

Foot and Ankle Characteristics of Children with an Idiopathic Toe-Walking Gait

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Background: Idiopathic toe-walking (ITW) in children has been associated with ankle equinus. Although equinus has been linked to foot deformity in adults, there has been limited investigation of the impact of equinus on structural foot change in children. We used the weightbearing lunge test and the six-item version of the Foot Posture Index (FPI-6) to evaluate the weightbearing foot and ankle measures of children with an ITW gait and to compare these with their age-matched peers.

Methods: Sixty 4-to 6-year-old children were grouped into ITW ($n = 30$) and non-toe-walking ($n = 30$) cohorts using a validated ITW tool. Ankle range of motion was determined with weightbearing lunge tests. The FPI-6 was calculated during weightbearing stance.

Results: There was a highly significant difference in the weightbearing lunge test measures between the ITW cohort and the non-toe-walking cohort. The FPI-6 comparison was not significant. The straight-leg lunge test had a statistically significant relationship with the FPI-6 in the ITW cohort.

Conclusion: Children with an ITW gait demonstrated reduced flexibility at the ankle joint but similar weightbearing foot posture compared with non-toe-walking children, showing that for children 4 to 8 years old, an ITW gait affects the available ankle dorsiflexion but seems to have a limited effect on weightbearing foot posture as measured by the FPI-6. (J Am Podiatr Med Assoc 103(5): 374-379, 2013)

Toe-walking gait is defined by the absence or limitation of heel strike in the contact phase of the gait cycle.¹ Idiopathic toe-walking (ITW) is a diagnosis given when there is no medical or physical reason for an absent heel strike.² An ITW gait style has been described as having a negative effect on the available ankle range of motion in children.^{3,4} Recently, one study focusing on joint stiffness in children with an ITW gait found that increased stiffness was localized to the ankle joint.⁵

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again describing the gait pattern's associated effect on the soft-tissue structures in the ankle region. The persistent adoption of a plantarflexed foot posture in the ITW gait style is thought to contribute to the equinus that has often been observed.^{2,3,6}

Equinus is a common descriptor of reduced range of motion at the ankle and has long been recognized as a contributing factor in ankle and foot pathologic changes⁷ and balance issues⁸ in older adults. However, there does not seem to be any research on localized effects of equinus on the feet of healthy children in the absence of neuromuscular causes. Instead, equinus and ITW research has focused on increasing the available ankle range of motion or achieving a plantigrade gait by conservative or surgical means.^{9,10}

Studies have quoted available ankle movement ranges for children with an ITW gait as being -5.2° (plantarflexion) to $+20^\circ$ (dorsiflexion),^{5,6,11,12} but only two of the studies^{5,6} described the method of measurement. These studies used the common

nonweightbearing measurement technique of a two-armed goniometer placed at the ankle. The goniometer is reported to provide a measure of the available ankle joint range of motion dependent on the dorsiflexion force applied, with poor reliability of measurement found with the pediatric patient.¹³ A reason for this inaccuracy may be that the variability of the applied force is not comparative to the body weight force at the ankle joint during gait. This variability in externally applied force, therefore, may not provide an accurate representation of available dorsiflexion. Furthermore, the accurate positioning of the goniometer when retesting the range of motion, or when tested by another clinician, has also challenged the reliability of experienced and novice clinicians.^{13,14} Research into other medical conditions affecting the foot and ankle has begun reporting use of the weightbearing lunge test. The use of this test has reported interrater and intrarater reliability of measures between novice and experienced clinicians in a blinded study of 13 healthy individuals, finding this method to have excellent reliability (intraclass correlation coefficient = 0.97).¹⁵ The weightbearing lunge test has also been validated with the use of ultrasound in 30 healthy individuals of both sexes. Use of ultrasound has demonstrated that the weightbearing lunge test is an appropriate method for measuring available ankle dorsiflexion,¹⁶ and the method of conducting the weightbearing lunge is well described in the literature.¹⁷ Owing to the ease of this test, it has been used successfully in other associative studies with young children as participants.¹⁸ This test can be conducted with both a straight leg, to measure gastrocnemius muscle flexibility, and a bent knee, to measure capsular flexibility and the potential osseous configuration at the ankle together with soleus flexibility.¹⁷ The straight-leg and bent-knee postures^{17,18} were replicated in this study, as described in the “Materials and Methods” section. It is reported that healthy children, 4 to 8 years old, have an average minimum of 29.2°¹⁷ and an average maximum of 36.6°¹⁸ of ankle dorsiflexion using this measurement technique.

Another tool that can be used to describe the static and weightbearing foot in children and adults is the six-item version of the Foot Posture Index (FPI-6).^{19,20} The scoring system of the FPI-6 is determined by six variable factors giving a numerical descriptor of the foot in stance. The FPI-6 user manual¹⁹ leads the user through a series of quick-scored assessments. The summation of these scores provides an overall FPI of -12 to +12, with a

negative FPI-6 indicating a supinated foot type; a positive FPI-6, a pronated foot type; and an FPI-6 of zero, a neutral foot type.¹⁹ The weightbearing foot profile of children with an ITW gait has not yet been described in any studies, to our knowledge.

This study aimed to profile the ankle range of motion and weightbearing static foot posture of children with an ITW gait compared with their peers to improve the understanding of any associated soft-tissue impact of the gait style using the inexpensive, reliable, valid, and easy-to-use lunge tests and the FPI-6. The use of two valid and reliable measures provides reference ranges for other researchers and potentially enables measures for studies of the implementation of targeted interventions to reduce the impact of ITW on ankle and foot structures.

Methods and Materials

The human research and ethics committees of Charles Sturt University (Albury, Australia), Monash Health (Cheltenham, Australia), and Peninsula Health (Frankston, Australia) approved this study.

Participants

Sixty 4- to 8-year old children were recruited via advertising to the general public in Melbourne, Australia. All of the children were assessed by a podiatric physician (C.W.) with 15 years of experience in assessing foot and leg conditions in children. The non-toe-walking and ITW cohorts each consisted of 30 children in the specified age range who were healthy at birth, were born after 37 weeks' gestation, and, when tested on the age-appropriate Brigance screen,²¹ scored above the cutoff point for risk of a developmental delay. In addition, children in the ITW cohort were required to have had a long-term history of intermittent toe-walking as reported by their parents, were currently toe-walking, were able to normalize their toe-walking gait on request, and were identified by a validated exclusionary tool²² as having an ITW gait. This exclusionary tool was developed and tested for validity and reliability to ensure that healthy children with an ITW gait were able enter a subsequent study on ITW gait.

Data Collection Tools and Procedure

Weightbearing Lunge Test. Ankle joint range of motion was measured by positioning the foot and ankle in a dorsiflexed and straight position to put

tension on the gastrocnemius muscle, soleus muscle, and ankle capsule.¹⁷ Ankle joint range of motion was measured with a digital inclinometer (LS160 S-Digit Mini digital inclinometer; Laser Depot, Adelaide, Australia) placed at the flat aspect of the Achilles tendon (Fig. 1). The digital inclinometer has demonstrated validity and ease of use²³ and has been used in the pediatric population in other foot and ankle studies.¹⁸

Before each test, the children removed their shoes, and the digital inclinometer was set to zero on the floor next to the child. To obtain the muscle flexibility of the gastrocnemius and soleus muscles, the foot being measured was placed perpendicular to the wall and the child was encouraged to lunge with the knee over the second toe. This position minimized rotation of the leg, thereby attempting to hold the foot in a neutral position; each child was assisted to hold this position by the examiner or a parent. The children placed their hands on the wall for support while being instructed to look at a spot on the wall. They were also encouraged to place the supporting leg in a comfortable position to minimize movement during the measurement procedure. If they were unable to hold still in this position, a parent was asked to help the child focus and remain still during the measurement. The child was then asked to repeat the test with the knee bent. The examiner was not blinded to which group the child was allocated, and the measures were collected over a 9-month period as a component of a larger study of sensory seeking and ITW gait. The examiner has also used this test in everyday clinical practice with this age group for the past 2 years.



Figure 1. Straight-leg weightbearing lunge test: a visual representation of the use of the digital inclinometer in ankle range-of-motion measurement.

The FPI-6. The child was then asked to take three to four steps in the same place to ensure that the feet were in a natural standing position. The FPI-6 was then calculated for each foot using the data sheet provided in the FPI-6 user manual.¹⁹

Demographic Data

Additional demographic characteristics were collected for analysis, including age, body mass index (BMI) (calculated as weight in kilograms divided by height in meters squared), sex, and ethnicity (white or nonwhite).

Analysis of Data

Analysis of the bent-leg and straight-leg lunge and FPI-6 data was based on the measurement made on the dominant foot. The dominant foot was determined by asking the child to kick a ball a number of times.²⁴ The decision to use only the dominant limb was based on the use of single-limb data being shown as appropriate in similar studies to satisfy the condition for independence.²⁵

The mean $\pm$ SD ages of the cohorts were initially calculated. These measures were used to establish how well the cohorts were matched. The data were then analyzed using a linear mixed model in ASReml-R. The BMI was analyzed with the fixed terms “age,” “sex,” and their interaction and “ITW.” Straight-leg lunge, bent-leg lunge, and FPI-6 test data were analyzed with only one fixed term in the model to fit the effect of the ITW category.²⁶ This method of analysis was determined as the most appropriate for handling the varied output of the lunge test and FPI-6 data. All of the data were checked to confirm that the model assumptions of homogeneity and independence were met and that the data approximated a normal distribution. Because the age range of the children in this study has been shown to have minimal influence on the lunge test¹⁷ and the FPI-6,²⁷ age was not factored into the data analysis.

Further relationship analysis was conducted using a linear model (analysis of variance) in ASReml-R to investigate the relationship that FPI-6 has with straight- and bent-leg lunge. This model included the main effects of “straight-leg lunge,” “bent-leg lunge,” and “ITW.” Also included in the model were the two-way interactions of “straight-leg lunge and ITW” and “bent-leg lunge and ITW.” The aim was to determine whether there was a statistical relationship between the straight- and bent-leg lunge data and the FPI-6 values of the

groups. A post hoc power analysis was conducted with G*Power (Franz Faul, Universität Kiel, Kiel, Germany)²⁸ to determine whether nonsignificant results were related to sample size.

Results

The mean $\pm$ SD age of the non-toe-walking cohort was 6.1 ± 1.25 years and of the ITW cohort was 6.0 ± 1.4 years. Although the cohorts were well matched in age, when analyzing the BMI, a two-way interaction of age and ITW ($P = .27$) was found. This interaction found the predicted BMI of the ITW cohort appearing to lower with the increase in age; however, these predicted BMI values were still within a normal BMI percentile when plotted on the clinical growth charts.²⁹ There were more male participants in the ITW cohort ($n = 19$) versus the non-toe-walking cohort ($n = 16$).

There was a significant difference between the cohorts in the straight- and bent-leg positions of the weightbearing lunge test. The straight-leg lunge results ($F_{58} = 105.30$, $P < .001$) and the bent-leg lunge results ($F_{58} = 84.91$, $P < .001$) are displayed in Table 1, and Figure 2 shows a box plot visual display of the difference between the cohorts. There was no significant difference between the cohorts when using the FPI-6 measure ($F_{58} = 3.35$, $P = .072$). Post hoc power analysis determined the difference between the lunge tests to be appropriately powered to have a 100% chance of detecting a large effect. The FPI-6 data between the cohorts were tested with power ($1 - \beta$) set at 0.80 and $\alpha = 0.05$, two tailed. This calculation found that the sample size would have to increase to an unreasonably large 262 patients. Thus, it is unlikely that the negative finding can be attributed to the current sample size.

It was determined from the ITW responses that there was no significant relationship between the FPI-6 and bent-leg lunge ($P = .314$). The interaction of the straight-leg lunge and ITW responses affected the FPI-6 value ($P = .001$), determining that the FPI-

6 value increased when there was a reduction in ankle range of motion. This relationship analysis indicated that the children displayed a more pronated foot type as the gastrocnemius muscle got tighter. The statistical analysis of relationship determined a predicted FPI-6 at intervals of ankle range of motion measure. Despite this, it was observed that the overall predicted measures were still within a normal range for children²⁷ in this age group (Table 2).

Discussion

This study confirmed that healthy children who exhibit an ITW gait have an associated ankle range of motion reduction and found that children with an ITW gait have similar static foot posture as their non-toe-walking peers. Findings also indicated that the reduction in ankle range of motion was not associated with the foot posture as measured with the FPI-6, which seems at odds with general clinical practice as reduced ankle range of motion is often associated with an increase in foot pronation. Although it has been well accepted that the flexible flat foot is present in the pediatric population, it may be proposed that any negative impact of reduced ankle dorsiflexion may not be noted until late childhood and adolescence if the toe-walking gait continues.

The mean FPI-6 values of both cohorts of children were within the normal range for this age group.²⁷ Although the mean FPI-6 for the ITW cohort was marginally higher, indicating a trend toward increased pronation at stance, these results were not significant ($P > .05$). Relationship analysis of the data also demonstrated that although a reduction in the ankle range of motion did have a slight effect on the static weightbearing posture (FPI-6) of the foot, this effect did not seem to increase the amount of static weightbearing pronation. A positive correlation between foot posture and reduced ankle range of motion has been demonstrated in older adults⁸ using these same measurement techniques; there-

Table 1. Weightbearing Lunge Test and FPI-6 Measurements

Measurement	NTW Cohort	ITW Cohort	F_{58}	P Value
Straight-leg lunge, dominant leg (°)	32.8 ± 0.9	20.1 ± 0.9	105.30	$<.001^a$
Bent-leg lunge, dominant leg (°)	36.3 ± 1.0	22.7 ± 1.0	84.91	$<.001^a$
FPI-6	3.5 ± 1.3	4.4 ± 3.1	3.35	.072

Note: Data are given as mean $\pm$ SE.

Abbreviations: FPI-6, six-item version of the Foot Posture Index; ITW, idiopathic toe-walking; NTW, non-toe-walking.

^aHighly significant at $P < .001$ (two-tailed).

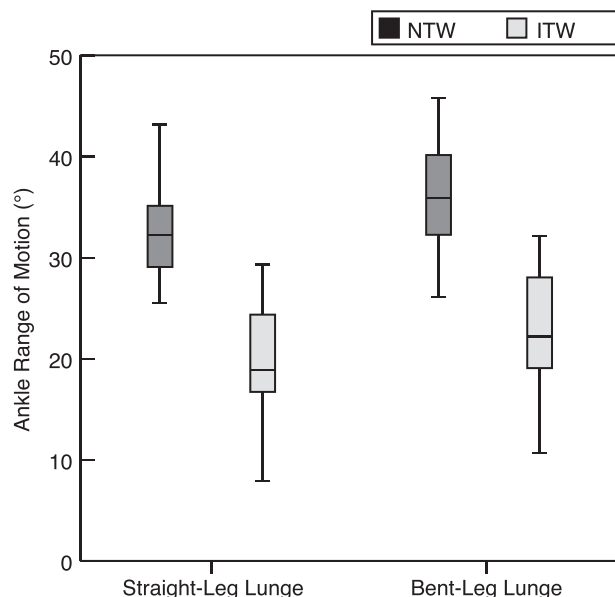


Figure 2. Weightbearing lunge box plot: a visual comparison between the non-toe-walking (NTW) and idiopathic toe-walking (ITW) groups of the mean $\pm$ SD ankle range of motion (degrees). The bottom and top of the boxes correspond to the 25th and 75th percentiles. The internal band is the 50th percentile (median). The plot whiskers extending outside of the boxes correspond to the lowest and highest data point.

fore, it is of interest that this finding was not similar in this age group. With aging and growth come hormonal changes and increased body weight together with structural foot changes and arch development, so it may be speculated that these also contribute to the changes noted in the FPI-6 of older adults with equinus.

In the absence of a longitudinal study, it cannot be determined whether the ankle range of motion

restriction was an effect of the toe-walking gait pattern or whether the child was born with a reduced range of motion, thus making a toe-walking gait the preferred and easier gait style. Nevertheless, because ITW gait is characterized by the ability to heel-toe walk but with a preference for intermittent toe-walking, it is assumed that the reduction in available ankle range of motion is a result of the gait pattern. The finding in this study of soleus muscle tightness and ankle capsular stiffness as measured by the bent-leg lunge warrants consideration during any equinus treatment of children with an ITW gait.

Conclusions

This study demonstrates associated ankle range of motion changes occurring in children with an ITW gait. The reduction in ankle range of motion found with the lunge test in the leg-straight and knee-flexed positions demonstrated muscular contraction and capsular stiffness in children with an ITW gait. Ankle capsule stiffness, as measured in the bent-leg lunge, is yet to be explored as other ITW research has described only the use of a nonweightbearing straight-leg lunge test. The weightbearing foot posture of children with an ITW gait was similar to that of their peers and seemed uninfluenced by the reduction in ankle range of motion, at least for children 4 to 8 years old.

A limitation of this study is that it was cross-sectional and, as a result, was unable to determine the impact of ITW gait over time. In addition, the study did not record any other foot posture, joint alignment, or anthropological clinical measures; inclusion of these in future studies may contribute to a better understanding of how an ITW gait pattern might impact the lower-limb musculoskeletal system and the osseous development of the foot. Future research should take these points into account.

Despite these limitations, the weightbearing lunge test is a reliable and valid tool to use when measuring the impact of ITW gait on the ankle. The FPI-6 may be considered in further research. As a result, future research into the treatment of ankle equinus associated with ITW should use the weightbearing lunge test as a method to monitor the impact of treatment modalities. It is proposed that foot structures may be impacted when there is a greater reduction in ankle range of motion for children with an ITW gait, and, as a result, a longitudinal study should consider inclusion of the FPI-6 only in collaboration with other anthropological and foot posture measures to determine

Table 2. Predicted FPI-6 Values for the Idiopathic Toe-Walking Group Based on Straight-Leg Lunge Results

Available Ankle Range of Motion (°)	Predicted FPI-6 (Mean $\pm$ SE)
10	5.8 $\pm$ 0.83
15	5.1 $\pm$ 0.53
20	4.4 $\pm$ 0.37
25	3.7 $\pm$ 0.51
30	3.0 $\pm$ 0.81
35	2.3 $\pm$ 1.15
40	1.6 $\pm$ 1.50

Abbreviation: FPI-6, six-item version of the Foot Posture Index.

whether changes in foot structure occur and the long-term impact of this gait.

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