to assess hamstring tightness and, in neuromuscular disorders, to determine contracture and high muscle tone.
- The presence of tight hamstring muscles in an infant without musculoskeletal dysfunction may be a sign indicating neuromuscular pathology or other medical conditions. [32]

10.2 Measurements

- SLR is the angle subtended between the raised leg and the horizontal plane (Fig. 4.20).

10.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard 360° goniometer.
- Examination table.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks

PRE-TEST

- Mark the following anatomical landmarks:
  - The femoral greater trochanter;
  - The lateral femoral condyle.

TEST

- Testing position, goniometer alignment and measurements are presented in:
  - Table 4.17 for infants with a temporary knee flexion contracture (KFC);
  - Table 4.18 for children with no KFC.
- Results are compared to the normative reference values in Figure 4.21.

TABLE 4.17. SLR IN INFANTS WITH A TEMPORARY KFC

Testing Condition

- The child must be in a relaxed state.
- Two testers are needed: one tester takes the measurements and the other extends the knee and assures standard stabilization techniques (Not shown).

Testing Position

- Supine.
- Neonates and infants are placed at the end of the examination table so that the contralateral hip can fully extend (Fig. 4.19).

Goniometer Alignment and Measurements

- The goniometer is placed on the standard anatomical landmarks:
  - The axis is aligned with the greater trochanter;
  - The stationary arm is parallel with the table top;
  - The movable arm is aligned with the lateral femoral condyle.
- SLR is performed with the knee in as much extension as possible. The angle at which the knee starts to flex further is measured as the end point and recorded as the SLR (Fig. 4.20).

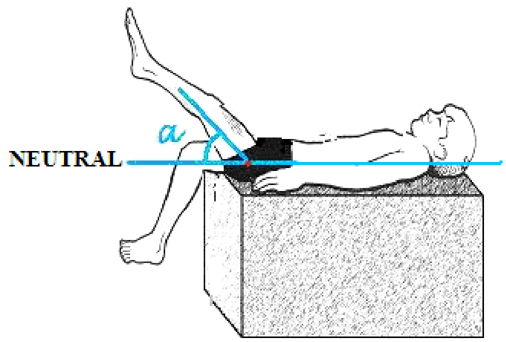


Figure 4.19. Clinical determination of SLR in children with KFC. (© IRDPQ-2008).

TABLE 4.18. SLR IN CHILDREN WITH NO KFC

Testing Condition

- Similar to Table 4.17.

Testing Position

- Supine.
- The contralateral leg is held flat on the examination table.

Goniometer Alignment and Measurements

- The goniometer is placed on the standard anatomical landmarks:
  - The axis is aligned with the greater trochanter;
  - The stationary arm is parallel with the table top;
  - The movable arm is aligned with the lateral femoral condyle.
- The angle at which the knee starts to flex is measured as the end point and recorded as the SLR (Fig. 4.20).

Figure 4.20. Clinical determination of SLR in children with no KFC. (© IRDPQ – 2008).

10.4 Normative Reference Values

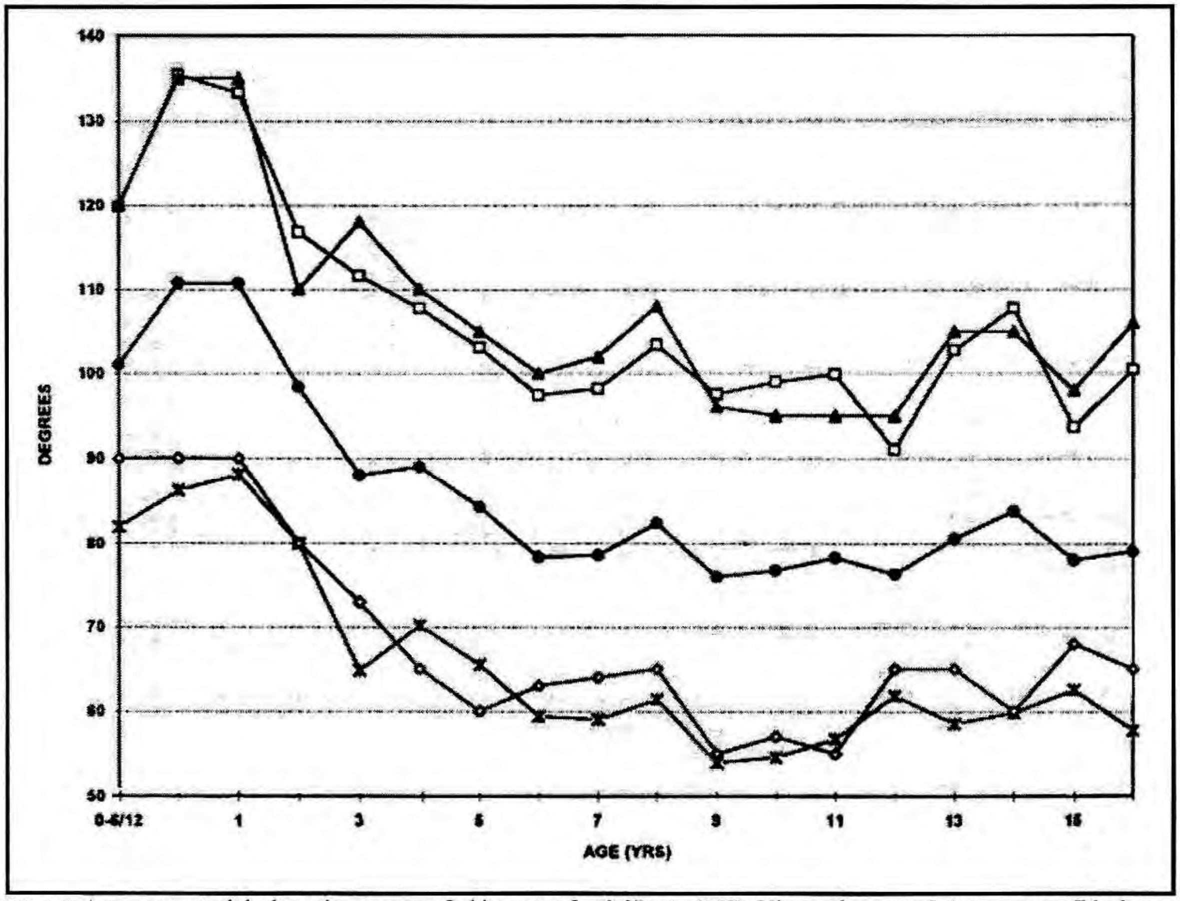


FIG. 4.21. Age versus straight-leg raise. •, mean; [white square], +2 SD; ×, -2 SD; [diamond operator], lower range; [black up pointing small triangle], upper range.

Reprinted with permission from Kuo., L.,Chung, W., Bates, E. and Stephen, J. (1997) The Hamstring Index. Journal of Pediatric Orthopaedics, 17, p. 4. [26]

10.5 Study Summary

Title: The Hamstring Index [26]	
Authors	Kuo, L., Chung, W., Bates, E., & Stephen, J.
Publication	Journal of Pediatric Orthopaedics, 17, 78-88.
Purpose of the Study	▪ To assess the limits of hamstring tightness by using three common tests. ▪ To examine variations between sides, gender, age and puberty. ▪ To assess the sensitivity and usefulness of the three methods.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of hamstring tightness.

Methods

Subjects

- The study sample consisted of 369 children, (182♀, 187 ♂); Australia.
- Age range: 2 weeks to 16 years.
- Children were divided into 18 groups according to age. Number of subjects varied from 20 to 26 in each age group.
- A total of 738 lower limbs were examined.

Testing Procedures and Instrumentation

- Weight and height, straight leg raise (SLR) test, popliteal angle (PA), toe-touching test (TTT) were measured by the senior author, in standardized positions.
- Instrumentation: Standard goniometer.

Data Analysis

- Intra-tester error, as described in other studies, was measured by performing each test on three subjects on three different occasions.
- The average value of both limbs was used in all measurements.
- Mean, standard deviation and range were calculated for each age group and gender.
- Hamstring tightness was defined when values were > 2 SD from the mean.

Results

Psychometric Properties: Non applicable.

*[*]The mean intra-examiner error was < 4° for the PA and SLR. Results are presented therein for each test, according to age.

SLR. From birth to 6 months: Average angle was 100°. Followed an increase to a peak of 110° over the next 12-18 months. SLR then decreased rapidly within 3 years to almost 80° at age 5-6 years, and then remained constant until skeletal maturity.
The 95% confidence limits indicate that children < 2 years with an SLR angle < 80° have excessively tight hamstrings. Left- and right- sided variations are minimal. Girls have more flexibility than boys in all age groups, except in year one. On average, SLR was 5°-10° greater in girls.

[**]**PA**=180° in all children aged < 2 years. Over the next 3-to 4- year period, the mean value decreased, to plateau at 155° by the age of 6 years. Girls have more flexibility than boys with a PA averaging between 5° and 10° in each age group.

TTT. The mean varied little between age groups, staying around 0 cm. But the range and 95% confidence limits varied widely particularly as age increased. Values extended between + 20 cm and – 20 cm in older children. Girls have more flexibility than boys with the increased reach varying between 2 and 4 cm. At puberty, in children between 10-16 years, there was little change in hamstring tightness during adolescence despite rapid growth and hormonal changes.

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[*] Intra-examiner variability is not to be interpreted as intra-examiner reliability.
[**] The definition of the PA in the present study refers to the popliteal complimentary angle.

10.5 Study Summary (Continued)

Authors' Conclusion
▪ SLR and PA are passive tests that are more sensitive of hamstring tightness allowing better examiner control. ▪ TTT is an active test subject to great variability and is not a pure test of hamstring tightness. It is not reliable in children < 3 years and results show wide SD making the test less discriminative. ▪ Girls have less hamstring tightness than boys.

Comments
▪ Internal and external validity, including sample size, (n =20 to 26 in each age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

Rotational Profile in the Lower Extremities

Summary

Rotational problems are common in children and are extremes of a normal developmental pattern [29, 38]. The condition is known to often resolve itself spontaneously. [38] However, they can be associated with developmental disabilities in children and are one of the most common reasons to visit a pediatric orthopedic clinic. [28, 41] Rotational problems may lead to esthetical complaints and children with internal rotations of the lower limbs may present minor functional problems such as frequent tripping. [28] Malau et al. (2007) [46] report in 7-10 year-old children with internal rotations of the lower limbs, lower gait velocity particularly in difficult balance conditions than typically developing children. Also, the development of head stabilization in space in this age group was affected as they adopted an “en bloc” operation of the head – trunk unit instead of the articulated mode systematically demonstrated by a control group. [46]

Rotational complaints in the lower limbs may also be a manifestation of an underlying disorder such as cerebral palsy and hip dysplasia. Before focusing on the rotational problem, the clinician should assess the child for abnormal muscle tone or any other musculoskeletal or neurological signs indicating that a more intensive assessment is needed. [25, 28, 39]

For routine clinical evaluation, a screening test to document the subject’s torsional profile was developed by Dr.Staheli et al. (1985). [38] This method differentiates which factors contribute to the rotational problems and the degree of severity related to them. [38, 28, 57] In-toeing originates from one or more of three sources, the proximal femur (femoral anteversion), the tibia (internal tibial torsion), or the forefoot (metatarsus adductus).

The “Staheli Rotational Profile” (SRP) is a composite of six measurements in the lower limbs. Normative reference values are reported for the first five variables. The assessment usually begins with clinical observation of the child’s gait pattern then progresses from proximal to distal body segments. [10] The six measurements are:

- Foot progression angle (FPA);
- Lateral hip rotation (LHR);
- Medial hip rotation (MHR);
- Thigh foot angle (TFA);
- Transmalleolar axis (TMA);
- Forefoot alignment.

A summary of the six measurements is presented in a clinical chart (Fig. 4.44).

VALIDITY AND RELIABILITY

The validity and intra-rater and inter-rater reliability of TFA and TMA measurements, using the goniometric method described by King and Staheli (1984), [25] was analyzed in 17 normal subjects (3 years to 24 years) and compared to computed tomography (CT). [40] The findings showed that the method is valid and reliable. A significant difference, averaging 5°, between gonio metric and CT torsion measures was found between testers, which is commonly reported as the margin of error for goniometric measurements. The results were also reproducible within an acceptable range (5°). [40]

This clinical method is reported as an accurate assessment tool to provide useful information on rotational alignment of the lower extremities for screening and descriptive purposes. [40, 41, 45] However, measurement error may be higher when measuring children with abnormal muscle tone or other pathology. [40] Also, obtaining reliable goniometric measure on a child can often be a challenge.

The method is challenged by Luchini et al. (1983) [29] reporting a significant variation in estimation of the various torsional components in intra-rater and inter-rater measurements (25° differences for TFA).

For additional information on the rotational profile measurements, refer to the ‘’up to date’’ pages, at the end of the references pages.

11. Foot Progression Angle

Age range: 1 year to 19 years.

11.1 Clinical Use

- The foot progression angle (FPA) is the dynamic assessment of the SRP. This angle is usually estimated by observing the direction of the foot during gait (in-toeing or out-toeing) and indicates the severity of the deformity. [25, 38, 55]
- FPA can be measured by analysing a series of footprints. [10, 25]

11.2 Measurements

- The FPA is the angular difference between the long axis of the foot (Fig. 4.22) and the line of progression during gait. [4, 38] (Table 4.19)
- Clinically, a difficulty can be encountered in this procedure when establishing a precise reference point for the line of progression since children, mostly the young ones, do not walk in a purely straight line.[10]

Figure 4.22. In a "normal" foot, the long axis of the foot is a line that passes from the center of the heel, (heel bisector) through the second and third toe. [4, 10, 35, 48.] (© IRDPQ-2008).

- Expression of values [25, 55]
  - A negative value is given for in-toeing (the long axis of the foot is directed inwardly);
  - A positive value is given for out-toeing (the long axis of the foot is directed outwardly);
  - A neutral value is given if the foot does not turn in or out.

11.3 Testing Procedures

REQUIRED EQUIPMENT

- A protractor.
- A long strip of paper divided in the center by a straight line.
- Powdered chalk.
- Masking tape.

PRE-TEST

- The child's feet are dusted with chalk to obtain a sequence of footprints.
- The walkway is prepared by securing the paper to the floor.

TEST

- Testing position and measurements are presented in Table 4.19.
- Results are compared to the normative reference values in Fig. 4.25. Abnormal FPA is described in terms of in-toeing or out-toeing beyond the normal mean.

TABLE 4.19. FOOT PROGRESSION ANGLE
Testing Position
▪ The child walks along the strip of paper. ▪ Six footprints are used to calculate the average FPA. [10, 38]
Measurements
▪ The angle between the long axis of the foot and the straight line on the paper is measured with a protractor (Fig. 4.23 and 4.24).

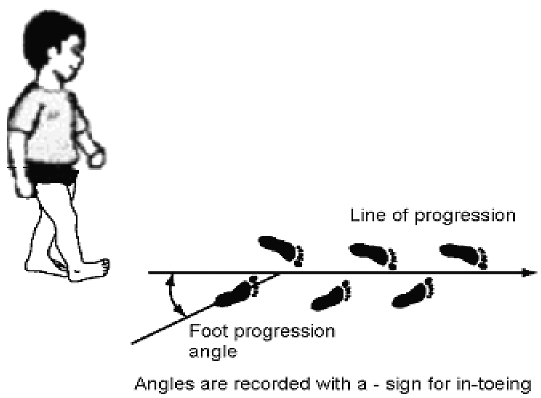

Figure 4.23. Clinical determination of in-toeing. (© IRDPQ-2011).

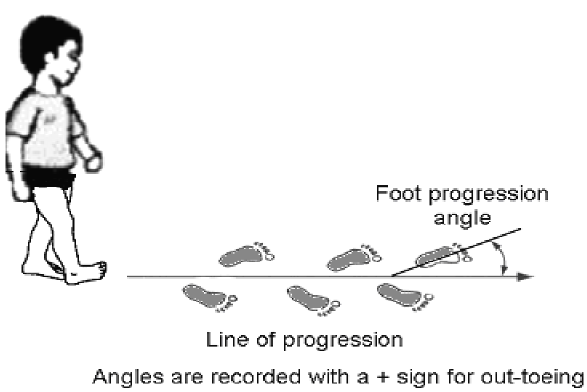

Figure 4.24. Clinical determination of out-toeing. (© IRDPQ-2011).

11.4 Normative Reference Values

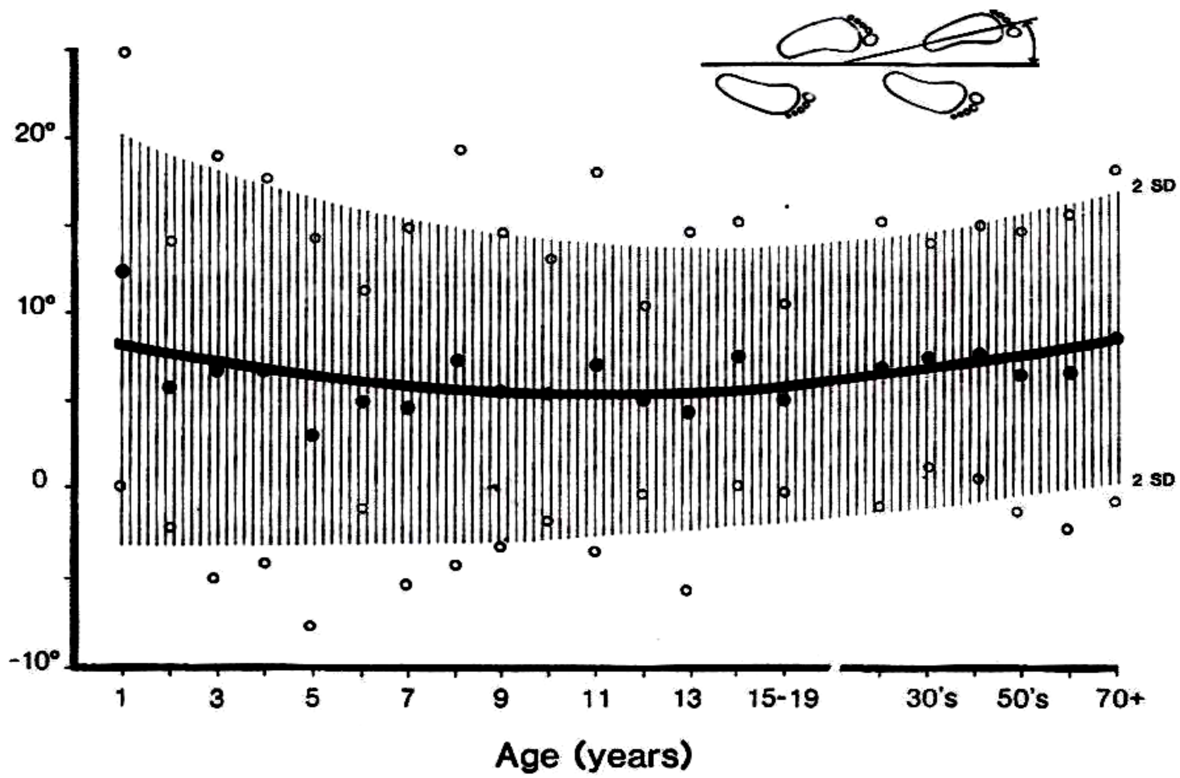

Figure 4.25. Foot-progression angle. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

Reprinted with permission from Staheli, L.T., Corbett, M., Wyss, C. and King, H. Lower-extremity Rotational Problems in Children. Journal of Bone and Joint Surgery. Amer. 1985, 67, p. 41. [38]

11.5 Clinical example

- 9-year-old child with an in-toeing gait pattern.
- The FPA angle = – 5 degrees. The angle is not within two SD of the mean of his age group and indicates abnormal in-toeing.

12. Lateral Hip Rotation and Medial Hip Rotation

12.1 Clinical Use

- To assess femoral torsional status and to evaluate soft tissue extensibility.[10] “If lax ligaments allow abnormally increased medial rotation and lateral rotation mobility, the findings cannot be used to discern torsional status. Limitation of lateral rotation range seems to be the principal finding.’’ [10]
- To classify the degree of severity of femoral torsion, if present.

12.2 Measurements

- Passive lareral hip rotation (LHR): Fig. 4.27.
- Passive medial hip rotation (MHR): Fig. 4.28.

12.3 Testing Procedures

REQUIRED EQUIPMENT

- Inclinometer. To facilitate the measurements, the inclinometer can be maintained over the center of the leg with a small Velcro strap, (Fig. 4.26).
- Examination table.

TEST

- Testing position, inclinometer alignment and measurements are presented in Table 4.20.
- Results for lareral hip rotation are compared to the normative reference values in Figure 4.29.
- Results for medial hip rotation in girls are compared to the reference values in Figure 4.30, and in boys in Figure 4.31.
- Rotational problems are referred to as “torsional deformities” when values fall outside the normal range. Classification of the degree of severity is presented in Table 4.21 and in Figure 4.32.

TABLE 4.20. LATERAL HIP ROTATION AND MEDIAL HIP ROTATION
Testing Condition
▪ The child has to be in a relaxed state and comfortable position.
Testing Position
▪ Prone. Pelvis is level. ▪ Hips are in neutral position. Knees are flexed to 90° (Fig. 4.26). ▪ For LHR, the contralateral limb is placed in mild flexion behind the tested limb.
Inclinometer Alignment and Measurements
▪ The inclinometer is placed over the center of the leg and levelled at 0° with the hip in neutral position [38] (Fig. 4.26). ▪ The hips are passively rotated in LHR (Fig. 4.27) or MHR (Fig. 4.28) until an unforced endpoint is met, at an angle that is maintained by gravity alone. [25]

Figure 4.26. Starting position. Inclinometer levelled at 0°.

Figure 4.27. Clinical determination of LHR.

Figure 4.28. Clinical determination of MHR.

12.4 Normative Reference Values

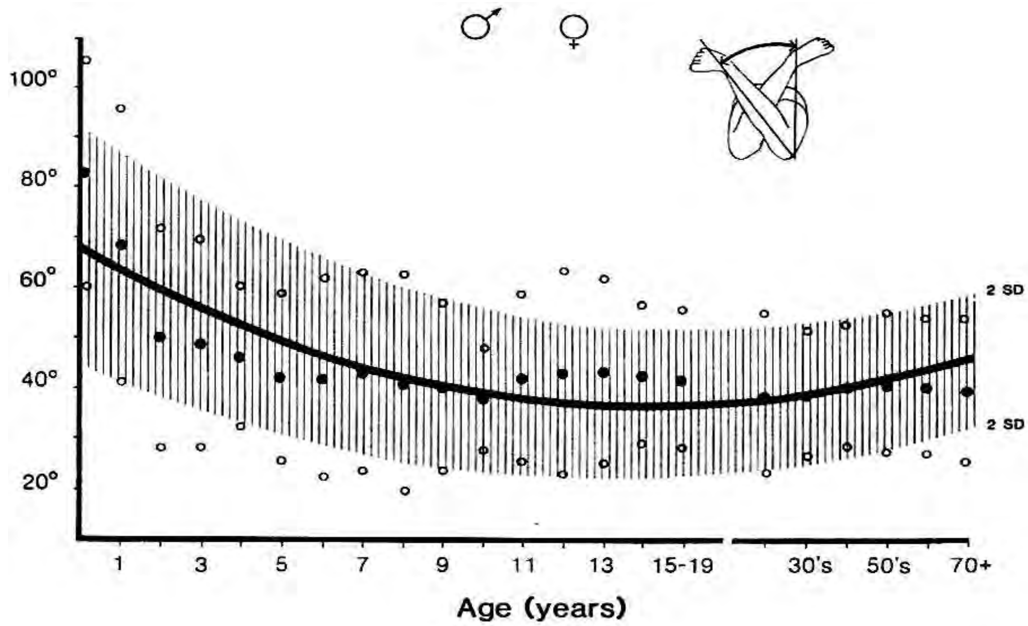

Figure 4.29. Lateral rotation of the hip in male and female subjects combined. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

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12.5 Normative Reference Values

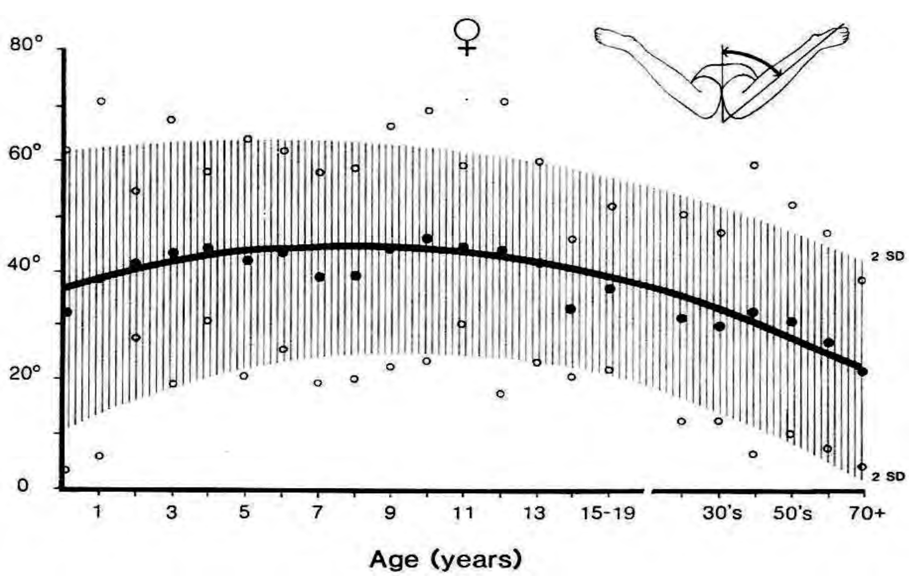

Figure 4.30. Medial rotation of the hip in female subjects. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

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12.6 Normative Reference Values

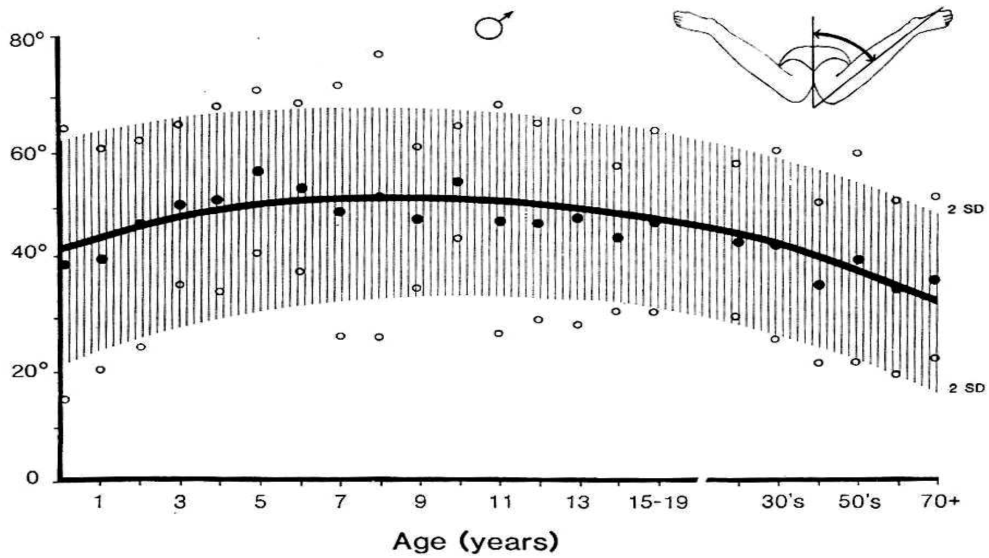


Figure 4.31. Medial rotation of the hip in male subjects. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

Reprinted with permission from Staheli, L.T., Corbett, M., Wyss, C. and King, H. Lower-extremity Rotational Problems in Children. Journal of Bone and Joint Surgery. Amer. 1985, 67, p. 41. [38]

TABLE 4.21. CLASSIFICATION OF SEVERITY OF MEDIAL FEMORAL TORSION [38]	Hip Rotations		
	MHR		*LHR*
Mild (2-3 SD from the mean)	70°–80°	**and**	10°-20°
Moderate (3-4 SD from the mean)	80°-90°	**and**	0°-10°
Severe (> 4 SD from the mean)	>90°	**and**	No LHR

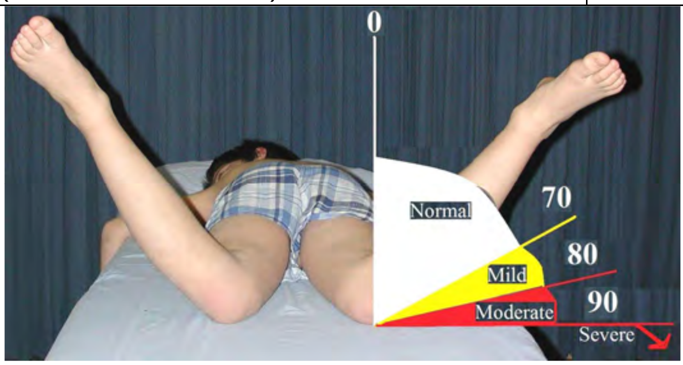


Figure 4.32. Classification of severity.(© IRDPQ - 2011).

Data from: Staheli, L.T., Corbett, M., Wyss, C. & King H. Lower-Extremity Rotational Problems in Children. Journla of Bone and Joint Surgery. Amer. 1985, 67, p. 45. [38]

12.7 Clinical Example

- 6-year-old girl.
- MHR range of motion = 85°; LHR range of motion = 5 °.
- Angle values are not within two SD of the mean of her age group and indicate moderate medial femoral torsion.

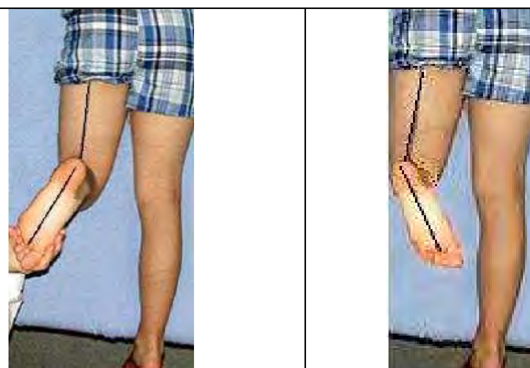
13. Thigh-Foot Angle and the Transmalleolar Axis-Thigh Angle

13.1 Clinical Use

- Internal tibial torsion (ITT) is the most common cause of in-toeing. [37 57] The child usually walks with the patella facing forward and the feet pointing inward. This results in an internal foot progression angle and an internal thigh foot angle (TFA) and internal transmalleolar axis-thigh angle (TMA).
- The TFA and the TMA are used to assess tibiofibular torsional status. Tibial rotation is defined as the relationship between the axis of rotation of the knee and the transmalleolar axis. [38]

13.2 Measurements

- The TFA is a composite measurement that reflects the rotation of both the tibia and the hind part of the foot. [4, 38] When the foot is normal this is the prefered measurement. [25] If the foot is deformed, the TFA cannot be used. Instead, the TMA angle is measured. [44]
- The TMA represents the torsional deformity of the tibia and is used in association with the TFA when the assessment of a more complex torsional deformity is needed. TMA angle minus TFA represents the deformity of the hind part of the foot. [38]
- In both measurements, the ankle has to be kept in neutral position. Testing is limited to children who do not present equinus deformities of the ankle. [48]
- Expression of values: Figure 4.33.



A : (+20 °)	**B :** (-20 °)

Figures 4.33. Expression of values of tibial torsion
A: External tibial torsion angle is reported with a plus sign (+);
B: Internal tibial torsion angle is reported with a minus sign (-).
(© IRDPQ - 2008)

13.3 Testing Procedures

A) Thigh-Foot Angle

Required equipment

- The authors of the present study measured the angles with a protractor but the technique was not illustrated or described. The authors also took photographic measurements and there was no significant differences between clinical examination and photographic measurements. Clinically, it is easier to measure TFA and TMA on digital pictures.
- Other studies measured the angles with a standard goniometer. The method described by Stuberg et al. (1991) [40] is the one that is presented.
- Hypoallergenic skin cosmetic crayon to mark anatomical reference points.
- Examination table.

PRE-TEST

- This is the more difficult part of the assessment and practice is necessary to achieve adequate measurements with values that are reproductible. [37]
- Mark the following reference points (Fig. 4.34):
  - The line bisector of the thigh;
  - The longitudinal axis of the foot.

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.22.
- Results are compared to the normative reference values in Figure 4.36.

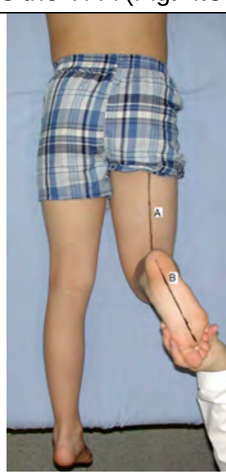
<table>
<tr><th colspan="2">TABLE 4.22. THIGH-FOOT ANGLE</th></tr>
<tr><td colspan="2">Testing Condition</td></tr>
<tr><td colspan="2">▪ Care has to be taken to assure relaxation of the tested leg to eliminate tibiofibular rotation by the hamstrings musculature during the measurements. [40]</td></tr>
<tr><td colspan="2">Testing Position</td></tr>
<tr><td colspan="2">▪ Prone. The tested limb has to be at right angles and neutral position at all times (Fig. 4.34).
▪ The pelvis is level. The tested knee is flexed to 90°.
▪ The ankle is kept in neutral plantar / dorsiflexion and neutral varus / valgus. The foot is depressed with one finger to bring the ankle into the normal weigh-bearing position.[37] (Fig. 4.35).</td></tr>
<tr><td colspan="2">Goniometer Alignment and Measurements</td></tr>
<tr><td colspan="2">▪ The movable arm is placed on the line bisector of the heel and the foot (longitudinal axis of the foot).
▪ The stationary arm is placed directly above the projection of the line bisector of the thigh. [40]
▪ The angle produced between the longitudinal axis of the foot in its neutral position and the long axis of the thigh is the TFA (Fig. 4.35).</td></tr>
<tr><td>


Figure 4.34. Anatomical reference points for TFA.
A: Line bisector of the thigh.
B: Longitudinal axis of the foot. (© IRDPQ – 2008).</td>
<td>

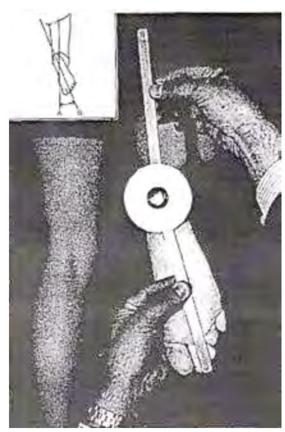



Figure 4.35. Goniometer alignment to estimate the TFA. Reprinted with permission from LWW from Stuberg, W., Temme, J., Kaplan, P., Clarke, A. and Fuchs, R. (1991) Measurement of tibial torsion and thigh-foot angle using goniometry and computed tomography. Clinical Orthopedics and Related Research. 272, p. 209. [40]</td></tr>
</table>

13.4 Normative Reference Values

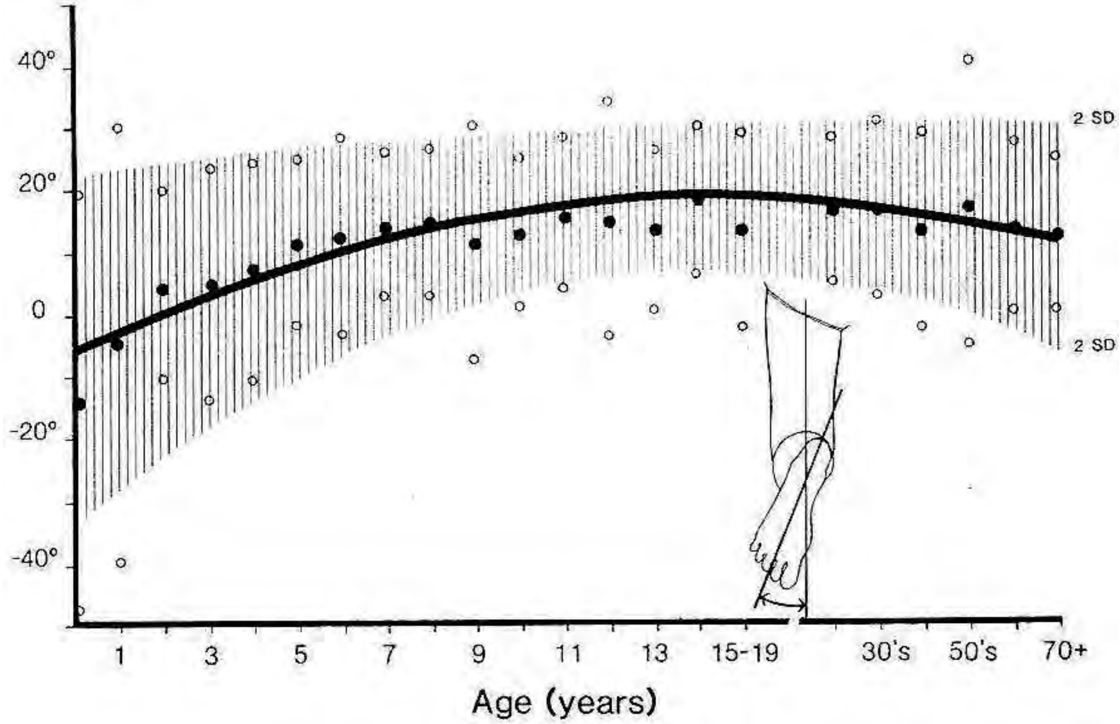


Figure 4.36. Thigh-foot angle. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

Reprinted with permission from Staheli, L.T., Corbett, M., Wyss, C. and King, H. Lower-extremity Rotational Problems in Children. Journal of Bone and Joint Surgery. Amer. 1985, 67, p. 43. [38]

B) TRANSMALLEOLAR AXIS-THIGH ANGLE

REQUIRED EQUIPMENT

- Refer to section 13.3 .

PRE-TEST

- Mark the following reference points (Fig. 4.37):
  - The line bisector of the thigh;
  - Locate the anterior-posterior malleolar bisections and mark a line joining them across the plantar aspect of the heel. [10] This line approximates the TMA.
  - Clinical suggestion*: In order to locate the center of the malleoli on the plantar aspect of the foot, a perpendicular line can be drawn from the malleoli bisections on each side of the foot. These two points are then connected on the plantar surface of the foot. This line approximates the transmalleolar axis (Fig. 4.37- line CD).

** Note: this was not used by the authors of the study*

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.23.
- Results are compared to the normative reference values in Figure 4.39.

TABLE 4.23. TRANSMALLEOLAR AXIS-THIGH ANGLE

Testing Condition

- Care has to be taken to assure relaxation of the tested leg to eliminate tibiofibular rotation by the hamstrings musculature during the measurements.[40]

Testing Position

- Prone (Fig. 4.37).
- The tested limb has to be at right angles and neutral position at all times.
- The pelvis is level.
- The tested knee is flexed to 90°.
- The ankle is kept in neutral plantar / dorsiflexion and neutral varus / valgus.

Goniometer Alignment and Measurements

- The movable arm is aligned with the bi-malleolar line.
- The stationary arm is aligned above or parallel to the projection of the line bisector of the thigh.
- The angle of the TMA is the angular difference between a line projected toward the heel at right angles to the transmalleolar axis and the axis of the thigh (Fig. 4.38).
  Ex.: The angle obtained with the goniometer in Figure 4.38 is 110°. TMA = 110° – 90° = 20°.

Figure 4.37. Anatomical reference points: Line CD approximates the transmalleolar axis.
(© IRDPQ – 2008).

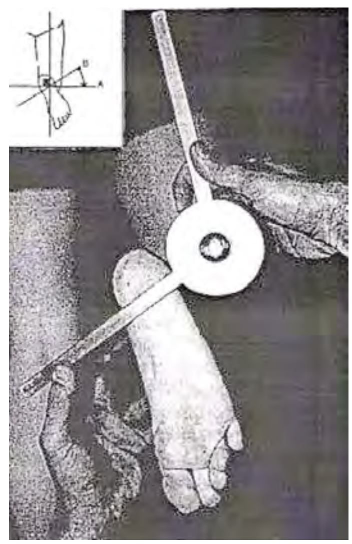


Figure 4.38. Goniometer alignment to estimate the angle of the TMA.
Reprinted with permission from LWW from Stuberg, W., Temme, J., Kaplan, P., Clarke, A. and Fuchs, R.(1991) Measurement of tibial torsion and thigh-foot angle using goniometry and computed tomography. Clinical Orthopedics and Related Research. 272, p. 209, p. 209.[40]

Note: Cusic & al. (1992)[10] estimated the TMA angle by drawing a perpendicular line from the TMA posteriorly on the heel. With a goniometer, they measured the angle formed by this perpendicular line and the long bisection of the thigh resulting in the TMA-thigh angle.

13.5 Normative Reference Values

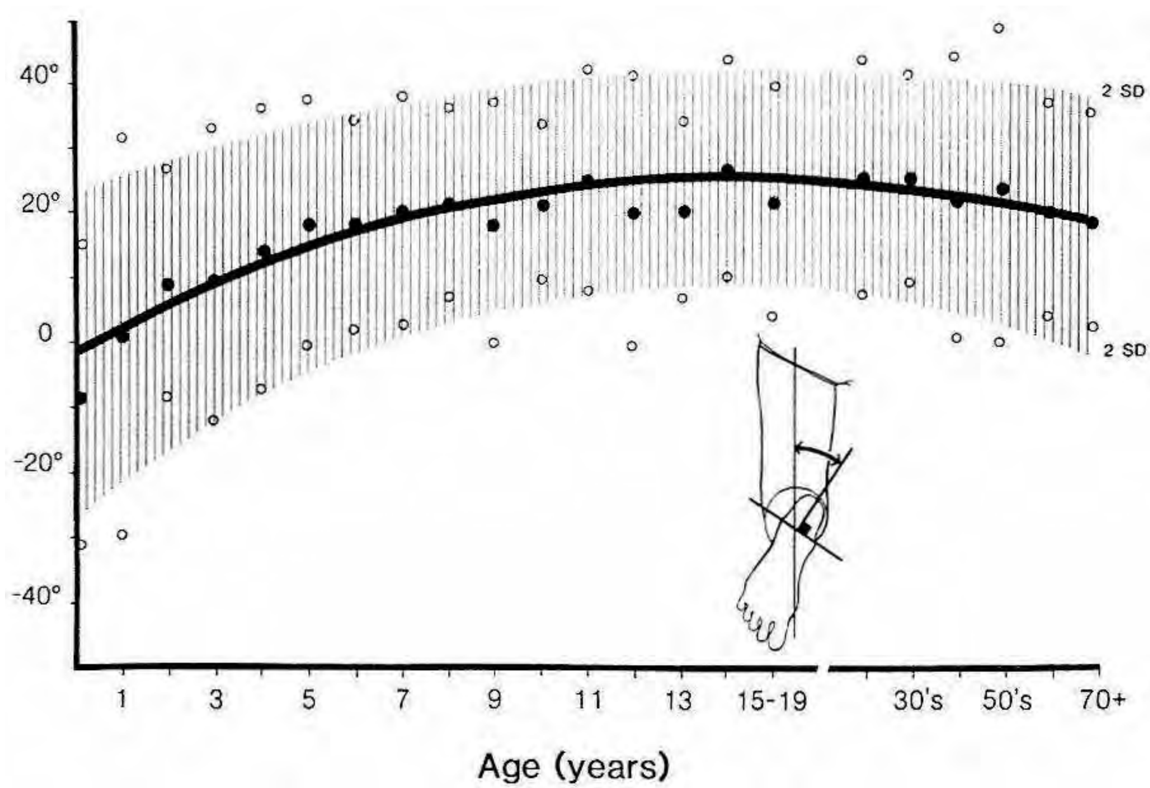


Figure 4.39. Angle of the transmalleolar axis. Mean values, plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

Reprinted with permission from Staheli, L.T., Corbett, M., Wyss, C. and King, H. Lower-extremity Rotational Problems in Children. Journal of Bone and Joint Surgery. Amer. 1985, 67, p. 43. [38]

13.6 Study Summary

Title: Lower-extremity rotational problems in children. Normal values to guide management [38]	
Authors	Staheli, L. T., Corbett, M., Wyss, C., & King, H.
Publication	The Journal of Bone and Joint Surgery, Amer. 67, 39-47.
Purpose of the Study	To establish normal values for the rotational profile.
Type of Population	☒ Normal ☐ Other :
Clinical Relevance	Assessment of femoral and tibial rotations in children who present an in-toeing or out-toeing gait pattern.

Methods

Subjects

- The study sample consisted of 500 healthy subjects. (279 ♀; 221 ♂). USA.
- Age range: ≤ 1 year to 70 years.
- The 500 subjects were divided into 22 groups according to chronological age in years. The number of subjects per age group is presented in Fig. 4.40. Both limbs were measured in each group. A total of 1,000 limbs were measured.

Testing Procedures and Instrumentation

- Foot progression angle (FPA), medial hip rotation (MHR), lateral hip rotations (LHR), thigh-foot angle (TFA) and angle of the transmalleolar axis (TMA) were measured by the same tester in the 500 subjects in both limbs. Both limbs were analyzed in standardized positions.
- Instrumentation: Gravity goniometer, protractor, camera.

Data Analysis

- Inter-examiner and intra-examiner variability were assessed for each measurement by clinical examination and photographic negatives. The average for both limbs for each subject was used in all measurements. Mean and standard deviation (SD) were calculated. The range of normal was defined as being within 2 SD from the mean.

Results

- **Psychometric Properties:** Non applicable.

* Inter-examiner variability mean errors in degrees for MHR was 3.33° (SD 4.90°), for LHR: 4.50° (SD 5.81°), for TFA: 5.02° (SD 6.30°), and for TMA: 6.78° (SD 8.90°).A F test of equality of variances of clinical examination and photographic negatives showed no significant differences (p >0.05).

FPA: Angles were the greatest and most variable during infancy. During childhood and adult life it showed little change: Mean was +10° and the normal range was between – 3° and +20°.

MHR

- Among all the measurements, only MHR angles showed gender related difference (p < 0.05).
- Angles were greater in females with a mean difference of 7°. MHR was greatest in early childhood and then declined from the middle of childhood on.
- For male subjects: Mean angle was about 50° (normal range: 25° to 65°).
- For female subjects: Mean angle was about 40°, (normal range:15° to 60°)

LHR

- Angles showed no gender related difference.
- LHR was greatest during infancy then declined and remained relatively constant during adult life.
- From the middle of childhood on, mean was about 45° (normal range: 25° to 65°).

TFA: Angles increased and became less variable during childhood. From the middle of childhood on, mean angle remained approximately 10°, (normal range: – 5° to 30°).

TMA: Angles increased and became slightly less variable with age. Mean angles and normal ranges were greater than TFA angles. From the middle of childhood on, the mean was about 20°, (normal range: 0° to 45°). Findings compare favourably with other studies.

13.6 Study Summary (Continued)

Authors' Conclusion
▪ TFA is easier to measure than TMA. ▪ TFA is the most practical measurement of the usual torsional deformity. ▪ In infancy: LHR is greater than MHR and with advancing age, LHR decreases while MHR increases. ▪ Out-toeing in infants, medial tibial torsion in toddlers, and medial femoral torsion in young children are extremes of a normal developmental pattern. In the vast majority, these rotational variations fall within the broad range of normal and require no treatment. ▪ Graphs showing normal values for the rotational profile of the lower limbs will allow the clinician to determine the location and the severity of torsional problems.

Comments
▪ Internal validity seems good. However, sample size is small in two age-categories (Fig. 4.40: 13 and 14 years old). The use of results as a trend for clinical guidelines is appropriate but data should be interpreted with caution in the 13- and 14- age- categories. * Intra-examiner variability is not to be interpreted as intra-examiner reliability.

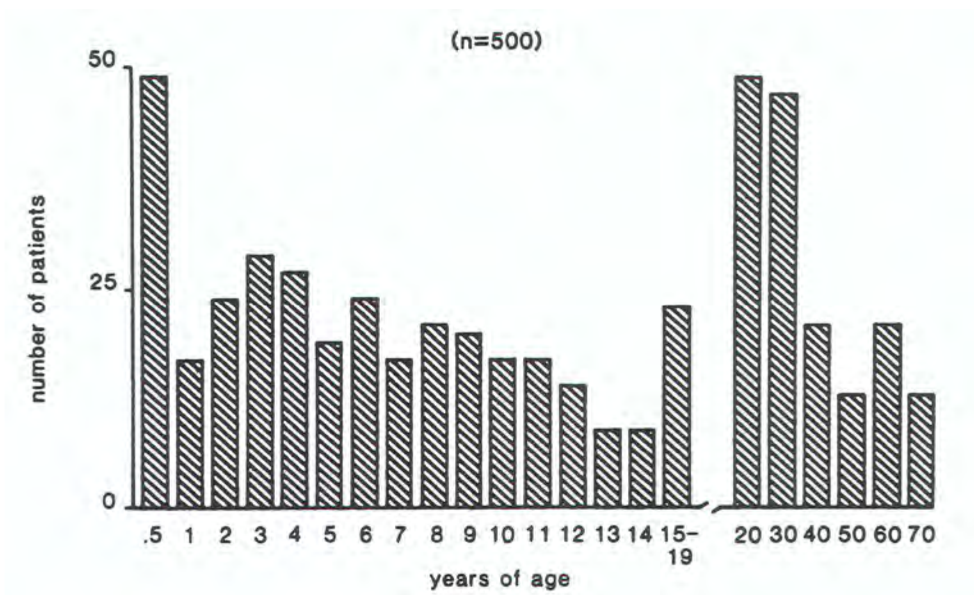


Figure 4.40. Distribution of subjects according to the twenty-two age group studied

Forty-eight subjects were less than one year old - eleven, one to two years olds – twenty-four, two to three years old and so on. There were no subjects between sixteen and twenty years old. Subjects who were more than twenty years old were divided into six ten-year age groups, as shown.

Reprinted with permission from Staheli, L.T., Corbett, M., Wyss, C. and King, H. Lower-extremity Rotational Problems in Children. Journal of Bone and Joint Surgery. Amer. 1985, 67, p. 40. [38]

14. Forefoot Alignment: Metatarsus Adductus

14.1 Clinical Use

- The final step in the assessment of the child's rotational profile is the foot evaluation verifying for metatarsus adductus.
- Metatarsus adductus is a source of in-toeing [10, 28] and is a factor to consider when proximal factors are normal. [10] Metatarsus adductus is characterized by adduction of the forefoot in relation to the hindfoot at the tarso-metatarsal joints. Some varus of the forefoot associated with the adduction may be observed, but the hindfoot or the heel is usually in the neutral position.

14.2 Measurement

- The assessment of metatarsus adductus (MA) is of a more subjective nature than the other rotational measurements and takes into account the long axis of the foot and the alignment of the forefoot.
- MA can be estimated by extrapolating a line bisecting the heel toward the toes (Fig. 4.41-B) or by analyzing footprints (Fig. 4.43).

14.3 Testing Procedures

REQUIRED EQUIPMENT

- Podograph (footprint mat) and paper.
- Hypoallergenic skin cosmetic crayon.
- Non-slip material.

PRE-TEST

- The non-slip material is placed under the podograph for safety reasons.

TEST

- Testing position and clinical evaluation are presented in Table 4.24.
- Classification of the degree of severity of MA is presented in Table 4.25.

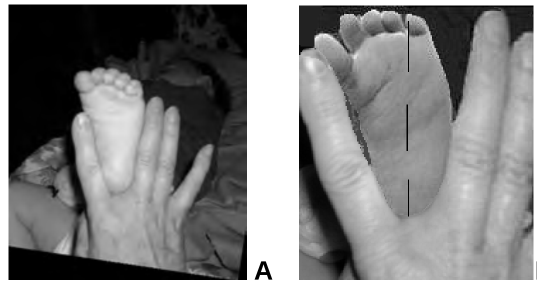
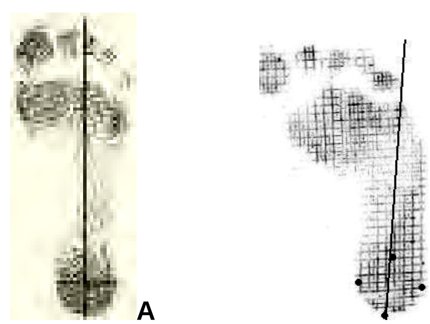
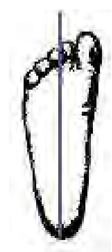
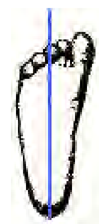
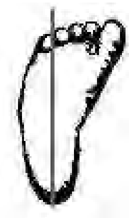
TABLE 4.24. TESTING POSITION AND CLINICAL EVALUATION FOR METATARSUS ADDUCTUS	
Testing Position	
▪ In infants, a simple test that may indicate the presence or not of MA is the V- finger test (Fig. 4.41-A and -B): ♦ The foot is observed from the plantar aspect. The infant's heel is in the examiner's hand second webspace; the medial foot rests against the index finger and the lateral foot rests against the middle finger; ♦ Observe if the forefoot deviates away from the middle finger. If the outer part of the foot does not align with the middle finger, MA might be present (Fig. 4.41-B); ♦ In MA, a C-shaped lateral foot border is created and in severe cases, with evidence of the styloid process of the fifth metatarsal. [54]	 A B **Figures 4.41. V-Finger Test examination and evaluation:** **A- Normal alignment;** **B- Metatarsus adductus.** (© IRDPQ – 2008).
▪ In older children, static footprints in standing can be used to determine forefoot alignment (Fig. 4.42, 4.43) .	 **Figure 4.42. Static footprints.** (©IRDPQ– 2008).
Forefoot Alignment Assessment and Classification of MA	
Forefoot alignment is determined by the projection of the long axis of the foot ▪ In infants, visual estimation of the long axis of the foot can be done during clinical examination. In MA, the heel bisector line projects toward the lateral toes. (Fig. 4.41-B). ▪ In older children, locate the center line of the weight area of the heel on the footprint,. The weight bearing surface of the heel is considered as an ellipse, its major axis showing minimum variation. The major axis of this ellipse defines the center line of the hindfoot (heel bisector). The heel is then bisected with a straight line toward the toes.[4, 48] ▪ In a ''normal foot'', this line passes through the second and third toe-web interspace,[4, 35, 48, 53] the heel in neutral position. (Fig. 4.43-A). ▪ In MA, medial deviation of the forefoot results in the long axis of the foot projecting toward the lateral toes. (Fig. 4.43-B). **Classification of the degree of severity of MA** ▪ The most widely accepted clinical classification of forefoot adduction is Bleck's classification [4, 53, 56] (Table 4.25) ▪ There are three degrees of severity and classification of the severity depends on: ♦ Where the heel bisector line falls between the toes; ♦ The amount of correction obtained by passive movement of the tarso-metatarso joint. [53]	 A B **Figures 4.43 :** **A- Long axis of the foot in a ''normal foot'';** **B- Long axis of the foot in metatarsus adductus.** (© IRDPQ – 2008).

TABLE 4.25. MA Degree of Severity Based on Bleck's Classification [4, 48]

Classification of Severity	**Normal Foot**	**Mild Deformity**	**Moderate Deformity**	**Severe Deformity**
Observation, in spontaneous position, where the heel bisector line falls between the toes. ↓				
Heel bisector line passes:	Between 2nd and 3rd toes = neutral position	Through 3rd toe	Between 3rd and 4th toes	Beyond 4th toe
Classification of Flexibility	**Normal Mobility**	**Flexible**	**Partially Flexible**	**Inflexible(rigid, fixed)**
Flexibility is classified according to the amount of correction obtained by passive movement of the tarso-metatarso joint, against the stabilized hindfoot.	Full abduction of the tarso-metatarsal joint	Tarso-metatarsal joint can be abducted beyond the midline heel bisector	The foot can be corrected only to the midline.	No abduction possible. The lateral border of the foot remains convex during abduction. Neutral anatomical position cannot be attained

(© IRDPQ – 2011)

Data from Bleck, E. E. (1982). [4]

14.4 Clinical Chart

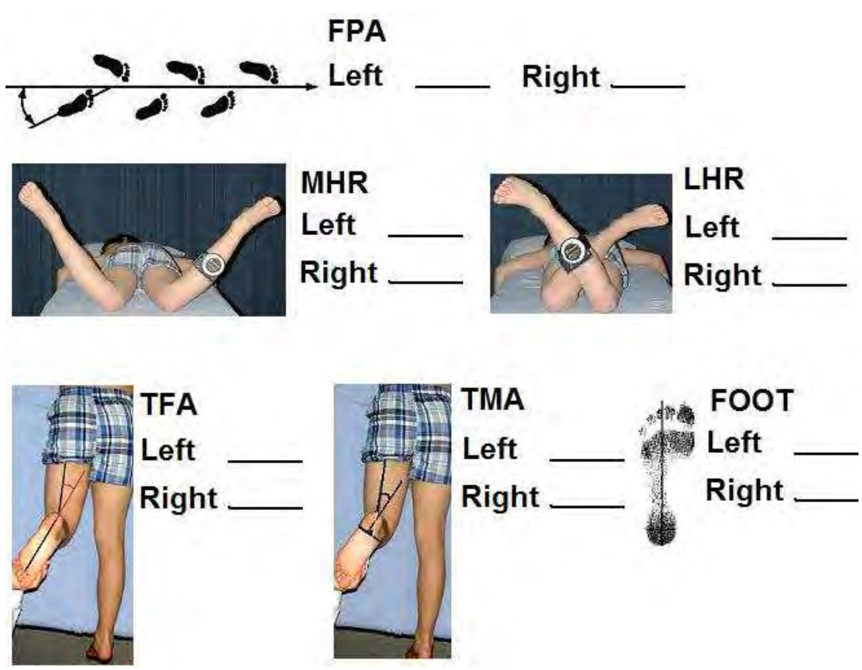


Figure 4.44. Summary of Staheli's rotational profile measurements. (© IRDPQ-2011).

Tibial Torsion

Summary

During the child's normal development, the tibia will rotate externally to bring the foot into its normal position of 15°, abducted from the sagittal plane. A normal deg ree of tibial torsion is essential for normal foot function. A lack of tibial rotation or internal tibial torsion will cause in-toeing while an excessive tibial rotation, or external tibial torsion, will cause out-toeing. [42]

Computed tomography (CT) is the gold standard for measurement of tibial torsion. [9] Clinically, tibial torsion can be estimated by measuring the transmallleolar axis (TMA). [39, 42]

Depending on which points of reference are used to measure tibial torsion, the recorded values will vary and are not directly comparable. [12]

Two studies were selected to assess tibial torsion and both use a different technique:

- Staheli and Engel -1972 [39] measured the TMA, with the knee in flexion, in children aged between 3 months and 13 years;
- Valmassy and Stanton -1989 [42] measured the TMA, with the knee in extension, in children aged between 1 ½ years to 6 years.

15. Measurement of the Transmalleolar Axis Angle, Knee in Flexion [39]

Age range: < 3months to 13 years.

15.1 Clinical Use

- The transmallleolar axis (TMA) or malleolar position is a measurement that indirectly assesses tibial torsion. [39, 42]
- Provides a standard method to estimate the TMA and can be used if forefoot adduction is present.
- Clinically, it is mostly used in children presenting an out-toeing or in-toeing gait.

15.2 Measurements

- Testing position: sitting (Fig. 4.45). (**Note**: Testing position for infants was not described by the authors).
- Anthropometric measurements:
  - The difference between the malleoli in the sagittal plane in cm (Fig. 4.47);
  - The width of the ankle in cm (inter-malleolar distance) (Fig. 4.48).
- A conversion grid is used to estimate the degrees of the TMA (Fig. 4.51).
- Expression of values:
  - External tibial torsion is reported with a plus sign (+);
  - Internal tibial torsion is reported with a minus sign (-).

15.3 Testing procedures

REQUIRED EQUIPMENT

- Calliper.
- Thin metallic ruler in cm increments.
- An elevated platform with a flat back wall (Fig. 4.45).

- Hypoallergenic cosmetic skin pencil to mark anatomical landmarks.

TEST

- Testing procedures are presented in Table 4.26.
- Results (the estimated angle) are compared to the normative reference values in Table 4.27.
- Summary of the testing procedures: Figure 4.50.

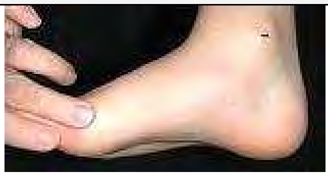
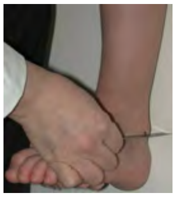
TABLE 4.26. TIBIAL TORSION MEASUREMENT [39]	
Testing position	
▪ The child sits on the platform. ▪ Thighs are directly in front of the hip joints and heels are against the vertical surface. ▪ The forefoot of the tested limb is held by an assistant at right angles to the back wall in both the sagittal and the horizontal planes. If forefoot adduction is present, the hindfoot should be used as the source of reference rather than the whole foot.	**Clinical example:** **9-year-old boy with an out-toeing gait.**  **Figure 4.45. Testing position .** (© IRDPQ – 2010).
Marking	
▪ Then, with the foot held in neutral position, the medial malleolus is held between the thumb and index finger and the center point is marked. (Fig. 4.46). ▪ The lateral malleolus is marked in a similar manner. The marking is done on the broadest portion of the fibula, at the level of the joint line, and not on the tip of the malleolus.	 **Figure 4.46. Marking of the bisection of the medial malleoli**. (© IRDPQ – 2008).
Three Measurements	
1- The difference between the malleoli in the sagittal plane	
▪ With the heel resting comfortably against the back wall of the platform, measure with the ruler: ♦ The distance between the marks over the medial malleolus and the back wall (A); ♦ The distance between the marks over the lateral malleolus and the back wall (B). Calculate the difference between these two measures: (A – B).	 **Figure 4.47. The position of the malleoli in reference to the back wall is measured** (© IRDPQ – 2010): A: Medial malleolus to back wall = 4.2 cm; B: Lateral malleolus to back wall = 3.2 cm; A – B = 1.0 cm .
2- The width of the ankle	
▪ With the calliper, the inter-malleolar distance is measured.	 **Figure 4.48. Inter-malleolar distance= 6.2 cm.** (© IRDPQ – 2010).

Table 4.26. Tibial Torsion Measurement (Continued)

3- Estimation of TMA

- By reporting the measurements on Staheli / Engel's conversion grid (Fig. 4.51), the angle of the TMA can be estimated by relating the difference in position of malleoli and the back wall (ordinate) with the inter-malleolar distance (abscissa).
- The point of intersection is carried out to a diagonal line to the right and estimates theTMA. .

The data from our 9-year-old boy is plotted on the ''example grid'' (Fig. 4.49) :

- The 6.2 cm inter-malleolar distance is plotted on the abscissa axis;
- The 1 cm difference in position of malleoli and the backwall is plotted on the ordinate axis;
- The point of intersection is carried out to a diagonal line to the right which gives an estimate of ~ 7.5 degrees.

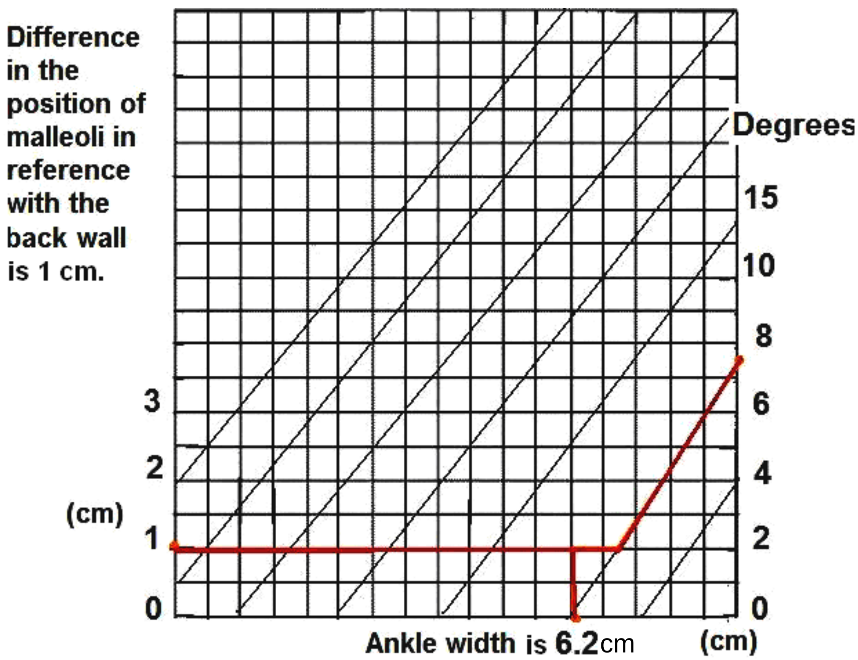


Figure 4.49. **<u>Example</u> grid showing how to estimate theTMA: The point of intersection is carried out to a diagonal line to the right.** (© IRDPQ – 2011).

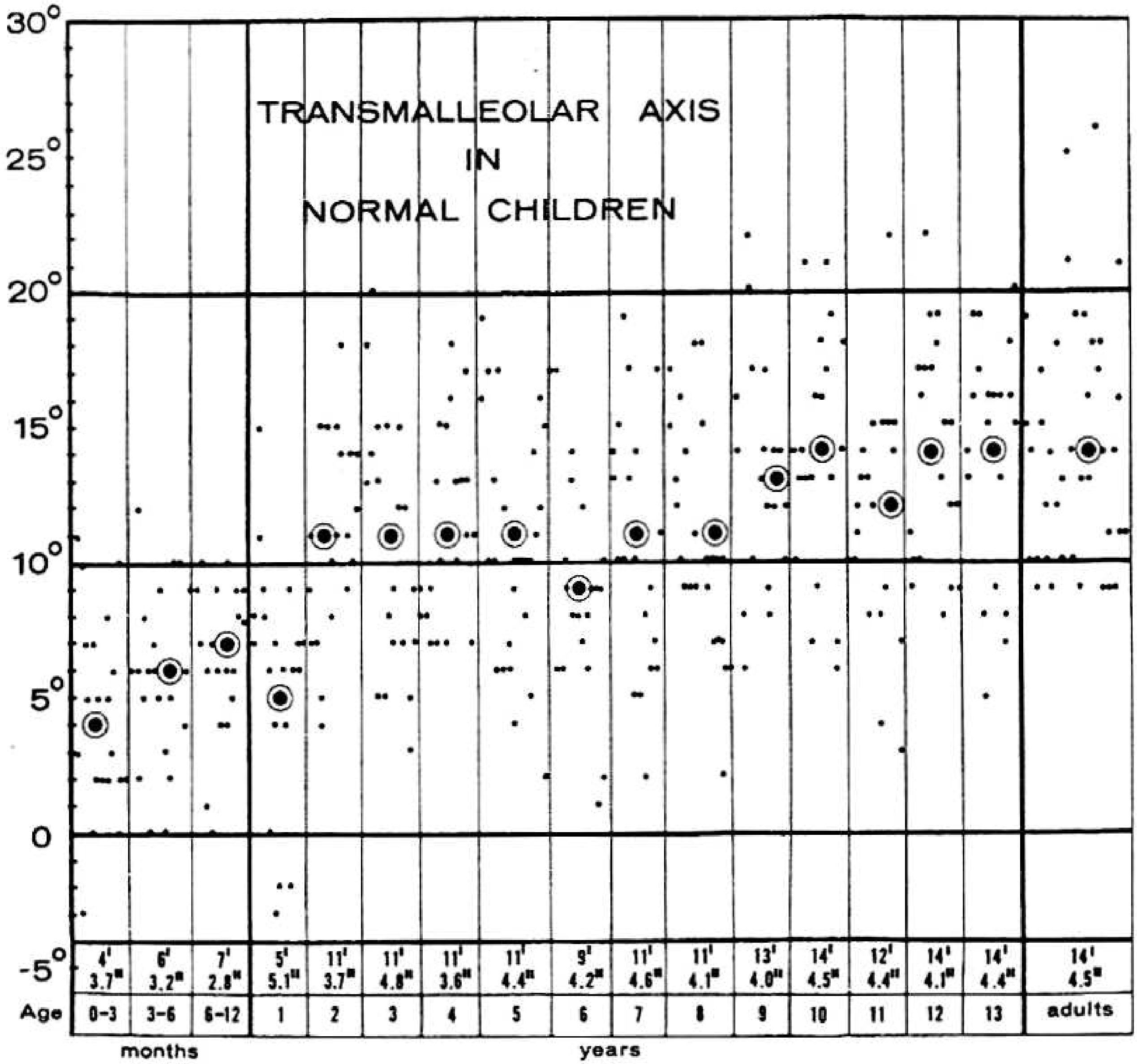
NB: This grid is used as an example *<u>and should not be used for assessment</u>*.
The conversion grid provided by Staheli and Engel (1972) [39] is presented in Figure 4.51.

The estimated angle is compared to the normative reference values/age group

- Our 9-year-old boy has a TMA angle of ~ + 7.5°. This angle is compared to the normative data in Table 4.27 for the 9-year-old group.
- This value (+ 7.5°) is within 2 SD of the mean of his age group and indicates normal external tibia torsion.

15.4 Normative Reference Values

Table 4.27. The transmalleolar axis in normal children and adults. The mean in each age group is indicated by the larger dot and circle. ' = the mean by age group. " = the standard deviation.

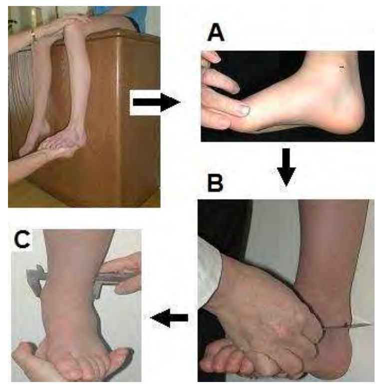


Reprinted with permission from LWW from Staheli, L. T., & Engel, G. M. (1972). Tibial torsion: a method of assessment and a survey of normal children. Clinical Orthopaedics and Related Research, 86, p 185. [39]

15.5 Clinical Practice Guidelines

- This method demonstrates that the transmalleolar axis angle averages about 5° of external rotation during the first year, 10° during mid-childhood and 14° in older children and adults. [39]

15.6 Summary



Summary of Staheli and Engel's technique:
The child is seated with the examiner holding the foot in a neutral position against a flat back wall.

(A) The mid-points of the malleoli are marked.

(B) The position of the malleoli in reference to the back wall are measured.

(C) The intermalleolar distance is determined.

Figure 4.50. Summary of the testing procedures. (© IRDPQ – 2011).

15.7 Clinical Chart

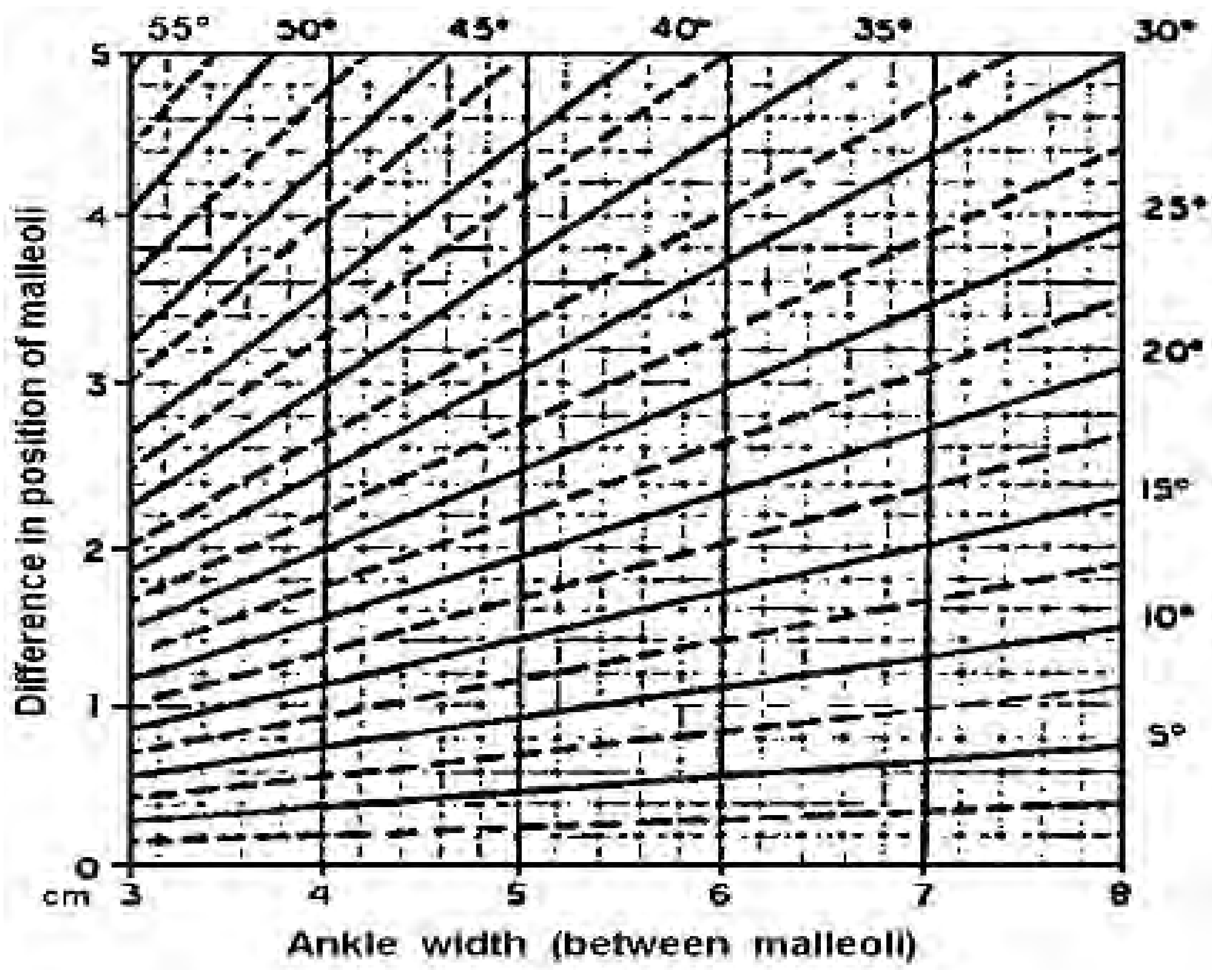


Figure 4.51. Conversion grid for the transmalleolar axis

Reprinted with permission from LWW from Staheli, L. T., & Engel, G. M. (1972). Tibial torsion: a method of assessment and a survey of normal children. Clinical Orthopaedics and Related Research, 86, p.184. [39]

Note: The authors suggest that the conversion chart can be used if the medial malleolus is more posterior, but this difference should be indicated by placing a minus sign before the figure. [39]

15.8 Study Summary

Title: Tibial Torsion: A Method of Assessment and a Survey of Normal Children [39]	
Authors	Staheli, L. T., & Engel, G. M.
Publication	Clinical Orthopaedics and Related Research, 86, 183-186.
Purpose of the Study	To develop a simple clinical method of assessing tibial torsion by calculating the transmalleolar axis.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of tibial torsion.

Methods

Subjects

- The study sample consisted of 160 healthy children and 20 adults. USA.
- Age of children: <12 months to 13 years.
- Children were divided into 16 groups based on chronological age. Each group consisted of 10 children (20 limbs).
- Both feet were evaluated in each age group (children and adults) for a total of 360 feet.

Testing Procedures and Instrumentation

- The transmalleolar axis (TMA) was measured in a standardized position, in sitting. Instrumentation: A calliper and a ruler.

Data Analysis

- Mean and standard deviation were calculated for each age group.
- To assess reproducibility of the method, 25 children (50 limbs) were studied twice. Each tibia was measured on each occasion and the results compared.

Results

Psychometric Properties: Non applicable.

- Values obtained in adults were similar to those seen in older children. No significant gender difference was demonstrated.
- External rotation of the TMA increases with age and progresses more rapidly during the first year of life and again in childhood.
- The mean of all patients on the right limb was 10.8° as compared with 10.4° for the left.
- Authors report that the principal disadvantage in measurement of the TMA is that it requires careful positioning of the foot by the examiner. Also, it is difficult to determine the relationship between two complicated joints. Recognizing this complexity, authors suggest that the clinician must rely on bony landmarks, the malleoli and use the TMA to assess tibial torsion.
- Compared to other studies, lower values of TMA were obtained. This is explained by the position of the knee in flexion during assessment compared to previous studies where measurements were done with the knee in extension or on skeletons.

Authors' Conclusion

- The present method fulfills many of the requirements desirable for measuring TMA: No need for special equipment; it is applicable to all age groups and results appear to be reproducible within an acceptable range. A clinical method of measuring TMA demonstrates that TMA averages about 5° of external rotation during the first year, 10° during mid childhood and 14° in older children and adults.

Comments

- Internal validity seems good. However sample size is small in each age group (n =10 per age group) and the use of results as a trend for clinical guidelines must be interpreted with caution.
- A conversion grid to estimate the TMA is presented therein.

16. Measurement of the Transmalleolar Axis, Knee in Extension [42]

Age range: 1 ½ years to 6 years.

16.1 Clinical Use

- The transmalleolar axis (TMA) or malleolar position is a measurement that indirectly assesses tibial torsion. [42]
- Provides a standard method to estimate the TMA and can be used if forefoot adduction is present.
- Mostly used in the presence of out-toeing or in-toeing gait.

16.2 Measurement

- The TMA is measured as being the angle between the line of midpoints of the medial and lateral malleoli (AB) and the frontal plane (BC) [42, 58] (Fig. 4.52).

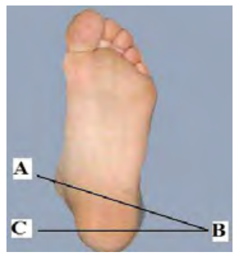


Figure 4.52. Reference point to estimate the TMA. (© IRDPQ – 2011).

16.3 Testing Procedures

REQUIRED EQUIPMENT

- The authors of the present study measured the TMA with a tractograph (Fig. 4.54).
- An extendable goniometer can be used (Fig. 4.55) which allows the arms of the goniometer to lie over anatomical reference points without need of support.
- Examination table.
- Hypoallergenic cosmetic skin pencil to mark the anatomical landmarks.

PRE-TEST

- Anatomical landmarks marking:
  - Position of the patella;
  - Femoral condyles;
  - Bisection of the medial and lateral malleoli from anterior to posterior, at the level of the ankle joint, are marked on the skin (Fig. 4.53-A)

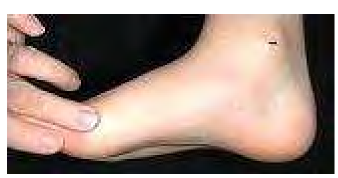


Figure 4.53-A. Bisection of medial malleolus.(© IRDPQ – 2011).

- Clinical suggestion: A perpendicular line is drawn downward from the malleoli bisections. These two points are then joined on the plantar surface of the foot (Fig. 4.53-B). This line approximates the transmalleolar axis as shown in Figure 4.52 (line AB).
  ***Note**: this was not used by the authors of the study .*

Figure 4.53-B. The projection of the malleoli bisections are joined on the foot's plantar surface to approximate the transmalleolar axis. (© IRDPQ – 2011).

TEST

- Testing position, goniometer alignment and measurements are presented in Table 4.28.
- Results are compared to the normative reference values in Table 4.29.

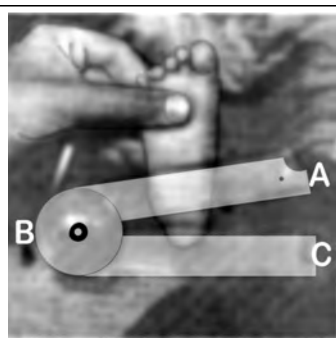
<table>
<tr><th colspan="2">TABLE 4.28. TRANSMALLEOLAR AXIS MEASUREMENT</th></tr>
<tr><td colspan="2">Testing Position</td></tr>
<tr><td colspan="2">▪ The child sits on the examination table, feet slightly over the edge (to facilitate accurate viewing of the malleoli and the placement of the goniometer):
♦ The femoral condyles are equidistant from the supporting surface;
♦ The patella parallel to the same surface;
♦ The knee is minimally flexed to put the proximal end of the tibia in the frontal plane. The knee is then extended with care not to rotate the leg. The patella is in the frontal plane;
♦ The foot must be held at a 90° to the leg (Fig. 4.5 5). with the subtalar joint in neutral position. If the subtalar joint is supinated, the tibia will rotate externally increasing the measurement obtained and opposite motion will happen if pronated.</td></tr>
<tr><td colspan="2">Goniometer Alignment and Measurements</td></tr>
<tr><td colspan="2">▪ The inferior arm is aligned with line B-C, parallel to the supporting surface and held in place (this is used as the reference point to the frontal plane).
▪ The superior arm is aligned with line A-B: This line is an imaginary line connecting the bisections of both malleoli and represents the TMA. (Fig. 4.54 and 4.55).</td></tr>
<tr><td>

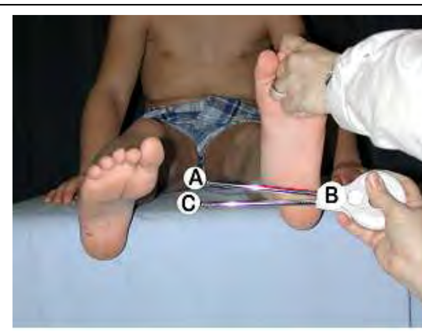
Figure 4.54. The TMA measured with a tractograph. Reprinted with the kind permission from the American Podiatric Medical Association from Journal of the American Podiatric Medical Association, 79 (9). Valmassy, R. and Stanton, B. (1989) Tibial torsion. Normal values in children, p. 433. [41]</td><td>

Figure 4.55. The TMA measured with an extendable goniometer (© IRDPQ – 2008).</td></tr>
</table>

16.4 Normative Reference Values

Table 4.29. Normal Values and Standard Deviations of the Transmalleolar Axis

Age (months)	Number of Children	Transmalleolar Axis (°)
18	3	5.5 ± 1.2
24–29	6	6.3 ± 1.6
30–35	7	5.7 ± 1.6
36–41	38	7.7 ± 2.0
42–47	25	8.1 ± 1.9
48–53	81	8.5 ± 2.3
54–59	55	9.3 ± 2.4
60–65	53	9.7 ± 2.1
66–72	13	11.2 ± 2.7

Reprinted with the kind permission from the American Podiatric Medical Association from Journal of the American Podiatric Medical Association, 79 (9). Valmassy, R. and Stanton, B. (1989) Tibial torsion. Normal values in children. [41]

16.5 Medical Guidelines

Most cases of internal tibial torsion resolve spontaneously. A great majority of children do not require treatment. For children aged ≤ 4 ½ -5 years, with important internal tibial torsion, the use of the Dennis-Browne bar at night is prescribed. Chirurgical intervention is very rare and, if necessary, only in children > 12 years.

16.6 Study Summary

Title: Tibial Torsion : Normal Values in Children [42]	
Authors	Valmassy, R., & Stanton, B.
Publication	Journal of the American Podiatric Medical Association, 79 (9), 432-435.
Purpose of the Study	To measure malleolar position in order to indirectly assess tibial torsion and to determine normal values for different age groups.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of tibial torsion with the knee in extension.

Methods

Subjects

- The study sample consisted of 281 children (random selection). The male/female ratio was approximately 1/1. Population consisted of different ethnic backgrounds. USA.
- Age range: 1 1/2 years to 6 years. Children were divided into groups based on chronological age at 6 months intervals. The number of children in the 18 month and 35 month age groups varied between 3 and 7 subjects. The number of children in the 36 month and 65 month age groups varied between 25 and 81 subjects. The number of children in the 66-72 month age group was 13.

Testing Procedures and Instrumentation

- All the measurements of the transmalleolar axis were taken by the same tester. Testing position was standardized in sitting. Instrumentation: Tractograph.

Data Analysis

- Data was submitted without regards to individual values or podiatric or orthopedic problems; thus a true normal value was obtained. The data points were grouped according to age and the angles of the TMA were recorded. Regression analysis, mean and standard deviations for each age group were calculated.

Results

- **Psychometric Properties**: Non applicable.
- Mean values are reported therein. Regression analysis shows that the average rate of increase of tibial rotation was 1.4°/year. The data show a con sistent increase in external rotation from 5.5° at 18 months to 11.2 degrees at 6 years. The authors report clinical measurements of the TMA that can be used to indirectly measure tibial torsion. Possible sources of error (mentioned by the authors): If the subtalar joint is not held in neutral position, or if the leg is allowed to rotate in the transverse plane, error in measure can occur. The data is consistent with other studies and it is expected that the TMA external rotation of 13° to 1 8° degrees, found in adults, is achieved by the age of 7 or 8 years.
- Discrepancy seen in the 30 to 35 months age group is probably due to the small sample size in this younger group. No statistically significant differences were found between the left and right extremities. Data of the present study show that 7.9 % of the children had at least one leg with a lower than average malleolar position and that 9.3% had at least one leg with a higher than average malleolar position. Only 1.1% had more than a 2° difference between malleolar position of the right and left leg extremities.

Authors' Conclusion

- An outline of normal values for malleolar position in different age groups and a description of a clinical method to assess tibial torsion, knee in extension are presented. The authors caution clinicians not to use these values as absolute parameters but more as a guide since wide variations do occur. They recommended proficiency with the method and analysis of results should be judged against experience with the method.

Comments

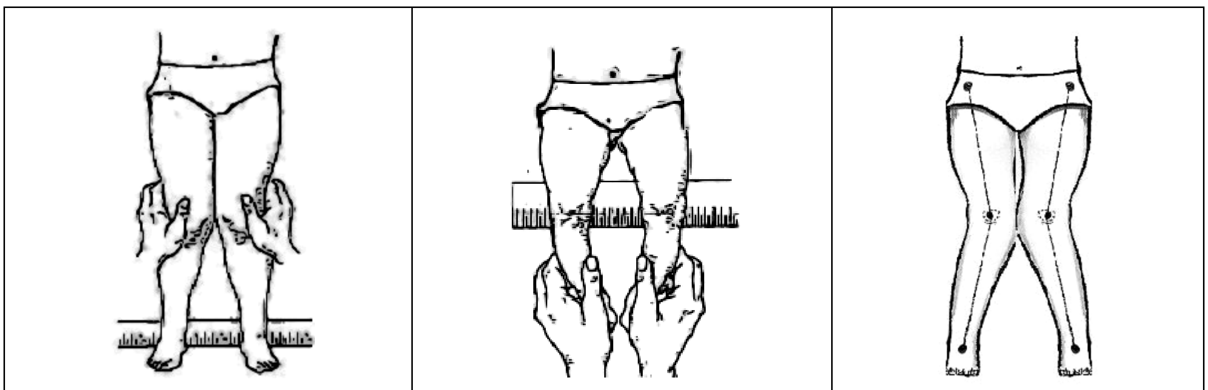
- Internal validity seems good. However, sample size is small in some age categories (Table 4.29) and the use of results in these age groups should be interpreted with caution. External validity in the other age groups (including sample size) seems good and the use of the data as a trend for clinical guidelines is appropriate.

Genu Valgum and Genu Varum

Summary

Normal physiological evolution in the leg alignment is present with age. There is a general transition from genu varum (bowlegs) to genu valgum (knock-knees) to neutral position and wide standard deviation is reported to be present at different ages. [16, 21]

- Genu valgum is the alignment of the knee with the tibia laterally deviated in relation to the femur. The lower legs are at an outward angle, such that when the knees are touching, the ankles are separated. The intermalleolar (IM) distance quantifies genu valgum (Fig. 4.56).
- Genu varum is the alignment of the knee with the tibia medially deviated in relation to the femur. It is a condition observed when a person stands with the feet and ankles together, but the knees remain widely apart. Clinically, genu varum is measured by calculating the intercondylar (IC) distance (Fig. 4.56).
- Tibiofemoral angle (TF) is the angle formed by the midlongitudinal axis of the thigh and the tibia. It quantifies genu varum and genu valgum (Fig. 4.56).
- IM and IC distances are measurements that have the disadvantage of being affected by the child's size. [18] The TF angle may be a more accurate way to quantify angulation of the lower limbs. [3,7,57]



IM distance	IC distance	TF angle

Figure 4.56. Clinical methods of assessment of genu varum or valgum. (© IRDPQ – 2008)

Three studies were selected to assess genu varum or genu valgum:

- Sutherland (1988) [52] measured the intercondylar and intermalleolar distances in children aged 1 year to 7 years, in supine position;
- Heath et al. (1993) [21] measured the tibiofemoral angle, intercondylar and intermalleolar distances in children aged 6 months to 11 years. Children under 2 years were tested in supine and the older children were measured in standing position;
- Cahuzac et al.(1995) [7] measured the tibiofemoral angle, intercondylar and intermalleolar distances in children aged 10 years to 16 years in standing position.

Factors to Consider When Consulting the Data

- Expression of values: IC, IM distances and TF angle values are expressed with a positive or a negative sign in reference to valgus or varus alignment. However, difficulties can arise when consulting the data since the angle values are not recorded in a similar manner between the three selected studies (Table 4.30; Table 4.31).

Table 4.30. Differences in the Expression of Values for IM and IC Distances Between the Selected Studies

Authors	IM distance *(Genu valgum)*	IC distance *(Genu varum)*
Heath & al. (1993) [21] Cahuzac &al. (1995) [7]	–	+
Sutherland (1988) [52]	+	–

Table 4.31. Differences in the Expression of values for TF Angle Between the Selected Studies

Authors	TF angle *(Genu valgum)*	TF angle *(Genu varum)*
Heath & al. (1993) [21]	– value	+ value
Cahuzac & al. (1995) [7]	+ value	– value

- Knowledge of these differences is important when consulting the authors' respective reference values. To facilitate the interpretation of the data, the meaning of the positive or the negative sign in regard to the leg alignment is defined with each method.

- The testing positions differed between the studies. The use of the method that is closest to the child's characteristics, in regard to age and capacity to stand, is suggested (Table 4. 32).

Table 4.32. Suggested Method in Relation to Age and Capacity to Stand

Age	Capacity to stand	Method from
< 1 year	-	Heath & al. (1993) [21]
1 - 7 years	Unable to stand	Sutherland (1988) [52]
2 - 10 years	Able to stand	Heath & al. (1993) [21]
10 -16 years	Able to stand	Cahuzac &al. (1995) [7]

17. Intercondylar and Intermalleolar Distance in Supine [52]

Age range: 1 year to 7 years.

17.1 Clinical Use

- Provides a standard method to assess knee angle alignment (genu varum, genu valgum).

17.2 Measurements

- IC distance is measured in cm. A minus sign (-) denotes genu varum (Fig. 4.59).
- IM distance is measured in cm. A plus sign (+) denotes genu valgum (Fig. 4.59).

17.3 Testing Procedures

REQUIRED EQUIPMENT

- Tape measure for IM and IC distances.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.
- Examination table.

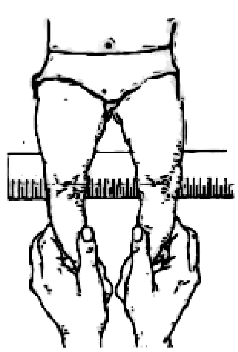
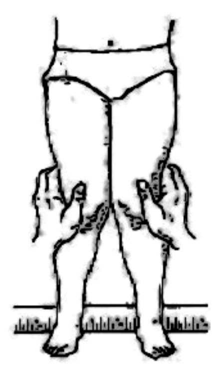
PRE-TEST

- Mark the following anatomical landmarks:
  - The femoral medial condyles (if measuring genu varum);
  - The center of the medial malleoli (if measuring genu valgum).

TEST

- Testing position and measurements are presented in Table 4.33.
- Results are compared to the normative reference values in Figure 4.59.

TABLE 4.33. IC AND IM DISTANCE

Testing Position	
▪ The child is held in supine to minimize movement during the test. The lower extremities are aligned.	
Alignment and Measurement	
▪ **Genu varum**: With the medial malleoli in contact, measure the distance in cm between the femoral medial condyles (Fig. 4.57).	**Genu valgum**: With the femoral medial condyles in contact, measure the distance in cm between the medial malleoli.(Fig. 4.58).
 **Figure 4.57. IC distance.** (© IRDPQ – 2011)	 **Figure 4.58. IM distance.** (© IRDPQ – 2011)

17.4 Normative Reference Values

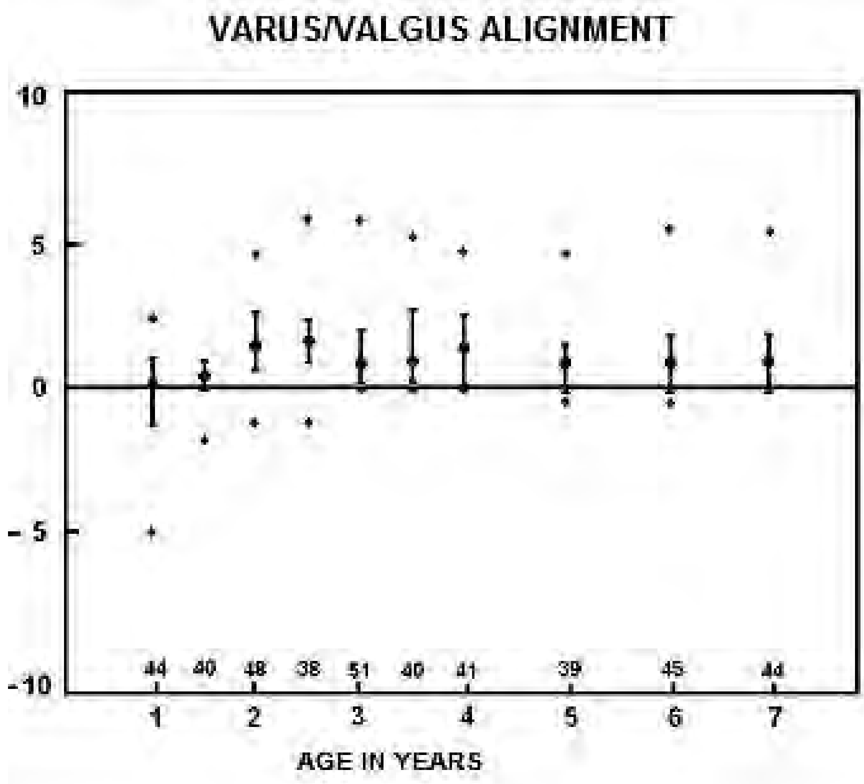


Figure 4.59. Varus / Valgus alignment of the knees, measured (in cm), with the subject supine, *vs*. age. (N=430)

© Sutherland, Olshen, Biden and Wyatt (1988), p. 44. [51]

- The vertical bar encompasses the middle 50% of subjects.
- The box indicates the median.
- Upper and lower markers show respectively the greatest and least values recorded.
- The number of subjects in each age-group is given along the horizontal axis.

17.5 Study Summary

Title: The Development of Mature Walking [52]	
Author	Sutherland, David H.
Publication	London: Mac Keith Press, 1988
Purpose of the Study	▪ To outline changes in gait from the ages of first walking to 7 years. ▪ To define mature gait in terms of specific gait parameters. ▪ To provide substantial base for comparing children with possible gait problems with normal children of the same age.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of gait velocity and different spatial parameters on a short walkway in a therapeutic setting.

Methods

Subjects

- The study sample consisted of 309 healthy children. Mostly Caucasians. USA.
- Age range: 1 year to 7 years.
- Subjects were divided into ten age groups based on chronological age in years within six-month intervals. For gait analysis, each group consisted of 36 to 49 subjects.

Testing Procedures and Instrumentation

- Various gait parameters were assessed and analyzed in a laboratory setting.
- Different anthropometric variables and range of motion in the lower extremities were measured. For range of motion analysis, 392 to 438 measurements were performed in each group.
- Instrumentation: Gait analysis laboratory and various measuring devices were used depending of the variables analyzed. Testing was done in different standardized positions.

Data Analysis

- Motion data was subjected to Fourier analysis to determine mean rotations across the gait cycle.
- Prediction regions, defining boundaries within 95 % of normal children, were calculated using the resultant Fourier coefficients. Details are available therein.

Results

Due to the vast amount of information presented in this study, only the data concerning the variables that were used for this document are presented.
Psychometric Properties: Non applicable.

- Gait
  - Normative data for gait parameters are presented therein.
  - Walking velocity increases with age in a linear manner from 1 to 3 years at a rate of about 11 cm/sec per year. From 4 to 7 years, the rate of change diminishes to 4.5 cm/sec.
  - Cadence in the 1-year-old subjects was ~ 22.5% more than the 7-year-olds. The main reduction occurs between 1 and 2 years of age. Cadence in the 7-year-olds is ~ 26% more than the normal adult's mean.

Musculoskeletal Variables

- Mean values for range of motions are presented therein for the left and right sides. There was no significant difference between sides ($p < 0.01$) for any age groups and for either gender.
- Hip internal rotation has a substantial variability throughout 1 to 7 years of age. Median range of passive hip internal rotation varies between 53° and 60°.

17.5 Study Summary (Continued)

Results (Continued)
▪ Median range of hip adduction throughout 1 year to 7 years was 20°. ▪ Hip abduction at 1 year shows a median range of passive hip abduction of 55°. At 7 years, the median range of passive hip abduction has gradually diminished to 45°. ▪ At 7 years, the straight leg raise test exceeded range of motion of most adults. ▪ Ankle dorsiflexion, straight leg raise test, hip abduction and external rotation gradually decreased with age. Dorsiflexion, from 1 year to 7 years, shows a significant decline with increasing age, from 25° at 1 year to 15° at 7 years. At 1 year, hip ext ernal rotation is greater than hip internal rotation. At 2 ½ years, hip internal rotation is greater than hip external rotation. ▪ Complete extension of the hip to 10° across all ag e-groups is in disagreement with other authors. ▪ The greatest spread of data in normal children for femoro-tibial alignment was in the direction of valgus. Results show similar trends as other studies but with greater variability and may be due to different measurement methods such as X rays versus clinical measurements. ▪ Finfings are consistent with other studies but some discrepancy exists with others which may be explained by the much larger sample size of the present study, the use of a permanent laboratory setting and in the assessment of free-speed gait.
Authors' Conclusion
Normative data for gait parameters, anthropometric and musculoskeletal measurements are available for normal children aged from 1 to 7 years. The ranges of motion are to be used as guidelines. The authors report that it would be unwise to label a child abnormal if he shows minor deviations from the presented values.

Comments
Internal and external validity (including sample size, *n* = 36 to 49 per age group) seems good and the use of results as a trend for clinical guidelines is appropriate.

18. Tibiofemoral Angle, Intercondylar and Intermalleolar Distances in Supine and Standing [21]

Age range: 6 months to 11 years.

18.1 Clinical Use

- Provides a standard method to assess knee angle alignment (genu varum, genu valgum).

18.2 Measurements

- TF angle is measured in degrees (Fig. 4.63).
  - A minus sign (-) denotes a valgus angle.
  - A plus sign (+) denotes a varus angle.
- IC distance is measured in cm. A plus sign (+) denotes genu varum (Fig. 4.63).
- IM distance is measured in cm. A minus sign (-) denotes genu valgum (Fig. 4.63).

18.3 Testing Procedures

Required equipment

- Tape measure for IM and IC distances.
- Standard goniometer for TF angle.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.
- Examination table.

Pre-Test

- Mark the following anatomical landmarks:
  - The femoral medial condyles (if measuring genu varum);
  - The center of the medial malleoli (if measuring genu valgum).

- To measure the TF angle (Fig. 4.60), small dots (~5mm) are marked over the:
  - Anterior superior iliac spine (ASIS);
  - Centers of patellae;
  - Mid point of the ankles.

Test

- TF angle
  - Testing positions, goniometer alignment and measurements are presented in Table 4.34.
  - Results are compared to the normative reference values in Figure 4.63.
  - Note: In the present study, the children were photographed and the TF angle was calculated on projected images. In clinical practice, a goniometer is commonly used.[3, 7]
- IC and IM distances
  - Testing positions and measurements are presented in Table 4.35.
- Results are compared to the normative reference values in Figure 4.63.

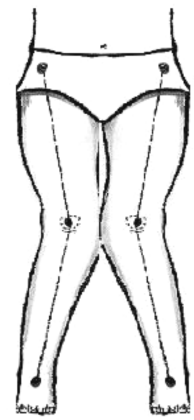
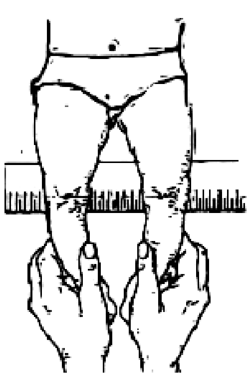
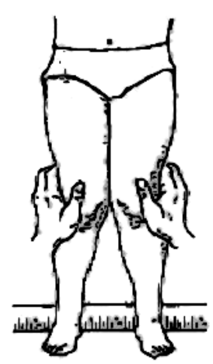
TABLE 4.34. TF ANGLE	
Testing Position	 **Figure 4.60. Clinical determination of the TF angle.**(© IRDPQ – 2008).
< 2 years ▪ The child is held in supine in anatomic position. ▪ Hips and knees in maximal extension (slight flexion generally exist < 1 year). ▪ Medial condyles or malleoli touching. **2 to 11 years** ▪ Standing in anatomic position. ▪ Hips and knees in maximal extension. ▪ Medial condyles or malleoli touching.	
Goniometer Alignment and Measurements	
▪ TF angle is measured by placing : ♦ The axis of the goniometer over the center of the patella; ♦ The upper arm in line with the ASIS; ♦ The lower arm in line with the center point between the malleoli (Fig. 4.60).	

TABLE 4.35. IC AND IM DISTANCE	
Testing Position	
< 2 years ▪ The child is held in supine in anatomic position. ▪ Hips and knees in maximal extension (slight flexion generally exist < 1 year). ▪ Medial condyles or malleoli touching. **2 years to 11 years** ▪ Standing in anatomic position. ▪ Hips and knees in maximal extension. ▪ Medial condyles or malleoli touching.	
Alignment and Measurements	
▪ **Genu varum**: With the medial malleoli in contact, measure the distance in cm between the medial condyles (Fig. 4.61).	▪ **Genum valgum**: With the femoral medial condyles in contact, measure the distance in cm between the medial malleoli (Fig. 4.62).
 **Figure 4.61. IC distance. A plus sign (+) denotes genu varum.** (© IRDPQ – 2011)	 **Figure 4.62. IM distance. A minus sign (-) denotes genu valgum.**

18.4 Normative Reference Values

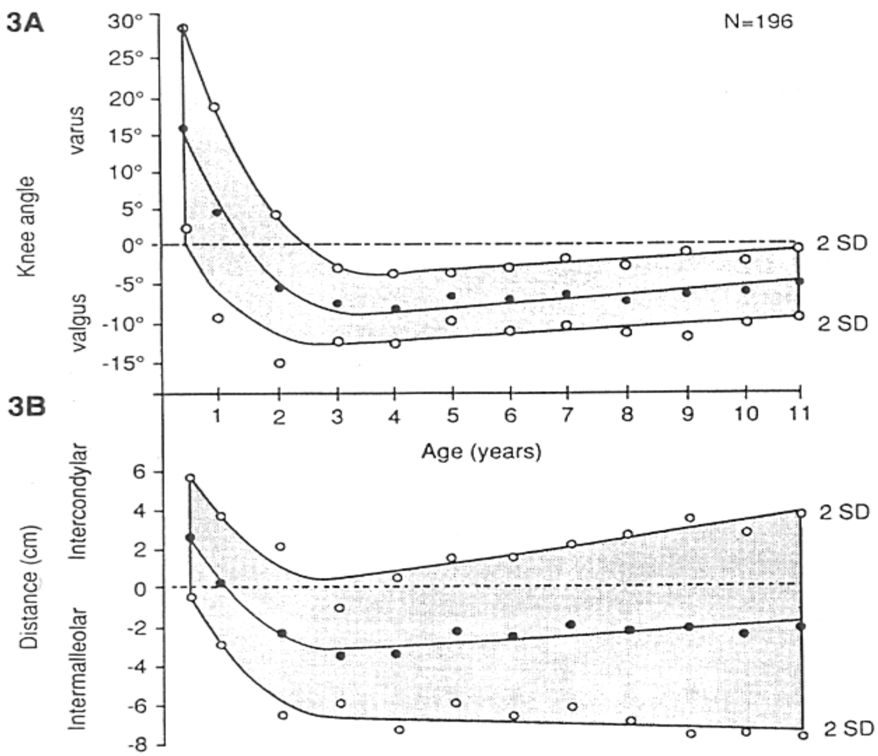


FIG. 3. For each of the 12 age groups, mean values (solid circles) and 2 SD (open circles) were plotted for knee angle **(A)** and intercondylar or intermalleolar distance **(B).** Lines and shaded areas show general trends.

©Heath, C. H. and Staheli, L. T. (1993) Normal limits of knee angle in white children-genu varum and genu valgum Journal of Pediatric Orthpaedics, 13, p.261. [21]

18.5 Medical Guidelines

- Genu varum is clinically accepted in children up to the age of 2 years.
- TF angle and IM, IC distances are defined in normal ranges when values are within 2 SD of the mean. Values beyond these limits are viewed as the threshold for concern.

18.6 Clinical example for TF angle

- 7-year-old boy:
  - TF angle = + 5°. Value is not within 2SD from the m ean of his age group and indicates genu varum (Fig. 4.63 A).

18.7 Clinical example for IM distance

- 5-year-old boy:
  - IM distance = - 4 cm. Value is within the 2SD range of the mean of his age group and indicates normal valgus angle.

18.8 Study Summary

Title: Normal Limits of Knee Angle in White Children-Genu Varum and Genu Valgum [21]	
Authors	Heath C. H, & Staheli L. T.
Publication	Journal of Pediatric Orthopaedics, 13, 259-262.
Purpose of the Study	To establish mean values and normal ranges for knee angle (KA), intercondylar distance (IC) or intermalleolar (IM) distance in white children. To describe differences that may exist between different ethnic groups.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of alignment of the lower extremities.

Methods

Subjects

- The study sample consisted of 196 healthy children (106 ♂ and 90 ♀). Caucasian; USA.
- 392 lower limbs were tested.
- Age range: 6 months to 11 years.
- Children were divided into 12 age groups based on their chronological age. The lowest number of subjects was in the 11-year-old group (n = ~13) and the highest number of subjects was in the 3-year-old group (n = ~ 25).

Testing Procedures and Instrumentation

- Measurements of KA, IM and IC distances were made by the same tester. Testing position was standardized. Instrumentation: Tape measure, goniometer and a camera for KA.

Data Analysis

- Mean, standard deviation and range were calculated for all measurements.
- Norms for KA in degrees and IM and IC distances are reported therein. Number of subjects per age category is small, but data is clinically interesting.
- KA, IM and IC distance measurements were compared between male and female subjects in each of the 12 age groups by the Mann-Whitney rank-sum test.

Results

- **Psychometric Properties**: Non applicable.
- Results are consistent with other studies. Authors report discrepancy with a study from China in KA measurements that can be explained by racial differences and the use of different measurement techniques.
- Normal limits established in this study for white children are of additional clinical significances in that they may be used to provide practical and accurate screening, influencing decisions regarding the necessity for further clinical and radiological assessment.
- **KA:** There is a trend from extreme bowlegs at age < 18 months to maximum knock knees at 4 years, followed by a gradual progression toward a neutral knee angle (0°). The greatest mean varus of 15.9° (SD 6.7°) at 6 months was followed b y a transitional phase to valgus at 1 and 2 years of age. Maximum valgus of 8.7° (SD 2.4°) was observed at 4 years with significant differences ($p < 0.05$) between sexes with girls being more knock-kneed. At age ≤11 years, all children continued to demonstrate mean valgus of 5.8° (SD 2.3°).
- **IC and IM Distances:** Measurements showed a similar trend to KA, from extreme varus at 6 months to maximum valgus between 3 and 4 years of age. The mean IC distance of 2.6 cm (SD 1.5 cm) at 6 months, ranging from 0 to 4.5 cm, was replaced by IC distance of ~ 0 cm at 1 year. The greatest IM distances of 3.5 cm (SD 1.3 cm) and 3.5 cm (SD 2.0 cm) were noted at 3 and 4 years, respectively. IM distance persisted in children after age 4 years with a minimum of 2.1 cm (SD 2.2 cm) at 7 years of age.

18.8 Study Summary (Continued)

Authors' Conclusion
▪ White children are maximally bowlegged at 6 months and progress toward approximately neutral knee angles (0°) by age 18 months. Between 2 and 11 years, they exhibit ≤12° physiologic valgus. The presence of varus during this period is considered abnormal according to the limits set forth in the present study.

Comments
▪ Internal validity seems good. However, sample size is small in most of the age groups (except the 3-, 4- and 7- years old), and the data should be considered with caution in the small sample age-groups. Internal and external validity in the other age groups, including sample size, seems good and the use of results as a trend for clinical guidelines is appropriate.

19. Tibiofemoral Angle, Intercondylar and Intermalleolar Distances in Standing [7]

Age range: 10 years to 16 years.

19.1 Clinical Use

- Provides a standard method to assess knee angle alignment (genu varum, genu valgum).

19.2 Measurements

- TF angle is measured in degrees (Fig. 4.67).
  - A plus sign (+) denotes a valgus angle
  - A minus sign (-) denotes a varus angle.
- IM distance is measured in mm. A minus sign (-) denotes genu valgum (Fig. 4.68).
- IC distance is measured in mm. A plus sign (+) denotes genu varum (Fig. 4.68).

19.3 Testing Procedures

REQUIRED EQUIPMENT

- Tape measure for IM and IC distances.
- Standard goniometer for TF angle.
- Hypoallergenic skin cosmetic crayon to mark anatomical landmarks.
- Examination table.

PRE-TEST

- To measure the TF angle (Fig. 4.64), small dots (~5mm) are marked over the:
  - Anterior superior iliac spine (ASIS);
  - Centers of patellae;
  - Mid-point of the ankles.
- To measure IM or IC distances, mark the following anatomical landmarks:
  - Femoral medial condyles;
  - Center of the medial malleoli.

TEST

- TF Angle
  - Testing position, goniometer alignment and measurements are presented in Table 4.36.
  - Results are compared to the normative reference values in Figure 4.67.
- IC and IM distances
  - Testing positions and measurements are presented in Table 4.37.
  - Results are compared to the normative reference values in Figure 4.68.

TABLE 4.36. TF ANGLE

Testing Position

- Standing in anatomic position, with either the knees or the ankles just touching.
- Hips and knees in complete extension with the patellae straight ahead.
- The child's arms are placed behind his back to increase the stability of the posture.

Goniometer Alignment and Measurements

TF angle is measured by placing:

- The axis of the goniometer over the center of the patella;
- The upper arm in line with the ASIS;
- The lower arm in line with the center point between the malleoli (Fig. 4.64).

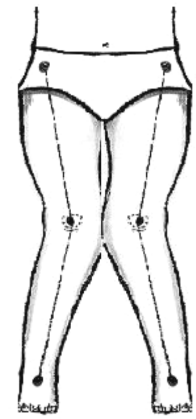


Figure 4.64. Clinical determination of the TF angle. (© IRDPQ – 2008).

TABLE 4.37. IC AND IM DISTANCE

Testing Position

- Standing position, with either the knees or the ankles just touching.
- Hips and knees in complete extension with the patellae straight ahead.
- The child's arms are placed behind his back to increase the stability of the posture.

Alignment and Measurement

- **Genu varum**: With the medial malleoli in contact, measure the distance in mm between the medial condyles (Fig. 4.65).
- **Genum valgum**: With the medial condyles in contact, measure the distance in mm between the medial malleoli (Fig. 4.66).

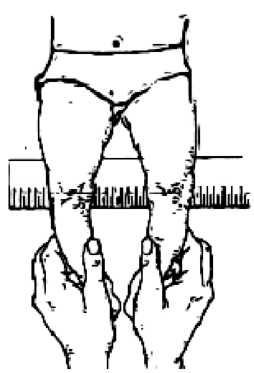
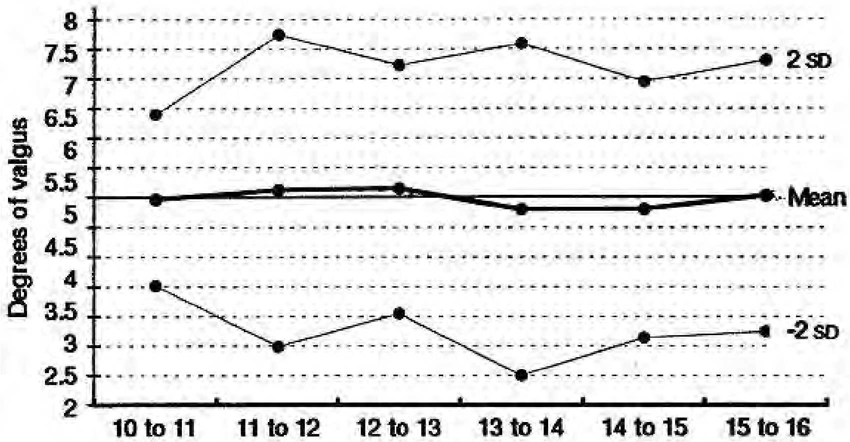


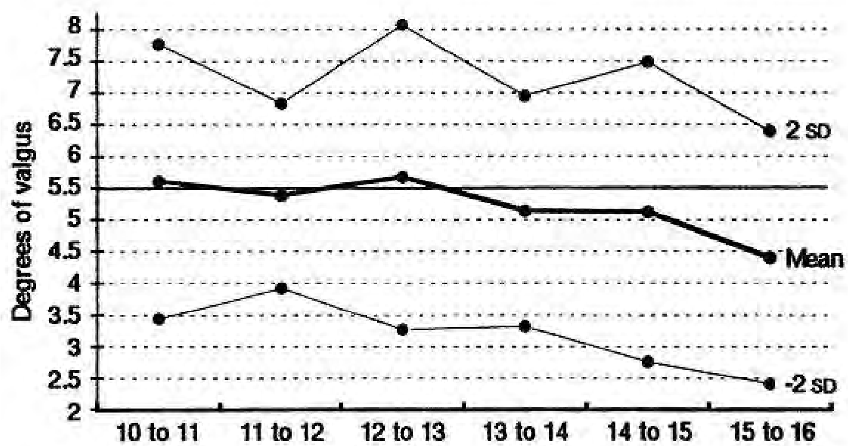
Figure 4.65. IC distance. (© IRDPQ – 2011)

Figure 4.66. IM distance. (© IRDPQ – 2011)

19.4 Normative Reference Values



TF angle of girls related to age in years.



TF angle of boys related to age in years.

Figure 4.67. Mean and two standard deviations (SD) in degrees for tibiofemoral (TF) angle in girls and in boys. Reprinted from : Cahuzac JP, Vardon D, Sales de Gauzy J. p. 730. [7]

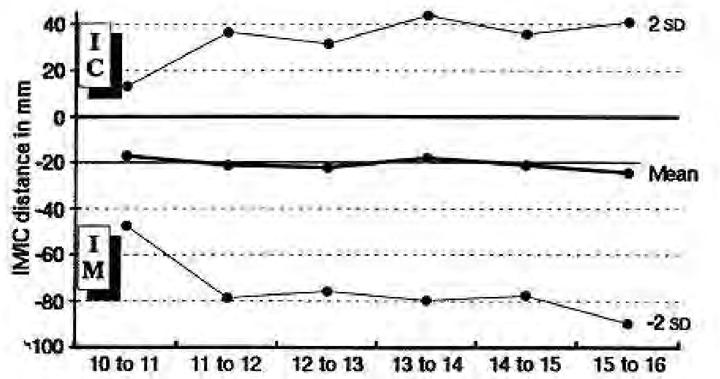
19.5 Clinical Example

- 13-year-9 month old girl: TF angle = + 7.5°. Value is within the mean of her age group but at the + 2 SD limit. Value represents important genu valgum. Close follow-up and orthopedic referral is suggested.

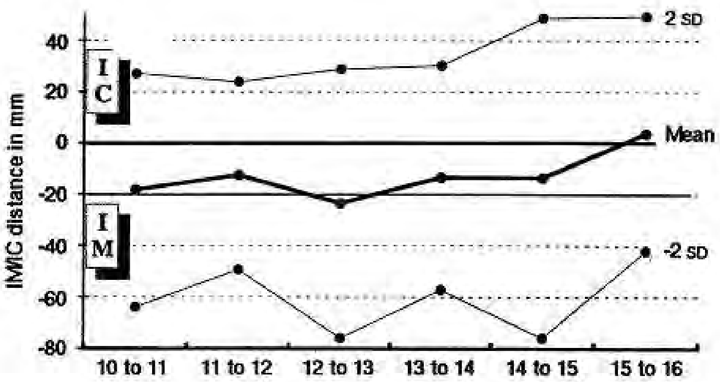
19.6 Clinical Practice Guidelines[7]

- No correlation was found between the TF angle and standing height, leg length and weight.
- Up to 13 years of age, mean valgus angle is 5.5°f or boys and girls.
- After 13 years of age, valgus angle differs according to gender and decreases in boys to a mean of 4.4° .
- Children showing greater values than these for genu varum or genu valgum may require careful follow-up and evaluation.[7]

19.7 Normative Reference Values



IC or IM distance of girls related to age in years.



IC or IM distance of boys related to age in years.

Figure 4.68. Mean and two standard deviations (SD) for IC and IM distance in mm in girls and in boys.

Reprinted from : Cahuzac JP, Vardon D, Sales de Gauzy J. [7]

19.8 Clinical Practice Guidelines

- Girls showed no significant change with growth.
- Boys: IC distance increased from the age of 14 years (-2 cm) to the end of growth (+0.5 cm).
- Children showing greater values than these for genu varum or genu valgum may require careful follow-up and evaluation.[7]

19.9 Study Summary

Title: KA and IC and IM Distance [7]	
Authors	Cahuzac, J. P., Vardon, D., & Sales De Gauzy, J.
Publication	The Journal of Bone and Joint Surgery, British Volume, 77-B, 729-732
Purpose of the Study	To determine the mean values and normal range for the tibiofemoral (TF) angle, intercondylar (IC) distance and intermalleolar (IM) distance in European children aged from 10 to 16 years.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of alignment of the lower extremities.

Methods

Subjects

- The study sample consisted of 427 healthy children (215 ♀, 212 ♂). France.
- Age range**:** 10 years to 16 years.
- Children were divided into six age-groups based on their chronological age. The lowest number of subjects was 56 and the highest number of subjects was 90.

Testing Procedures and Instrumentation

- All measurements were made by the same examiner using standard techniques for TF angle, IC-IM distances. TF angle was measured using the method of Heath & Staheli.
- Anthropometric measurements were weight, height and leg lengths.
- Testing position was standardized in standing.
- Instrumentation: Standard goniometer, measuring tape.

Data Analysis

- Intra-examiner variability was measured with ten children (20 measurements). Each child had repeated measurements at one-month intervals.*
- Linear regression, determination coefficient, analysis of variance and independent sample t-tests were used. Null hypothesis was rejected at ($p < 0.05$). Mean, standard deviation and range were calculated.

Results

- **Psychometric Properties**: Non applicable.
- The average SD for the measurements was 0.93 degree for the TF angle and 6.25 mm for the IC - IM distance.
- Intra-examiner variability* lies within the average range of other studies. The discrepancy between the mean values reported by Cheng et al. could result from racial difference.

TF Angle

- Mean values and normal ranges are reported therein. There were no significant differences between sexes until the age of 14 years ($p > 0.3$). Boys after 14 years of age showed a gradual and significant decrease of the valgus angle to 4.41 degrees ($p < 0.001$). At 16, boys were more bow-legged than girls ($p = 0.0004$).

* Intra-tester variability is not to be interpreted as intra- tester reliability.

19.9 Study Summary (Continued)

Results
IC-IM Distances ▪ Mean values and normal ranges are reported therein. Girls showed no significant change with growth. IC distance in boys increased from the age 14 years (-2 cm) to the end of growth (+0.5 cm). **TF Angle Versus IC-IM Distances** ▪ Correlation between those two measurements was significant. Determination coefficient for boys of $r^2 = 0.82$. For girls $r^2 = 0.74$. The TF angle measurement was more accurate because the SD of the IC or IM distance was greater than the mean value. **Standing Height, Leg Length and Weight** ▪ No correlation was found between TF angle and standing height, leg length or weight. Similar results were found between the IC distance, IM distance and the three variables. Obesity did not increase TF angle or IM distance. Results show that until 13 years of age, the valgus angle was 5.5 degrees for boys and girls. A new finding was that after 13 years of age, the angle differed according to gender. Girls had a constant valgus of 5.5 degrees whereas the valgus decreased in boys to a mean of 4.4 degrees. Authors report that conclusions concerning the aetiology of the normal growth pattern in healthy adolescent boys cannot be drawn from this study
Authors' Conclusion
In the present study, girls had a constant valgus (5.5 degrees) and displayed an IM distance of < 8 cm or an IC distance of < 4 cm. By contrast, boys had a varus evolution (4.4 degrees) during the last two years of growth and displayed an IM distance of < 4 cm or an IC distance of < 5 cm. Values above these for genu varum or genu valgum may require careful follow-up and evaluation.

Comments
Internal and external validity, including sample size (*n* varied between 56 and 90 in each group) seems good and the use of results as a trend for clinical guidelines is appropriate. The discrepancy existing between the present study and Cheng et al. (1991) [8] was also reported by Heath et al. (1993) [21] showing possible racial differences in leg alignment.

Joint Hypermobility

Summary

Joint hypermobility (JH) or ligamentous laxity is a common benign phenomenon in healthy children and usually diminishes throughout childhood [1, 11, 15, 27] as mobility decreases as age increases. [27] Children are reported to be more flexible than adults and hypermobility is considered present when joint range of motion is excessive. [6, 13, 22, 30]

Joint hypermobility usually does not influence the physical functioning and the physical and psychosocial welfare of healthy children. [34] Not all hypermobile children will be symptomatic or will develop musculoskeletal problems later in life. [30] However, in a small proportion of children, joint hypermobility may progress with other musculoskeletal complaints derived from the joint hypermobility condition without a demonstrable systemic rheumatological disease. This condition is recognized as the Joint Hypermobility Syndrome (hypermobility + symptoms = Joint Hypermobilty Syndrome). [1, 17]

Joint hypermobilty syndrome (JHS) is also called benign joint hypermobility syndrome (BJHS). The term "benign" is used to differentiate the condition from more important musculoskeletal syndromes. [33]

CLINICAL SYMPTOMS

There appears to be a trend towards a greater frequency of articular complaints in hypermobile children compared to age and sex matched controls.[2] There is an association between joint hypermobility and arthralgia. [1, 6, 11, 15, 17, 30] It was observed that up to 40% of JH children had developed symptoms of arthralgia in one year and are the ones that are usually seen in pediatric rheumatology. [2, 11, 15] Joint complaints in the lower limbs are symptoms often reported. [13, 30]

Some children with JHS may present delayed motor development, poor balance skills and clumsiness. [1, 50] Children may present loss of function. [1] Poor coordination, limitations in physical activities or in school physical education activities and significant absences from school are reported because of symptoms. [1]

AGE, GENDER AND ETHNIC CHARACTERISTICS

Hypermobile joints present a range of motion that exceeds the norm for that subject taking into consideration age, sex and ethnic characteristics. [2, 6, 13, 22, 36, 43] These three variables are factors that seem to have the most impact on the degree of joint mobility. [22, 27, 33, 47]

JH would appear to be specific to a given population. The criteria should be adjusted according to age group [27]. It is suggested that each country or geographic region would need to evaluate its specific criteria in order to obtain its own specific cut-off score. Since there are no "gold standards", (no universally accepted diagnostic criteria), testing BJHS is a particular diagnosis problem. [17, 33]

There exist different screening tests for JH and these tests hould be used as clinical guidelines. The clinician must take into consideration the limits of generalizing the results.

SCREENING TESTS

Two different screening tests to assess JH were selected:

- Beighton Score Index; [43]
- Lower Limb Assessment Score (LLAS). [13]

BEIGHTON SCORE INDEX [43]

A most widely screening test for detecting generalized joint laxity is the Beighton Score Index (BSI). [11, 43] It is clinically easy to use [22, 43] and is reported to be suitable for epidemiological studies. [43]
The BSI is designed to assess JH and is a complementary tool to the diagnosis of Joint Hypermobilty Syndrome. [50] It is not used as the sole criterion for diagnosis of JHS. [30] For more detailed information, we refer the reader to Table 4.41, for consultation on the revised diagnostic criteria for the benign joint hypermobility syndrome.

The BSI documents the joint laxity distribution, but it does not indicate the degree of hypermobility [50] and focuses more in the upper extremities than the lower extremities. The use and the set cut-off score of the Beighton score index in children is cited as being a controversial issue in the literature. [13, 22, 27]

VALIDITY AND RELIABILITY

- A review of the literature by Remvig et al. (2007) [33] reports that the Beighton scoring recommendations were correlated with a global joint mobility index as well as with two other scoring systems, the Carter and Wilkinson, and the Rotes-Querol. All illustrate high concurrent validity with one another.

- For additional information on the Beighton Score Index, refer to the ‘’up to date’’ pages at the end of the reference pages.

LOWER LIMB ASSESSMENT SCORE (LLAS) [13]

LLAS is another screening test that is used to measure hypermobility, specifically in the lower limbs.
Inter-tester reliability was reported to be 0.84 (Intraclass correlation coefficient).

20. Beighton Score Index [43]

Age range: 4 years to 12 years.

20.1 Clinical Use

- Screening test used to detect generalized joint laxity**.**

20.2 Measurements

- Nine movements (four on each side of the body) and one trunk flexion movement are assessed. In the present study, the two first movements were passively performed by the tester and the three last movements were actively performed by the child (Table 4.38).
- None of the parameters can be used separately since the finding in one joint does not imply that it is present in other joints. [27]

TABLE 4.38. BEIGHTON SCORE INDEX CLINICAL MANEUVERS	
1. Passive dorsiflexion of the little finger bilaterally (Fig. 4.69).	Performed by the tester without causing pain.
2. Passive wrist flexion and thumb opposition bilaterally (Fig. 4.70).	
3. Active elbow extension bilaterally (Fig. 4.71 , A and B).	Performed by the child
4. Active knee hyperextension bilaterally (Fig. 4.72, A and B).	
5. Active trunk and hip flexion (Fig. 4.73).	

20.3 Testing Procedures

REQUIRED EQUIPMENT

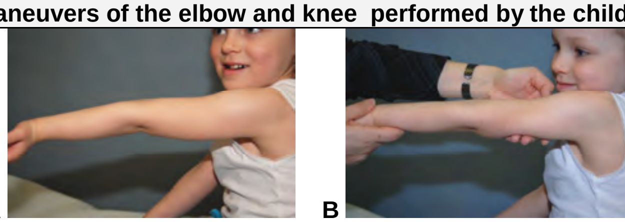
- A gravity goniometer can be used to measure elbow and knee extension (Fig. 4.72-A).
- Beighton Score Index sheet (Table 4.39).

PRE-TEST

- Initial training is required if the clinician is not familiar with the set criteria and positioning.
- Prior to the assessment, familiarize the child with the testing procedures by showing the illustrations of the testing positions (Table 4.39).
- The child is dressed in comfortable clothing.

TEST

- Standardized method and scoring for each of the nine testing positions are described in the BSI score sheet (Table 4.39).
- Calculation of the Beighton Score [43]
  - The first four items are conducted both on the right and the left sides. A score of one point is given for each movement if the criterion is met. A score of zero is given if the criterion is not met.
  - The scores are summed to yield a total score ranging from 0 to 9.
- Results (the total score) are compared to the BSI cut-off point score, according to age, to determine if the child is hypermobile or not (Table 4.40).

Table 4.39. BSI Score Sheet	*- Hypermobility Positive Test = 1.* *- Criterion not met = 0.*	
Passive clinical maneuvers of the hand performed by the tester without causing pain	**Left**	**Right**
 **Figure 4..69** Passive dorsiflexion of the fifth finger of more than 90° with the wrist in mid position.	0 1	0 1
 **Figure 4.70** Passive movement of the thumb so that the thumb touches the ventral side of the lower arm.	0 1	0 1
Active clinical maneuvers of the elbow and knee performed by the child		
A  **B** **Figures 4.71** **A** : Active extension of the elbow of more than 10°. **B** : The rater may lead the movement but not conduct it passively.	0 1	0 1
A  **B** **Figures 4.72** **A** : Lying supine, active extension of the knee of more than 10°. **B** : The rater may lead the movement but not conduct it passively.	0 1	0 1
 **Figure 4.73** Bending forward with stretched knees so the palms of the hand touch the ground. The rater may guide the movement.	0 1	
TOTAL SCORE		
The total score is compared to the cut-off point: Table 4.40.		

Data from Van der Giessen et al. (2001), p. 2728. [43]

TABLE 4.40. THE CUT-OFF POINT SCORE ADJUSTED ACCORDING TO AGE SCORE [43]	
To report a positive Beighton score, an indicator of generalized hypermobility, the total score is compared to the BSI cut-off point score.	
Age	**Cut-off point score set at:**
In children 4 - 9 years	≥ 5
In children ≥10 years	≥ 4

Data from : Van Der Giessen et al (2001), p. 2729. [43]

20.4 Study Summary

Title: Validation of Beighton Score and Prevalence of Connective Tissue Signs in 773 Dutch Children [43]	
Authors	Van Der Giessen, L. J., Liekens, D., Rutgers, K. J., Hartman, A., Mulder, P. G., & Oranje, A. P.
Publication	The Journal of Rheumatology, 28, 2726-2730.
Purpose of the Study	To validate the Beighton Score for Dutch children. To determine the prevalence of connective tissue signs in a particular connective tissue disorder.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	Assessment of generalized joint hypermobility.

Methods

Subjects

- The study sample consisted of 773 healthy children (378♀, 395♂). The Netherlands.
- Age range: 4 years to 12 years.

Testing Procedures and Instrumentation

- Prior to the present study, the testers (2) received one month of training with the Beighton Score (BS). A pilot study for inter-tester variation was conducted with 48 children. Children were familiarized with the examination procedures by showing them photographs. The children did 2 passive movements of the Beighton Score and the other movements were conducted by the testers. Joint mobility, connective tissue signs and hand dominance were assessed. Testing positions were standardized. Instrumentation: The Beighton Score index.

Data Analysis

- Chi-square test, Spearman rank correlation coefficient, Wilcoxon rank-sum test, McNemar and Kappa coefficient were calculated for different variables.

Results

Psychometric Properties: Good inter-tester agreement was observed (Kappa=0.81) in a pilot study.

- Connective tissue signs occurred only incidentally.
- For joint mobility: A score of ≥ 4 was observed in 20.8% (range 0-49%) of children. There was a significant negative rank correlation (r_s = -0.451, p≤ 0.0005) with the BS and age. The older the child, the lower the score. There was good agreement (kappa = 0.65) between the measurement on the left and the right sides at all ages.
- Generalized hypermobility was observed in 5.8% of children aged 4-9 years when a cut-off point ≥ 5 was used.
- Generalized hypermobility was observed in 5.3% of children older than 10 years when a cut-off point ≥ 4 was used.
- Results are comparable with other studies but discrepancies with another study in the difference in percentage of children having hypermobility could not be explained. There was no significant difference between genders in joint mobility and connective tissue signs.

Authors' Conclusion

- The present study validated the criteria for performing the Beighton Score in Dutch children. A cut-off point of ≥ 5 is suitable for children aged between 4 and 9 years and a cut-off point ≥ 4 for children over 10 years. Authors report that there is no reason to assume that there is a higher % of hypermobile children in the Netherlands and, although it is not possible to extrapolate the data, findings are suspected to be relevant for caucasian children.

20.4 Study Summary (Continued)

Comments
▪ Internal and external validity, including sample size (*n* = 773) seems good and the use of results as a trend for clinical guidelines is appropriate. ▪ Clinicians must be aware of the limits in generalizing the results to different ethnic backgrounds.
TABLE 4.41. REVISED DIAGNOSTIC CRITERIA FOR THE BENIGN JOINT HYPERMOBILITY SYNDROME (BJHS) [60]
Major Criteria ▪ A Beighton score of 4/9 or greater (either currently or historically). ▪ Arthralgia for longer than 3 months in 4 or more joints. **Minor Criteria** ▪ A Beighton score of 1, 2 or 3/9 (0, 1, 2 or 3 if aged 50+). ▪ Arthralgia (> 3 months) in one to three joints or back pain (> 3 months), spondylosis, spondylolysis/spondylolisthesis. ▪ Dislocation/subluxation in more than one joint, or in one joint on more than one occasion. ▪ Soft tissue rheumatism > 3 lesions (e.g. epicondylitis, tenosynovitis, bursitis). ▪ Marfanoid habitus (tall, slim, span/height ratio >1.03, upper-lower segment ratio less than 0.89, arachnodactily [positive Steinberg/wrist signs]). ▪ Abnormal skin: striae, hyperextensibility, thin skin, papyraceous scarring. ▪ Eye signs: drooping eyelids or myopia or antimongoloid slant. ▪ Varicose veins or hernia or uterine/rectal prolapse. **Diagnosis of BJHS** ▪ Positive if in the presence of two major criteria, or one major and two minor criteria, or four minor criteria. ▪ Two minor criteria will suffice where there is an unequivocally affected first-degree relative. The new criteria were validated in adults but not in children ≤16 years.

21. Lower Limb Assessment Score [13]

Age range: 7 years (SD 1.9 years).

21.1 Clinical Use

- The Lower Limb Assessment Score (LLAS) measures hypermobility exclusively in the lower limbs in children.

21.2 Measurements

The LLAS is a composite scoring system of 12 joint movements occurring in several planes of motion, assessed in the lower limbs, on both sides (Table 4.42).

1. Hip abduction.
2. Hip flexion.
3. Knee hyperextension.
4. Knee anterior draw test.
5. Knee rotation.
6. Ankle joint dorsiflexion.
7. Ankle anterior draw test.
8. Subtalar joint inversion.
9. Midtarsal joint inversion.
10. Midtarsal joint ab/adduction and dorsi / plantar flexion.
11. Metartarso-phalangeal movement.
12. Excessive subtalar joint pronation.

21.3 Testing Procedures

Required equipment

- Ruler with cm increments (optional).
- Standard goniometer to respect standardized testing positions.
- Hypoallergenic cosmetic skin pencil to mark anatomical bony landmarks.
- Examination table.

Pre-Test

- Initial training is required if the clinician is not familiar with the set criteria and positioning used to isolate the joints.
- The child is barefoot.

Test

- Testing positions:
  - Standing for excessive subtalar joint pronation;
  - Supine for all other measurements.
- The standardized method for each of the 12 assessed movements is described in Table 4.42.
- The calculation of the LLAS is explained in Table 4.43:
  - The 12 items are conducted both on the right and the left sides. A score of one point is given for each movement if the criterion is met. A score of zero is given if the criterion is not met;
  - For each side, the scores are summed to yield a total score ranging from 0 to 12.
- The total score of each side is compared to the LLAS cut-off point score, set at ≥7, to determine joint hypermobility.

Table 4.42. Lower Limb Assessment Score	LEFT		RIGHT	
HIP FLEXION – The patient lies supine; the examiner flexes one hip fully; the other leg must stay fully extended on the couch. Does the mid-anterior area of the thigh drop easily onto the stomach/chest with a loose feel to the movement, using a minimum to moderate application of force?	YES	NO	YES	NO
HIP ABDUCTION – The patient lies supine, with hip and knees flexed; the knees are dropped outwards and down to the couch, the soles of the feet remain together. With the examiner's hand against the lateral femoral condyle, can the knees come down to the couch sufficiently to let the back of the examiners hand touch the couch? - minimal application of force required.	YES	NO	YES	NO
KNEE HYPEREXTENSION – The patient lies supine; the knees are relaxed and straight; With minimal force, keeping the femoral condyles on the couch, can the heel be lifted at least 3 cm off the couch (greater than 2 finger widths)?	YES	NO	YES	NO
KNEE ANTERIOR DRAW TEST – The patient is supine; the hips and knees (90°) are flexed; the examiner gently sits of the foot to stabilise it; moderate pressure is placed against the femoral condyles as the tibia is pulled forwards. Is there a definite, obvious forward movement of the tibia against the femur? Palpable "clunking" of the joint surfaces moving against each is indicative of a positive draw sign.	YES	NO	YES	NO
KNEE ROTATION – The patient lies supine; the examiner flexes the hip and knee to 90° and palpates the tibial tubercle; holding the malleoli and ankle firmly, the tibia is rotated medially and laterally on the femur. Normal movement is 1cm medially and laterally. Does the tubercle move easily beyond 1cm in any direction or greater than 2 cm overall? With increased internal movement the head of the fibula/lateral condyle of the tibia may also be seen to move.	YES	NO	YES	NO
ANKLE JOINT DORSIFLEXION – The patient lies supine; the knee is flexed to 45°; with moderate to strong force the ankle is dorsiflexed. Does the ankle flex more than 15 degrees? Along with the increased movement there may be bulging of the skin and subcutaneous fat anterior to the ankle.	YES	NO	YES	NO
ANKLE ANTERIOR DRAW TEST – The patient lies supine; the knee is flexed to 45°; the examiner grasps the heel along the plantar and posterior surfaces with one hand and applied a stabilising force against the anterior of the tibia with the other hand. Using a strong anterior force, can the calcaneum and talus be brought forwards on the tibia? Any forward movement felt is a positive result.	YES	NO	YES	NO
SUBTALAR JOINT INVERSION – The patient is supine with their feet over the end of the couch; the examiner holds the posterior surface of the heel and moves the heel into inversion without moving the leg. Is excessive inversion of the subtalar joint seen using minimal force? The sole of the foot or visualisation of the neck of the talus should show movement of 45° inwards, the lateral head of the talus will be very prominent.	YES	NO	YES	NO
MIDTARSAL JOINT INVERSION – The patient is supine with their feet over the end of the couch; the midtarsal joint is isolated from the subtalar joint; the forefoot is grasped from lateral to medial along the metatarsals; only minimal - moderate force is applied to invert the midtarsal joint. Does the midtarsal joint invert beyond 45° so that the plantar surface of the metatarsal heads can be brought inwards by 45 degrees?	YES	NO	YES	NO
MIDTARSAL JOINT AB/ADDUCTION AND DORSI/PLANTARFLEXION – The patient is supine with their feet over the end of the couch; the examiner grasps and stabilises the rearfoot; the forefoot is moved in the direction of ab/adduction and dorsi/plantarflexion. Normal movement should be 1 cm in each direction. With minimal force, does the forefoot move easily, almost "wobbling", in an increased amount? Excessive movement in either of the two planes is a positive result.	YES	NO	YES	NO
METATARSOPHALANGEAL MOVEMENT – The patient is supine with their feet over the end of the couch; the hallux is dorsiflexed using minimal – moderate force. Does the hallux dorsiflex easily beyond 90° relative to the metatarsal?	YES	NO	YES	NO

Table 4.42. (Continued).

Lower Limb Assessment Score	LEFT		RIGHT	
EXCESSIVE SUBTALAR JOINT PRONATION – The patient is to march on the spot and stop on command; the patient is asked to invert their foot and hold the position close to subtalar joint neutral; the patient is then asked to relax their foot; the movement is observed. Does the arch lower and flatten fully, excessively and easily, with the talus bulging medially ? The pronation noted should be at the end of range of the subtalar joint motion so that no further pronation is possible	YES	NO	YES	NO
To score, each limb is calculated separately giving a left score and right score. Each YES is given one mark. A total of score of 12 marks is available.	TOTAL:			

Reprinted with permission from Ferrari J, Parslow C, Lim E, Hayward A. (2005) Joint Hypermobility : The use of a new assessment tool to measure lower limb hypermobility, p 419-420. [13]

Calculation

TABLE 4.43. CALCULATION OF THE LLAS SCORE

- Each limb is calculated separately, giving a left score and a right score. If the criterion is met, a score of one point is given. If the criterion is not met, a score of zero is given (Table 4.42).
- The scores are summed to yield a total score ranging from 0 to 12 for each side.

LLAS Clinical Maneuvers	***- Hypermobility Positive Test = 1. - Criterion not met = 0.***			
	Left side		**Right side**	
	Negative	*Positive*	*Negative*	*Positive*
Hip flexion	*0*	*1*	*0*	*1*
Hip abduction	*0*	*1*	*0*	*1*
Knee hyperextension	*0*	*1*	*0*	*1*
Knee anterior draw test	*0*	*1*	*0*	*1*
Knee rotation	*0*	*1*	*0*	*1*
Ankle joint dorsiflexion	*0*	*1*	*0*	*1*
Ankle anterior draw test	*0*	*1*	*0*	*1*
Subtalar joint inversion	*0*	*1*	*0*	*1*
Midtarsal joint inversion	*0*	*1*	*0*	*1*
Midtarsal ab/adduction and dorsi / plantar flexion	*0*	*1*	*0*	*1*
Metatarso-phalangeal movement	*0*	*1*	*0*	*1*
Excessive subtalar joint pronation	*0*	*1*	*0*	*1*
TOTAL SCORE				
Positive joint hypermobility score: ≥ 7				

21.4 Study Summary

Title: Joint Hypermobility: The Use of a New Assessment Tool to Measure Lower Limb Hypermobility [13]	
Authors	Ferrari, J., Parslow, C., Lim, E., & Hayward, A
Publication	Clinical and Experimental Rheumatology, 23, 413-420.
Purpose of the Study	To assess the validity and reliability of the lower limb assessment score.
Type of Population	☒ Normal ☒ Other: Possible hypermobile and hypermobile children.
Clinical Relevance	Assessment of joint hypermobility in the lower limbs.

Methods

Subjects

- The study sample consisted of 225 school age children. England.
- Children were divided in three groups based on joint mobility:
  1. A normal group included 116 children (66♀, 50 ♂) from primary classes. Mean age: 7 years (SD 1.9 years);
  2. A possible hypermobile group included 88 children (46♀, 42 ♂) from a pediatric foot and gait clinic (no child was diagnosed with hypermobility). Mean age: 9.89 years (SD 3.39 years);
  3. A known hypermobile group included 21 children (13♀, 8 ♂) referred from a pediatrician or rheumatologist. Mean age: 9.18 years (SD 3.55 years).

Testing Procedures and Instrumentation

- Twelve joint movements in the lower extremities were assessed in standardized positions for each motion. Instrumentation: Lower limb assessment score (LLAS); goniometer.
- A comparison was made between the LLAS and the Beighton score index.

Data Analysis

- A pilot study was undertaken prior to the research and inter-tester repeatability of the LLAS was measured using reliability analysis with 22 children. Distribution of data was initially examined for normality and parametric tests or non-parametric tests were carried out based on the distributions found. $P < 0.05$ was considered statistically significant.

Results

Psychometric Properties: Inter-tester reliability measured with intraclass correlation coefficient was 0.84 (95% CI=0.62 to 0.93).

- No significant difference was found between the left and right sides.
- Authors suggest that the Beighton Score was unable to clearly differentiate hypermobility between the 3 groups (p=0.053).
- There was disagreement between the scores in school children: 26.7% of children appeared to have a positive Beighton score that was not accompanied by a positive lower limb score. LLAS was able to differentiate more clearly between the 3 groups (p< 0.001).
- A threshold was calculated to define hypermobility using the LLAS and to set a cut-off score. The point of the ROC curve that showed the most useful score in terms of sensitivity and specificity was 7/12 for the LLAS.

Authors' Conclusion

- Authors present a new assessment tool for the diagnosis of joint hypermobility in the lower limbs and report that the LLAS shows benefits over the Beighton Score.
- The Lower Limb Assessment Score could be useful for prospective studies and aid in the diagnosis of lower limb conditions that may be related to joint hypermobility.

Comments

- Internal and external validity, including sample size (*n* = 225) seems good and the use of results as a trend for clinical guidelines is appropriate.

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Up to Date References

Validity and Reliability / Hip Measurement

2008-2011	
Lee, K. M., Chung, C. Y., Kwon, D. G., Han, H.S., Choi, I.H. & Park, M.,S. (2011) Reliability of physical examination in the measurement of hip flexion contracture and correlation with gait parameters in cerebral palsy. *Journal of Bone and Joint Surgery. Am*. *93*(2):150-158.	Results showed, in terms of interobserver reliability, high intraclass correlation coefficients and the smallest mean absolute differences in cerebral palsy children and normal controls. In terms of convergent validity, results showed, in a control group, high correlation coefficients in kinetic and kinematic variables but Staheli prone hip extension test showed higher results in the patient group.
Glanzman, A., Swenson, A. E. & Kim, H., (2008) Intrarater Range of Motion Reliability in Cerebral Palsy: A Comparison of Assessment Methods. *Pediatric Physical Therapy,* 20 (4), 369-372	Intra-rater reliability had high interclass correlations (ICCs) for Staheli and Thomas tests of hip extension.
2006-2007	
Mutlu, A., Livanelioglu, A. & Gunel, M. K. (2007) Reliability of goniometric measurements in children with spastic cerebral palsy. *Medical Science Monitor,* 13, CR323-329.	Intra-testing reliability and inter-test reliability scores were high.
Owen, J., Stephens, D. & Wright J. G. (2007) Reliability of hip range of motion using goniometry in pediatric femur shaft fractures. *Canadian Journal of Surgery*, 50, 251-255.	Most ICCs for the different aspects of hip range were between 0.2 and 0.5, indicating slight agreement. Goniometric measurement, using standardized protocols for the hip, has low reliability.
McWhirk, L. B. & Glanzman, A. M. (2006) Within-session inter-rater realiability of goniometric measures in patients with spastic cerebral palsy. *Pediatric Physical Therapy*.18(4), 262-265.	Interclass correlation coefficients ranged from 0.582 (hip extension) to 0.929 (popliteal angle).

Validity and Reliability / Popliteal Angle Measurements

2006-2007	
Ten Berge, S. R., Halbertsma, J. P., Maathuis, P. G., Verheij, N. P., Dijkstra, P. U. & Maathuis, K. G. (2007) Reliability of popliteal angle measurement: a study in cerebral palsy patients and healthy controls. *Journal of Pediatric Orthopaedics,* 27(6), 648-652	All intraclass correlation coefficients (ICCs) were lower in the CP group compared with healthy controls. The ICC for intraobserver differences was higher than 0.75 for both groups. The ICC for interobserver reliability of visual estimates and goniometric measurements was low for both groups. Measurements in the CP group seemed to be less reliable than measurements in the control group. Intraobserver reliability is reasonable for both groups, but lower in CP patients than in controls. Interobserver reliability of both visual estimates and goniometrical measurements is poor. No significant differences in reliability have been found between visual estimation and goniometric measurement. Because of poor interobserver reliability of popliteal angle measurement, this should not be the only variable in clinical decision making in CP patients.
McWhirk, L. B. & Glanzman, A. M. (2006) Within-session inter-rater realiability of goniometric measures in patients with spastic cerebral palsy. *Pediatric Physical Therapy*. 18(4), 262-265.	Interclass correlation coefficients ranged from 0.582 (hip extension) to 0.929 (popliteal angle).
2001-2003	
Fosang, A. L., Galea, M. P., McCoy, A. T., Reddihough, D. S. & Story, I. (2003) Measures of muscle and joint performance in the lower limb of children with cerebral palsy*. Developmental Medecine and Child Neurology.* 45(10), 664-670.	Test-retest results varied widely in different passive ROM in the lower limbs. These measurement tools should be used with caution when evaluating changes in young children with CP.
Thompson, N. S., Baker, R. J., Cosgrove, A.P., Saunders, J.L. & Taylor, T.C. (2001) Relevance of the popliteal angle to hamstring length in cerebral palsy crouch gait. *Journal of Pediatric Orthopaedics*. 21(3), 383-387.	Challenges the popliteal angle measurement as an indicator of complete hamstring tighness.

Validity and Reliability / Rotational Profile Measurements

2008-2010	
Chung, C. Y., Lee, K. M., Park, M. S., Lee, S. H., Choi, I. H. & Cho, T. J. (2010). Validity and reliability of measuring femoral anteversion and neck-shaft angle in patients with cerebral palsy. *Journal of Bone and Joint Surgery*. *Am*. 92,1195-1205. doi:10.2106/JBJS.I.00688	The validity , interobserver and intraobserver reliability of the physical examinations were determined by comparing the results with computed tomography. The trochanteric prominence angle test showed excellent concurrent validity and reliability. Hip internal rotation also showed good concurrent validity and excellent reliability ,whereas hip external rotation appeared to be unsuitable for predicting femoral anteversion. The neck-shaft angle on the anteroposterior internal rotation radiograph of the hips showed excellent concurrent validity and reliability.
Lee, S. H., Chung, C.Y., Park, M. S., Choi, I. H. & Cho, T. J. (2009) Tibial torsion in cerebral palsy: validity and reliability of measurement. *Clinical Orthopaedics and Related Research*. 467(8):2098-2104. Epub 2009 Jan 22.	Validity and reliability physical examination of TFA, TMA and the second toe test was assessed with a correlation study with two-dimensional computed tomographic (CT). Interobserver reliability was greatest for the TMA followed by TFA and then by the second toe test. In terms of the concurrent validity, the correlation coefficients for the CT measurements were 0.62, 0.52, and 0.55. When depicting tibial torsion by physical examination, all three methods had substantial validity, but test reliability and validity were highest for TMA measurements
Hüseyin, A., Hüseyin, E., Bülent, K., Ahmet K. & Serdar, N. (2008) Post therapeutic lower extremity rotational profiles in children with DDH. *Journal of Children's Orthopaedics*. 2(4), 255–259. doi: 10.1007/s11832-008-0113-1.	Foot-progression angle was measured clinically, TMA angle photographically, hip rotations and TFA were measured clinically and photographically. Results were compared with Staheli's data for normal children. No significant difference was found between any photographic and clinical measurement data ($p > 0.05$). The lower extremity rotational profiles of children with DDH who received appropriate treatment did not differ significantly from those of normal children, but internal and external hip rotations in McKay type II and IV cases were below the averages of normal hips and McKay type I and II hips. In addition, no difference was found between patients treated by derotation osteotomy and others.
Jacquemier, M., Glard, Y., Pomero,V., Viehweger, E., Jouve, J. L. & Bollini, G. (2008). Rotational profile of the lower limb in 1319 healthy children. *Gait & Posture.* 28(2):187-193. Epub Jan 16.	Tibial Torsion was assessed using the method described by Staheli and Engel, whereas Femoral Anteversion was assessed using the method described by Netter. Good intra-observer reliability is reported in healthy children. Normative data were statistically defined in this work using the +/-2S.D. range.

1997	
Kozic, S., Gulan, G., Matovinovic, D., Nemec, B., Sestan, B. & Ravlic-Gulan, J. (1997). Femoral anteversion related to side differences in hip rotation. Passive rotation in 1,140 children aged 8-9 years. *Acta Orthopaedica Scandinavica,* 68(6):533-536.	This study was performed to assess if range of passive hip motion is reliable for predicting abnormal femoral anteversion. Passive medial and lateral rotation in extension in both hips of 1,140 children was measured. The angle of femoral neck anteversion was measured using biplane radiography. To predict an abnormally high anteversion angle (above mean +2SD), the difference between medial and lateral rotation must be 45^0 or more, whereas an abnormally low anteversion angle (lower than mean -2SD) could be predicted when the lateral rotation was at least 50 degrees higher than the medial rotation.

Validity and Reliability / Beighton Score

2007-2011	
Smits-Engelsman, B., Klerks, M. S. & Kirby, A. (2011). Beighton Score: A Valid Measure for Generalized Hypermobility in Children *The Journal of Pediatrics,*158, 119-123, 123.e1-4	Children's joints and movements were assessed according to the Beighton score by qualified physiotherapists and by use of goniometry measuring 16 passive ranges of motion of joints on both sides of the body. The Beighton score, when goniometry is used, is a valid instrument to measure generalized joint mobility in school-age children 6 to 12 years. No extra items are needed to improve the scale. In white children between6 and 12 years of age, it is recommended that 7/9 be the cutoff for the Beighton score.
Juul-Kristensen, B. Røgind,H., Jensen, D. V. & Remvig L.. (2007) Inter-examiner reproducibility of tests and criteria for generalized joint hypermobility and benign joint hypermobility syndrome. *Rheumatology (Oxford*). 46,1835-1841. Epub 2007 Nov 15.	Results show good-to-excellent reproducibility of tests and criteria for GJH and BJHS. Future research on the validity of the tests and criteria for joint hypermobility is urgently neede
2003	
Boyle, K.L., Witt, P. & Riegger-Krugh C. (2003) Intrarater and Interrater Reliability of the Beighton and Horan Joint Mobility Index. *Journal of Athletic Training*. 38(4), 281–285.	Results suggest that the intrarater and interrater reliability of the BHJMI composite and category scores is good to excellent for females from 15 to 45 years of age.

Normative Reference Values

for Musculoskeletal Conditions and Functional Motor Abilities in the Pediatric Population

Literature Review and Clinical Guidelines

Part 5

The Foot

Complete document :

www.irdpq.qc.ca/communication/publications/documents_disponibles.html

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Part 5

The Foot

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Summary

There exists a wide variety of foot shapes and foot arch structures, [7,9,10,11,16] and these morphological differences are considered normal. [3,6,11,12, 15, 16,20] In young children, variations are reported to be greater due to physiological changes, [2,6,7,8, 15,18,20] and can be considered developmental profiles. A low arch or flat foot has been traditionally regarded as undesirable. [15] Flexible flatfoot is a common finding in children under the age of 6 years and is a developmental variation. A small minority of children will have flat feet by the age 10 years. Pes Planus rarely leads to gait problems or chronic pain if it persists into adulthood. [21] Pathological forms include the flexible type that falls outside the normal range, as well as the flat foot that is due to a structural abnormality, such as is found in tarsal coalition. Structural flat feet usually show some stiffness and can cause disability. [15]

The evolution of the normal foot arch, [15,24] classification of foot morphology and testing procedures are reported as topics of some debate in the literature. [1,3,7,10,13,16,19] The controversy existing over different techniques is not adressed in the present document. The selected assessment tools are recognized as methods that can be used effectively for screening studies and for individual assessments in a clinical setting.[7,10] These testing procedures are used to define and categorize arch structure in children [6,7,9,13,14,15, 16] or calcaneal position.[3] However, no methods have been universally established [9,10] and recorded values from each method will vary and are not directly comparable. [13]

Description of Foot Types

Findings agree that one of the primary criteria for the classification of foot structures is the height of the medial longitudinal arch (MLA), [7,9] which will influence the shape of the footprint.[9] Clinically, three foot types can be described according to the structure of the MLA and calcaneal position [3] (Table 5.1).

Table 5.1. Description of Three Foot Types

Foot Parameters	*Type 1*	*Type 2*	*Type 3*
	Foot neutrally aligned	High arch foot (Pes cavus)	Low arch foot (Pes planus)
Structure of the MLA	Average arch structure	High arch structure	Low or absent arch structure
Calcaneal Position	The bisection of the posterior aspect of the calcaneus is close to perpendicular to the supporting surface.	The bisection of the posterior aspect of the calcaneus is inverted.	The bisection of the posterior aspect of the calcaneus is everted.

Data from: Cubukcu, Alimoglu, Balci, and Beyazova, p.217. [3]

Clinical Assessment

The MLA and calcaneal position can be measured by two quantitative methods:

1) Indirect methods
↓
Footprint Analysis

2) Direct methods
↓
Anthropometric Measurements

FOOTPRINT ANALYSIS

Footprint analysis is a simple low-cost effective and readily available method for assessing foot type [9,10,12,13,16] in clinical settings and in screening studies. [1,3,6,9,10,12,13, 15]

Footprints obtained in weight bearing positions represent the surface area covered by foot contact on the supporting surface. The imprints allow the evaluation of the shape of the foot and the pressure distribution under the foot.

A typical footprint (Fig. 5.1) includes the hindfoot imprint (the calcaneus), the midfoot imprint (arch + isthmus) and the forefoot imprint (metatarsal heads + toes). [16]

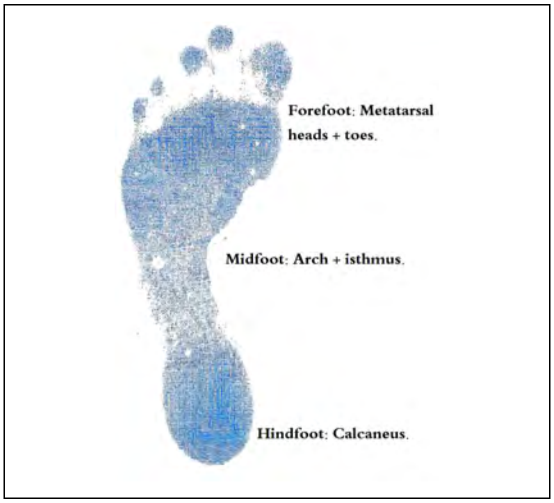

Figure 5.1. Foot imprint. (©IRDPQ-2008).

A. The Arch Index

The arch index (AI) is a parameter that can be measured from a foot imprint to define the foot arch. Some authors report that it should not be inferred that the description obtained from footprints is necessarily valid to describe the structural characteristics of the feet. [1] However, in a more recent study, the AI was calculated with digital image processing methods and a significant correlation was found between the AI and the arch height, confirming that foot arch type does correlate with the footprint parameter, AI. [19]

B. Validity of the Staheli's Arch Index

The Staheli's Arch Index (SAI) is the method that was selected for the assessment of the MLA from plantar footptints. The SAI is the ratio of the arch width in the mid-foot region with the heel width, obtained by footprints [4, 15, 22] (Fig. 5.2).
The correlation between the SAI obtained by footprints, with radiological measurements was evaluated in children with flexible flat feet. Positive correlation was found between the arch index and talo-first metatarsal angles and talo-horizontal angles ($p < 0.05$), [10] indicating that increasing talar inclination has an increasing effect on the arch index. These results demonstrate that footprint analysis can be used effectively in routine practice and for screening studies as a guide for describing the shape of the medial arch of the foot. [10]

ANTHROPOMETRIC MEASUREMENTS

Anthropometric measurements consist in analyzing parameters in reference to bony landmarks and the supporting surface. Two methods are presented:

- The Navicular Height (NH) is a direct bony measurement of the navicular, considered the keystone of the MLA.[7, 23] Findings showed no significant difference in the NH between gender and body weight demonstrating that NH may prove to be a more universal measurement for the pediatric population. [7] It is reported as being a more discriminative tool regarding age difference, suggesting it provides a useful and easily obtained clinical measure. [7]

- The Relaxed Calcaneal Stance Position (RCSP) indicates the position of the calcaneus in the frontal plane. The RCSP does not affect the height of the MLA [11] and, in asymptomatic subjects, wide ranges were recorded.[14]

Reliability of NH and RCSP

There is controversy regarding the reliability of the NH and the RCSP measurements in children. A summary of the information from the selected studies is presented in Table 5.2 and in Table 5.3, respectively.

Table 5.2. Summary of Measurement Characteristics of the NH in Children

Research Studies	Age	Number of Subjects	Reliability		Conclusion
			Intra-tester	*Inter-tester*	
Gilmour et al.(2001)[7]	5 years 6 months to 10 years 11 months	*n* =20 *(Intra-tester)* *n* =13 *(Inter-tester)*	High	Moderate	Reliable when used by the same examiner and within acceptable limits between testers.
Evans et al. (2003)[5]	4 years to 6 years	*n* = 29	Poor	Moderate to poor	More reliable in adolescents but not in young children.
	8 years to 15 years	*n* = 30	Good	Moderate	
Morrison et al.(2005)[23]	9 years to 12 years	*n* = 13	High	Not tested	Reliable when used by the same examiner.

Table 5.3. Summary of Measurement Characteristics of the RCSP in Children

Research studies	Age	Number of Subjects	Reliability		Conclusion
			Intra-tester	*Inter-tester*	
Sobel et al. (1999)[14]	5 years to 17 years	*n* =14	High	High	Reliable.
Evans et al. (2003)[5]	4 years to 6 years	*n* = 29	Poor	Moderate to poor	More reliable in adolescents but not in young children.
	8 years to 15 years	*n* = 30	Good	Moderate	

1. Footprint Analysis – Staheli's Arch Index [15]

Age range: 1 year to 19 years.

1.1 Clinical Use

- The Staheli's Arch Index (SAI) expresses how curved is the medial longitudinal arch and enables the classification of foot type.
- The child's footprint can be used as a guide in follow-ups to document the development of the foot arch. Subsequently, progress can be assessed more objectively by reviewing serial footprints.

1.2 Measurements

- The plantar arch index establishes a relationship between central and posterior regions of the footprint and is the measurement of the support width of the central region to the foot (A) and of the heel region (B) in millimeters. [22]
- SAI is obtained by calculating the ratio of the width in the mid-foot region, (isthmus) (A), with the mid-heel region, called the heel width (B), obtained by footprints (Fig. 5.2). [4,15, 22]

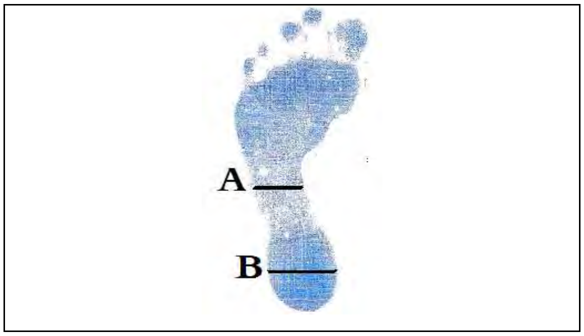

Figure 5.2. Clinical determination of SAI: A/B.
(©IRDPQ-2008).

1.3 Testing Procedures

REQUIRED EQUIPMENT

- Footprinting ink mat (podograph) and paper.

  Note: Footprints, in the present study, were obtained by chalking the sole of the foot and then making an impression on paper (Fig. 5.3). In clinical practice, footprint mats are now routinely used.
- Ruler in mm increments.
- Non-slip material
- Chair (for minimal support if the subject has balance problems).

PRE-TEST

- Non-slip material is placed under the podograph for safety reasons.

TEST

- Testing position and measurements for the SAI are presented in Table 5.4.
- Results are compared to the normative reference values in Figure 5.6.

TABLE 5.4. STAHELI' S ARCH INDEX [15]

Testing Position

- Dynamic footprints : In the present study, dynamic footprints were recorded. The child stepped in powdered chalk and then took a step on a sheet of paper. In order to conform to these testing procedures, and since the foot is a dynamic structure that undergoes changes during a step, it is suggested to record dynamic footprints by having the child take a step on the podograph. (Fig. 5.3).

- Static footprints : However many studies have calculated the SAI by using static footprints (Fig. 5.4). [10, 12, 17] The suggested method is to have the child take a step with the non-tested foot onto one side of the podograph, followed by the placement of the tested foot onto the inked mat. The non-tested foot is then slightly raised from the supporting surface and placed back on the ground. The child walks off the podograph by clearing the tested foot first. [17]

Figure 5.3
Dynamic footprints by having the child take a step on the podograph. (© IRDPQ-2008).

Figure 5.4
Static footprints on a podograph. (© IRDPQ-2008).

Measurements

- **Calculation of the Plantar Arch Index**: To maximize standardization, the method described by Hernandez et al. (2007)[22] is suggested. To obtain the measurement of the support width of the central region of the foot and of the heel region trace the following lines (Fig. 5.5):
  - A line is drawn tangent to the medial forefoot edge (metatarsal width) and to the mid-heel region. The mean point of this line is calculated.
  - From this point, a perpendicular line is drawn, crossing the footprint. This is the mid-foot region for the measurement of the arch width. The isthmus is measured in mm.
  - The same procedure is repeated for the heel tangency point. This is the measurement of the mid-heel width.
  - SAI = A/B. The smaller the ratio is, the higher is the arch structure.

Figure 5.5 *Measurement of the width of the central region (A) and heel region (B) of the foot, in millimeters, on a footprint. The plantar arch index is obtained by dividing A value by B value.*

© Hernandez, Kimura, Ferreira Laraya, and Fávaro, p. 69. [22]

1.4 Normative Reference Values

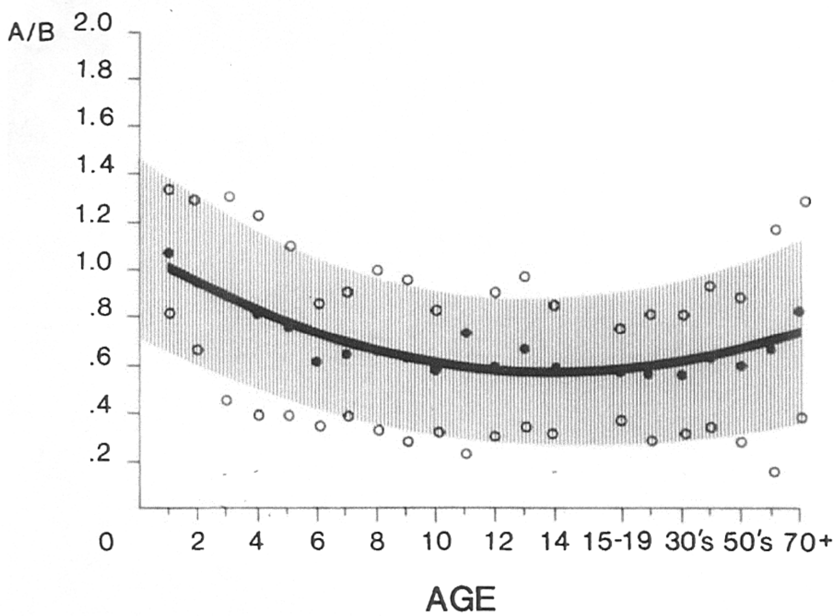

Figure 5.6

The mean values for the arch index and two standard deviations for each of the twenty-one age-groups. The solid line shows the mean changes with age; the shaded area shows the normal ranges. The actual values for each age-group are represented by solid circles for the mean and open circles for two standard deviations.

©Staheli, Chew, and Corbett, p. 428. [15]

1.5 Clinical Example

9-YEAR-OLD CHILD

- The arch width (A) = 10 mm.
- The heel width (B) = 38 mm.
- SAI: 10 / 38 = 0.26. The arch index is not within 2 SD from the mean of his age group and indicates an important high arch foot.

1.6 Medical Guidelines

- General recommendations for pes planus and pes cavus are presented in Tables 5.5 and 5.6, respectively. These recommendations are based on clinical expertise and not on scientific studies.
- Prior to the recording of footprints, it is important to consider dynamic ankle and foot function, therefore, the assessment begins by observing the child's gait. This will give a better perspective of foot function and possible compensations during gait.
- Flatfoot is considered normal in children up to 5 years of age. The foot arch usually develops later on.

<table>
<tr><th colspan="3">TABLE 5.5. GENERAL RECOMMENDATIONS IN THE PRESENCE OF PES PLANUS IN CHILDREN</th></tr>
<tr><th>Age</th><th>Clinical Signs</th><th>Recommendations</th></tr>
<tr><td rowspan="3">≥ 5 years – ≤ 8 years</td><td>No pain.</td><td>No recommendation.</td></tr>
<tr><td>In the presence of pain.</td><td>Schaphoid pads.</td></tr>
<tr><td>In obese children with pain and severe flatfoot.</td><td>Foot orthoses.</td></tr>
<tr><td>≥ 8 years</td><td>Presence of pain or if the child is obese.</td><td>A general rule is the use of foot orthoses.</td></tr>
</table>

TABLE 5.6: GENERAL RECOMMENDATIONS IN THE PRESENCE OF PES CAVUS IN CHILDREN

Clinical Signs	Recommendations
A high arch foot does not usually cause problems.	If the condition is very severe, referral to neurology is recommended.
Some young teenagers may present pain due to plantar fasciitis.	They may benefit from foot orthoses, but this is an exceptional situation.

1.7 Study Summary

Title: The Longitudinal Arch. A Survey of Eight Hundred and Eighty-Two Feet in Normal Children and Adults [15]	
Authors	Staheli L. T., Chew D. E., & Corbett M.
Publication	The Journal of Bone Joint and Surgery. Am. 1987, 69, 426-8.
Purpose of the Study	To establish the normal range of the longitudinal arch in all age groups in a normal population.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	To document the configuration of the foot. Classification of foot type.

Methods

Subjects

- The study sample consisted of 441 children (255 ♀, 186 ♂). USA.
- Age range: 1 year to 80 years.
- Subjects were divided into 21 groups based on chronological age in years. Age and number of subjects per group are presented in Fig. 5.7.

Testing Procedures and Instrumentation

- Dynamic footprints were recorded. The arch index (AI) was measured as the ratio of the width in the arch region with the width in the heel region.

Data Analysis

- Mean and standard deviation (SD) were calculated. The range of normal was defined as being within 2 SD from the mean.

Results

- **Psychometric Properties**: Non applicable.
- There was a significant linear relationship between the right and left arch indices (r = 0.93), so the average values obtained from the two feet were calculated.
- Data for male and female subjects were pooled for analysis and interpretation (r^2_{PB} = 0.02). Curvilinear regression lines were drawn to show general trends. These lines (Fig.5.6) are the best fit through the data points.
- Normal range of the AI is broad throughout life. During infancy, the normal value ranges from about 0.70 to 1.35 indicating that a width in the arch area of about 1.3 times the width of the heel is within the normal range. After middle childhood, the AI has a broad normal range from about 0.30 to 1.0 through adulthood.
- Reference values for each of the 21 age groups are presented therein.

Authors' Conclusion

- The longitudinal arch of the sole of the foot usually develops during childhood and there is no evidence that flexible flat foot of any degree produces disability.
- Impressions of the footprint combined with clinical evaluation provide a practical means to document the configuration of the foot.

1.7 Study Summary (Continued)

Comments

- Number of subjects is small in the 1-, 13- and 14- year- age groups (Fig. 5.7) and results should be used with caution in these age groups. However, results are consistent with other studies. Internal and external validity in the other age groups, including sample size, seems good and the use of results as a trend for clinical guidelines is appropriate for these age groups.

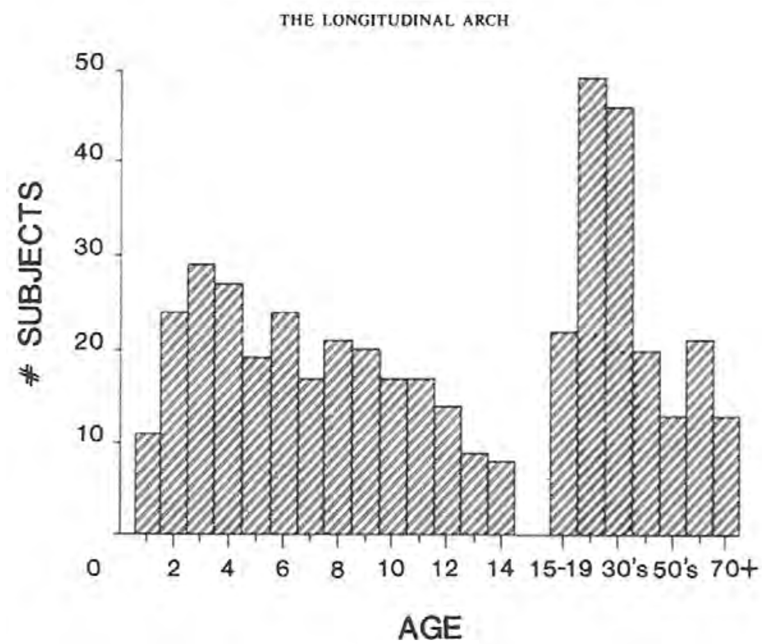

Figure 5.7
The age distribution of subjects for each of the twenty-one age-groups.

©Staheli, Chew, Corbett, p. 427. [15]

- **Consistency of Measurements:** Prior to this study, Engel and Staheli (1974) [4] analyzed the evolution of torsion in the lower limbs in childhood. Reproducibility of measurements was evaluated on five children on two separate occasions and the median and range of the differences between the two sets of values were determined:
  - For the arch width, the median difference was 1 mm and the range was 0 to 5 mm;
  - For the heel width, the median difference was 1 mm and the range was 0 to 6 mm.

2. Anthropometric Measurements – Navicular Height [7]

Age range: 5 years 6 months to 10 years 11 months.

2.1 Clinical Use

- The NH is a direct measurement of the medial longitudinal arch. [7, 23] It enables the classification of the foot arch structure.

2.2 Measurements

- NH is the distance between the navicular tuberosity and the supporting surface (Fig. 5.8).

2.3 Testing Procedures

REQUIRED EQUIPMENT

- Ruler in mm increments. (The authors of the present study used a Vernier height gauge).
- An elevated platform on which the child can safely stand. This allows accurate viewing of the navicular.
- Hypoallergenic skin cosmetic crayon.

PRE -TEST

- Prior to the assessment, if need be, have the child stand on the platform so he becomes familiar with the testing position. The child is instructed that he will have to stay upright during the assessment and that no stepping is allowed.

TEST

- Testing position and measurements are presented in Table 5.7.
- Results are compared to the normative reference values for NH measurements in Table 5.8.

<table>
<tr><th colspan="2">TABLE 5.7. NAVICULAR HEIGHT</th></tr>
<tr><td colspan="2">Testing Position</td></tr>
<tr><td colspan="2">▪ The child stands on the platform in a static relaxed stance position.
▪ The foot is in a relaxed calcaneal stance.</td></tr>
<tr><td colspan="2">Measurements</td></tr>
<tr><td>▪ The most prominent point of the navicular tubercle is mark with a fine line on the skin.
▪ NH is obtained by measuring, to the nearest millimeter, the distance between the supporting surface at a 90° angle to a line drawn on the navicular tubercle.</td><td>

Figure 5.8. Method of positioning and clinical determination of navicular height measurement. (© IRDPQ – 2008).</td></tr>
</table>

2.4 Normative Reference Values

Table 5.8. : Mean and Standard Deviation of Measurements Navicular Height (NH) and Arch Index (AI) of Total Study Population and Subgroups.

	Group 1 (6 yrs) N=168 feet	Group 2 (8 yrs) N=184 feet	Group 3 (10 yrs) N=192 feet	Total Study N=544 feet
NH X	27 mm	31 mm	34mm	31mm
Sd	4 mm	5 mm	6 mm	6 mm
AI X	.22	.21	.21	.21
Sd)	.06	.06	.07	.07

NH: navicular height; AI: arch index; X: mean; Sd: standard deviation; mm: millimeters

© Gilmour, Burns, p. 495. [7]

2.5 Clinical Example

- 9-year-3-month old child:
  - NH = 39 mm. The value is within 2 SD from the mean of his age group and indicates a ''normal'' high arch foot.

2.6 Medical Guidelines

- General recommendations for pes planus and pes cavus are presented in section 1.6.

- When using this method, special attention should be given to children around the age of 10 years. It is known that 10% of the children of this age group may present an accessory navicular.
- An accessory navicular is usually located on the medial side of the foot, proximal to the navicular and where the posterior tibial tendon attaches to the real navicular bone (Fig. 5.9).
- The presence of an accessory navicular can falsify the NH measurement.

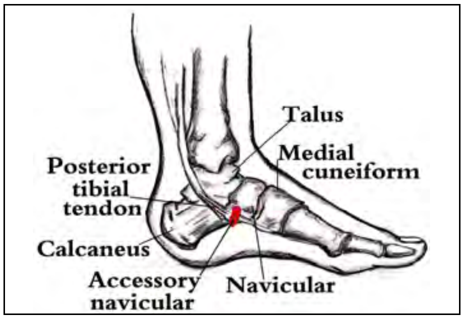

Figure 5.9. Accessory navicular.
(© IRDPQ – 2010).

2.7 Study Summary

Title: The Measurement of the Medial Longitudinal Arch in Children [7]	
Authors	Gilmour J. C., & Burns Y.
Publication	Foot & Ankle International, 2001, 22, 493-8.
Purpose of the Study	To provide objective measurements of the medial longitudinal arch in children. To investigate the influence of age, gender, limb dominance and body weight.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	To document the configuration of the foot. Classification of the foot type.

Methods

Subjects

- The study sample consisted of 272 healthy children (128 ♂, 144 ♀). Australia.
- Age range: 5 years 6 months to 10 years 11 months.
- Children were divided into specific grade year groups, with one year grade separation between each group.

Testing Procedures and Instrumentation

- The arch index (AI) and the vertical height of the navicular (NH) were measured in standardized position.
- Instrumentation: Area meter, Vernier height gauge.

Data Analysis

- Mean and standard deviation of measurements were calculated.
- Intra-rater reliability using Pearsons *r* Correlation Coefficient for NH and AI were undertaken on 20 subjects (40 feet) and inter-rater reliability on 13 subjects (26 feet) by three physiotherapists.

Results

Psychometric Properties

- Intra-rater reliability (n = 20 subjects, 40 feet) for NH = 0.91 (excellent); for AI = 0. 95 (excellent).
- Inter-rater reliability (n = 13 subjects, 26 feet) for NH = 0.77-0.80 (very good); for AI = 0.78-0.94 (excellent). Findings of the study suggest that there is a high degree of repeatability for both measurement techniques for the same examiner. The inter-rater was slightly less, but within acceptable limits.

NH Measurements

- The NH is a direct bony measurement of the navicular, considered the keystone of the MLA. The NH may prove to be a more universal measurement for the pediatric population given the fact that there was no significant difference in the NH between gender and body weight. It was more discriminative regarding age difference, suggesting it provides a useful, easily obtained clinical measure.
- It is clinically easier to obtain than the arch index measurement of the present study.

AI Measurements

- The AI measurements provided a slightly better reliability in children over the age of 8 years. They were slightly more reliable than the NH measurements but showed less change with age and were influenced by gender and body weight.

Authors' Conclusion

The authors suggest that both the NH and the AI measurements are reliable in establishing data for the MLA in a population of children aged 6 to 11 years. However, the NH may prove to be a more universal measure for the pediatric population and a direct measure of the MLA. The authors recommend the use of the NH for the assessment of the MLA.

Comments

Internal and external validity including sample size (n =84 to 96 in each group) seems good and the use of results as a trend for clinical guidelines is appropriate.

3. Anthropometric Measurements – Relaxed Calcaneal Stance Position [14]

Age range: 5 years to 17 years.

3.1 Clinical Use

- The relaxed calcaneal stance position (RCSP) indicates the position of the calcaneus in the frontal plane after all compensatory pronation has taken place at the subtalar joint : [24]
  - The calcaneus is considered to be in varus when it is inverted to the transverse plane.
  - The calcaneus is considered to be in valgus when it is everted to the transverse plane.

3.2 Measurements

- RCSP is the angle formed by the posterior aspect of the calcaneus to the supporting surface in stance position, measured with a standard goniometer (Fig. 5.12).

3.3 Testing Procedures

REQUIRED EQUIPMENT

- Standard 360° goniometer with 2° increments.
- Examination table.
- A fine marking hypoallergenic non permanent pen and a flexible metallic 6 inch ruler to bisect the posterior aspect of the calcaneus.
- An elevated platform on which the child can safely stand is suggested. This facilitates the alignment of the goniometer and allows accurate viewing when reading the obtained angle.

PRE-TEST

- Prior to the assessment, if need be, have the child stand on the platform so he becomes familiar with the testing position. The child is instructed that he will march in place, then be asked to stop and remain in a relaxed stance position. No stepping is allowed.

TEST

- Two testers are needed. One to stabilize the ankle and foot in neutral position while the other marks the skin with the pen.
- Testing position, goniometer alignment and measurements are presented in Table 5.9.
- Results are compared to the normative reference values in Figure 5.13.

TABLE 5.9. RELAXED CALCANEAL STANCE POSITION

Testing Position

- Prone (Fig. 5.10):
  - The child is aligned on the examination table, feet hanging over the edge of the table.
  - The ankle is dorsiflexed to 90°, so that the planta r surface of the heel is perpendicular to the leg in the sagittal plane.
  - The subtalar joint is not rotated in varus or in valgus attitude.
  - The posterior aspect of the calcaneus is bisected with a fine marking pen. The irregularity of the calcaneal tuberosity may render the bisection difficult.
- Standing (Fig. 5.11):
  - The child then stands on the platform.
  - He marches in place at least 5 times on each foot until achievement of a comfortable angle and base of stance.

Figure 5.10: In prone, bisection of the posterior aspect of the calcaneus. (© IRDPQ-2008).

Figure 5.11: In standing, comfortable angle and base of stance achieved. (© IRDPQ – 2008).

Goniometer Alignment and Measurements

- The movable arm is aligned on the calcaneal bisection line.
- The stationnary arm is aligned parallel to the supporting surface.
- RCSP is the angle formed by the bisection of the posterior aspect of the calcaneus to the supporting surface during relaxed standing. [14]

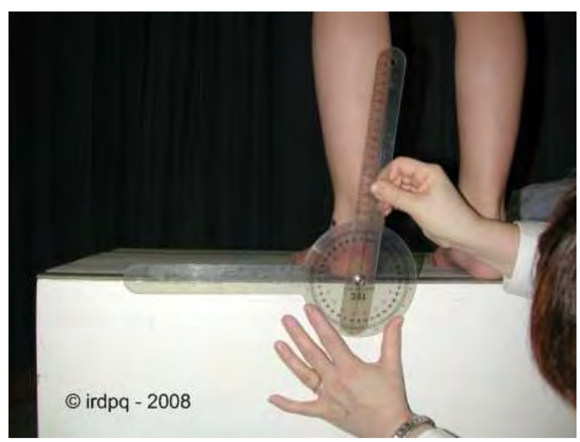

Figure 5.12. Method of positioning and clinical determination of RCSP. (©IRDPQ-2008).

3.4 Normative Reference Values

Note: *95% of children had a RCSP between 1° varus and 12° valgus.* [14]

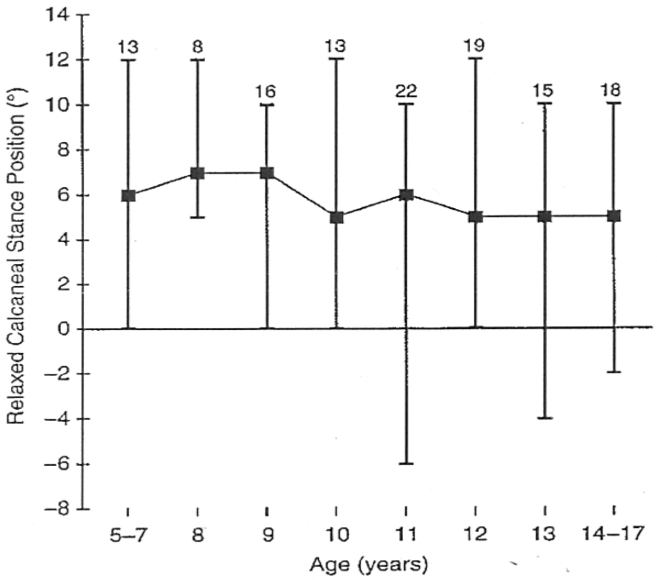

Figure 5.13 : Age and relaxed calcaneal stance position. Solid squares indicate mean relaxed calcaneal stance position, with vertical lines representing ranges. Numbers above vertical lines are numbers of children. On the y-axis, positive values indicate valgus, and negative values indicate varus.

© Sobel, Levitz, Caselli, Tran, Lepore, Lilja, …and Wain, p. 262. [14]

3.5 Clinical Example

- **12-year-old boy :** RCSP = 11°. This angle is at the upper extreme limit of the normal range of his age group and indicates important valgus of the calcaneus. Close follow-up is suggested.

- **8-year-old girl :** RCSP = - 4°. This angle is not within the normal range of her age group and indicates important varus of the calcaneus.

3.6 Medical Guidelines

General recommendations for important valgus in children are presented in Table 5.10. These recommendations are based on clinical experience and not on scientific studies.

TABLE 5.10. GENERAL RECOMMENDATIONS WHEN RCSP MEASUREMENTS INDICATE IMPORTANT VALGUS OR VARUS IN CHILDREN

Age	Clinical Signs	Recommendations
≤ 8 years	Pain but no obesity.	Scaphoid pads.
≤ 8 years	Valgus with severe flat feet and/or obesity.	Foot orthoses.
≥ 8 years	Pain or gait problems.	
≥ 8 years	Obesity.	

3.7 Study Summary

Title: Reevaluation of the Relaxed Calcaneal Stance Position. Reliability and Normal Values in Children and Adults [14]	
Authors	Sobel, E., Levitz, S. J., Caselli, M. A., Tran, M., Lepore, F., Lilja, E., … Wain, E.
Publication	Journal of the American Podiatric Medical Association, 1999, 89, 258-64.
Purpose of the Study	▪ To determine the reliability of the relaxed calcaneal stance position. ▪ To determine normal values in a non clinic population of healthy adults and children.
Type of Population	☒ Normal ☐ Other
Clinical Relevance	▪ Assessment of the calcaneus' position in standing.

Methods

Subjects

- The study sample consisted of 88 healthy adults and 124 children. (34 ♀, 90 ♂ children). USA.
- Age range: 5 years to 17 years. (72 children were of elementary-school age, from 5 to 11 years).
- The subjects were divided into eight groups based on chronological age in years. The number of subjects varied from 8 to 22 in each group.
- Number of feet analyzed in children = 248 feet.
- Note: Only the data concerning the pediatric populaton is presented.

Testing Procedures and Instrumentation

- RCSP was measured in all subjects by one tester. Both feet were measured in a standardized position.
- Instrumentation: Standard goniometer.

Data Analysis

- Intra-tester reliability was determined by having three testers measure the RCSP on two separate occasions on fourteen volunteers. Both feet were measured for each subject.
- Intra-tester reliability was also determined through the use of an electro-goniometer, which is reported to be highly accurate and reliable.
- Inter-tester reliability was determined by comparing the results of the three testers.
- Pearson's correlation, mean and standard deviations (SD) were calculated. Normal values included plus or minus 2 SD from the mean value. Intra class correlation coefficient (ICC) was used to examine intra-tester reliability and ANOVA for inter-tester reliability. Additional information is presented therein.

3.7 Study Summary (Continued)

Results

- **Psychometric Properties:**
  - Intra-tester reliability was very good (ICC>0.80) for experienced examiners and greatest mean difference was 0.5°.
  - Inter-tester reliability: There was no significant difference between the three testers with a greatest mean difference of 1.23° between any two measurements taken with a standard goniometer. There was also no significant difference between measurements taken with the electro-goniometer with a greatest mean difference of 2.28°.
- Normal values for orthopedic measurements include plus or minus 2 SD from the mean value which encompasses more than 95 % of the population. [14] In the present study, 95% of children had a RCSP angle between 1° varus and 12° valgus showing that there are wide ranges for the RCSP in healthy children. The mean relaxed calcaneal stance position for children was 5.6° valgus (SD 2.9°). (Range: 6° varus to 12° valgus).
- With children, the RCSP did not correlate with age, height, or weight. There was no significant difference by sex or sidedness. There was no significant difference between the RCSP of adults and children.
- The average relaxed calcaneal stance position does not decrease with age.

Authors' Conclusion

- Reliability and normal values for RCSP were determined in a non clinic population of healthy adults and children ranging in age from 5 to 36 years.
- The RCSP demonstrated wide ranges from 6° varus to 12° valgus in children.
- The values reported in the present study correspond with the results of other empirical studies; the theoretical normal value for the relaxed calcaneal stance position of 0° (± 2°) would be invalid.
- The RCSP was found to be a reliable measurement when used by the same examiner (intra-tester reliability).
- Inter-tester reliability of RCSP was less than intra-tester reliability but was of 2.5° between testers, showing that intra-tester measurements demonstrate reasonable reliability for clinical measurements.
- The theoretical normal values of 0° (± 2°) as an indicator of pathology was not found and thus should not be used as an indicator of pathology.

Comments

- Internal validity seems good. However, sample size is small in two age-categories (8-and 10-year-olds) and data must be interpreted with caution. For the others categories the use of results as a trend for clinical guidelines is appropriate.
- Intra class correlation coefficient would have been a better indication to examine inter-tester reliability.

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2011	
Chen KC, Yeh CJ, Kuo JF, Hsieh CL, Yang SF, Wang CH. (2011).Footprint analysis of flatfoot in preschool-aged children. *Eur J Pediatr*. May;170(5):611-7. Epub 2010 Oct 23.	Footprint measurements (2,638 static footprints) of flatfoot in a population of preschool-aged children (3 to 6 years) were analyzed. The Clarke's angle (CA), Chippaux-Smirak index (CSI), and Staheli arch index (AI), were used for comparison with clinical diagnosis. The clinical diagnosis as a gold standard compared with the results of the CA, CSI, and AI and displayed in a receiver operating characteristic (ROC). Ratios were calculated given their cutoff points, and their pretest/posttest probabilities were plotted as the Fagan nomogram. The optimal cutoff points for CA, CSI, and AI were 14.04°, 62.70%, and 107.42%, respectively, and all of them showed high sensitivity. In conclusion, this study demonstrated that footprint analysis methods are suitable for diagnosing flatfoot in preschool-aged children, and that the most appropriate cutoffs are as follows: CA ≤ 14.04°, CSI > 62.70%, and AI > 107.42%. The CSI had a predictive probability of more than 90% and is recommended in screening for flatfoot in preschool-aged children.
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Bosch K, Gerss J, Rosenbaum D.(2010) Development of healthy children's feet--nine-year results of a longitudinal investigation of plantar loading patterns.Gait Posture. Oct;32(4):564-71. Epub 2010 Sep 15.	In a longitudinal design, 36 healthy German children were followed over the course of nine years. The children had a mean age of 14.6 ± 1.8 months at the first appointment and 122.8 ± 2.0 months at the last appointment. Dynamic foot loading was evaluated with plantar pressure measurements during walking and static footprints were taken to determine changes in foot form. The established database can be used as comparative values for clinical decisions about the normal foot development.
Morrison SC, Ferrari J. (2009). Inter-rater reliability of the Foot Posture Index (FPI-6) in the assessment of the paediatric foot. *J Foot Ankle Res* Oct 21;2:26.	30 subjects aged 5 - 16 years were recruited for the research. Two raters independently recorded the FPI-6 score for each participant. Almost perfect agreement between the two raters was identified. The FPI-6 is a quick, simple and reliable clinical tool which has demonstrated excellent inter-rater reliability when used in the assessment of the paediatric foot.
Redmond AC, Crane YZ, Menz HB. (2008) Normative values for the Foot Posture Index. J *Foot Ankle Res.*, Jul 31;1(1):6.	Studies reporting FPI data were identified by searching online databases. A set of population norms for children, adults and older people have been derived from a large sample. Foot posture is related to age and the presence of pathology, but not influenced by gender or BMI. The normative values identified may assist in classifying foot type for the purpose of research and clinical decision making.

	Accessed October 26 , 2011 : User guide and manual : http://www.leeds.ac.uk/medicine/FASTER/z/pdf/FPI-manual-formatted-August-2005v2.pdf Data score sheet : http://www.leeds.ac.uk/medicine/FASTER/z/pdf/FPI-Reference-sheets.pdf