



# Orthopaedic Interventions for Pediatric Patients: The Evidence for Effectiveness



## Independent Study Course 15.1.3



## Idiopathic Toe Walking: A Diagnosis of Exclusion or a Developmental Marker

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## Orthopaedic Interventions for Pediatric Patients: The Evidence for Effectiveness

Mary Ann Wilmarth, PT, DPT, MS, OCS,  
MTC, Cert MDT—Editor



March 2005

Dear Colleague,

I am pleased to welcome you to *Idiopathic Toe Walking: A Diagnosis of Exclusion or a Developmental Marker* by Nancy Dilger, MA, PT, PCS. This is the third monograph in the Orthopaedic Section Independent Study Course series 15.1 entitled *Orthopaedic Interventions for Pediatric Patients: The Evidence for Effectiveness*.

Ms Dilger is a board certified clinical specialist in pediatric physical therapy. She received a bachelor of science degree in physical therapy from Florida International University and a master of arts with a specialization in developmental disabilities from New York University. Ms Dilger has a vast amount of experience in working with a pediatric population. She currently works at her private practice, Footprints Pediatric Physical Therapy.

This monograph starts with a review of the literature related to idiopathic toe walking. The terminology can be somewhat enigmatic at times, and Ms Dilger helps to clarify this. The author then discusses in detail the differential diagnosis of idiopathic toe walking. Ms Dilger covers the basics regarding evaluation and the various options for interventions as well as the effectiveness of each intervention. She elaborates with written and photographic examples, and concludes with case studies that look at patients having the diagnosis of idiopathic toe walking. The appendixes include a range of screening and assessment tools that will be useful in the clinic.

Upon completion of this monograph the participant will be better able to differentially diagnose those patients with true idiopathic toe walking. However, questions also will be raised, thus leading back to the title of this monograph, *Idiopathic Toe Walking: A Diagnosis of Exclusion or a Developmental Marker*.

I want to give special acknowledgement to Thomas G. McPoil, Jr, PT, PhD, ATC, for his expert editorial assistance with this monograph.

I think that you will find this monograph to be an informative, practical, and useful reference for working with your pediatric patients. Enjoy your reading!

Best regards,

Mary Ann Wilmarth, PT, DPT, MS, OCS, MTC, Cert MDT  
Editor

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## Idiopathic Toe Walking: A Diagnosis of Exclusion or a Developmental Marker

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### LEARNING OBJECTIVES

Upon completion of this monograph, the course participant will be able to:

1. Define idiopathic toe walking.
2. Recognize and differentiate among the various types of idiopathic toe walking.
3. Explain the various etiologies of idiopathic toe walking.
4. Define the incidence of idiopathic toe walking.
5. Describe the muscle histology found in idiopathic toe walking.
6. Compare and contrast the electromyographic findings of unaffected peers versus individuals with cerebral palsy versus individuals with idiopathic toe walking.
7. Describe the dynamics as well as the musculoskeletal implications of idiopathic toe walking.
8. Define characteristic kinematic patterns of knee and ankle motion that differentiate idiopathic toe walking from spastic diplegia.
9. Explore the current interventions for idiopathic toe walking.
10. Compare the nonsurgical to surgical approaches with respect to changes associated with the alteration of muscle length.

### INTRODUCTION

When a child is toe walking, the reason for this altered gait may extend beyond a musculoskeletal perspective. Toe walking is where the weight is primarily on the forefoot, through the metatarsal heads, with the toes relatively flat at an angle to the foot, resulting in a toe-toe gait pattern.<sup>1</sup> Children may walk with normal, efficient, and well-coordinated gait patterns. However, weight bearing is on the metatarsal heads or forefoot with the ankles at 10° to 30° of plantarflexion, and with passive dorsiflexion of 5° and passive plantarflexion of 10°. These children achieve their developmental milestones within normal limits (WNL) and are independent ambulators at a normal age; however, they are on their toes from the inception. A term used to describe a toe-toe gait pattern without a known etiology in children, is *idiopathic toe walking* (ITW). An operational definition of ITW is as follows: an equinus gait, initially without fixed contractures, with passive dorsiflexion range of motion (ROM) of the plantarflexor musculature to dorsiflex to at least neutral (0°) with the subtalar joint inverted and with the knee extended.<sup>2</sup> It may be further described as the presence of equinus without abnormal tone, deformity, sensory, or reflex status.<sup>3</sup> Idiopathic toe walking or idiopathic toe walker is frequently a diagnosis of exclusion, but is it really *idiopathic*?

The purpose of this monograph is to provide an overview of ITW. This will be done by reviewing the literature; noting the factors that may contribute to toe walking; reviewing the electromyography (EMG) of ITW; explaining the lower leg kinematics of normal gait and toe walking; examining evaluative techniques; and exploring the current interventions used with children who have been diagnosed as idiopathic toe walkers.

### REVIEW OF THE LITERATURE

#### Clarification of Terminology

According to the literature, there are classifications that vary to describe toe walking in individuals without neurological signs.<sup>4</sup> Two of these include habitual toe walking and short tendo calcaneus, the difference being that the latter presents with limited dorsiflexion ROM. Others are tendo Achilles contractures and idiosyncratic toe walking or ITW. Each classification varies slightly, but in order to maintain consistency within this monograph, the term *idiopathic toe walking* (ITW) will be used, unless otherwise specified.

Toe walking due to an unknown etiology was first addressed in the literature as congenital short tendo calcaneus. In 1967, Hall et al<sup>5</sup> published the first study describing the condition of congenital short tendo calcaneus. The patients were found to have neither congenital contractures (by virtue of birth records) nor neurological signs, and they appeared normal but walked on their toes. At the time they were seen, they had contractures of the calf musculature of 30° to 60°, and these were not necessarily symmetrical.<sup>5</sup>

In 1973, Levine<sup>6</sup> published a clinical case report of a family where several members were affected with what was felt to be congenital short tendo calcaneus. In this situation, an 8-year-old boy presented to the clinic walking on his toes. In addition, it was noted that he was known to have emotional problems and performed poorly at school. He had undergone bilateral calcaneal tendon lengthenings at 5 years of age because he walked on his toes from the inception, at 12 months of age. The boy's 12-year-old brother walked on his toes, had a normal neurological evaluation, was diagnosed with cerebral palsy (CP), and underwent bilateral calcaneal tendon lengthenings. The boy's 4-year-old sister also walked on her toes and had no neurological signs. The paternal grandparents had no clinical signs of toe walking, while the paternal aunt had mild signs as determined by the authors from a phone conversation. This pattern of occurrence led the author to believe that what was considered to be congenital short tendo Achilles was an inherited trait. More specifically, it was considered to be an autosomal dominant trait with a variable expressivity.<sup>6</sup>

In 1977, Griffin et al<sup>7</sup> published a study about children who habitually toe walked. This was felt to be a diagnosis of exclusion, as there was no evidence of clonus or muscle activity at rest on EMG. The patients were determined to have normal neurological status, and the only clinical sign of concern was the limitation of active dorsi-

flexion during gait. Of the 20 subjects in this study, there were 3 examples of familial tendency. One subject was recognized because his father, who was also walking on his toes, brought him into the clinic. This was felt to confirm Levine's statement regarding a hereditary trait.<sup>7</sup>

### **Incidence and Etiology**

There are various opinions regarding the incidence and etiology of ITW. One belief is that toe walking not associated with CP occurs in 7% to 24% of the normal pediatric population and affects boys more than girls. There is a familial tendency and usually a bilateral manifestation of equinus; however, the degree of plantarflexion or decreased ROM may not necessarily be symmetrical.<sup>8-10</sup>

A contrary opinion is that the incidence is not really known because toe walking is considered by some to be an acceptable transition in normal development, sometimes occurring with beginning walkers. The child diagnosed as an idiopathic toe walker may well have been the product of a normal birth and developmental history, achieving developmental milestones within an acceptable framework of time. Thus, the presentation of limited passive dorsiflexion of 5° to 10° with the knee extended and the subtalar joint in neutral along with a normal neurological status is not fully understood. Furthermore, the tightness of the calf musculature may be the consequence of ITW rather than the cause.<sup>11</sup>

Some believe that ITW may be due to an unknown central nervous system deficit or a neuropathic process, as seen by changes in muscle properties.<sup>12</sup> Eastwood et al<sup>12</sup> performed muscle biopsies on 33 children, ranging in age from 1.9 to 12.8 years. The muscles biopsied were the tibialis anterior of 2 children; the vastus lateralis of 2 children; the gastrocnemius of 20 children; and the soleus of 1 child. This was a detailed enzymatic and histochemical study that resulted in abnormalities suggestive of a neuropathic entity contributing to ITW or toe walking in the absence of a neurological disorder. There was an increase in type I muscle fibers found in the gastrocnemius, with a mean of 63%. Although there are no studies of the percentage of type I fibers in children, in adults the norm for the gastrocnemius is 50%.<sup>12</sup>

Type I muscle fibers contain the most mitochondria of the 3 major muscle fibers in human skeletal muscle. Characteristics of type I muscle fibers include being dependent on oxidative phosphorylation, tonic slow contracting, and resistant to fatigue. Compared to type IIA and IIB, type I fibers have more blood capillaries.<sup>12</sup>

The process of denervation atrophy is suspected in the presence of atrophic angular fibers with an increase in the activity of nonspecific esterase. Evidently, a number of specimens had an increase in type I fibers and type grouping, which is consistent with degeneration and regeneration. The nerve supply will dictate fiber type by axonal branching to reinnervate denervated fibers, and thus the fibers will convert to the muscle type as determined by the nerve's axon.<sup>12</sup>

Another rationale for the etiology of ITW is the delayed maturation of the corticospinal tract.<sup>10</sup> This results in the lack of inhibition of the stretch reflexes, resulting in toe walking with possible increased deep tendon reflexes, but without fixed equinus. This type of ITW is thought to be familial and resolves spontaneously between 6 and 8 years of age.<sup>10</sup>

Toe walking as a unilateral incident has also been documented in the literature. Domb et al<sup>13</sup> found that musculoskeletal deformities may be produced by soft tissue venous malformations of muscles. This is caused by a subsequent contracture of the muscle or muscles. In the event the muscles involved are the plantarflexors, the result can be an equinus deformity. This study cites 3 such incidences that resulted in unilateral toe walking.<sup>13</sup>

### **DIFFERENTIAL DIAGNOSIS**

#### **Toe Walking as an Associated Characteristic**

Toe walking may be associated with a number of disorders and diagnoses. These may include, but are not limited to: CP, myopathy, spina bifida, muscular dystrophy, tethered cord syndrome, acute myopathies, autism, mental retardation, childhood schizophrenia, dystonia musculorum deformans, diastematomyelia, spinal cord tumor, and spinal dysraphism.<sup>4,8,10,14</sup>

The most common cause of toe walking is CP, as shown in Figures 1A to D.<sup>14</sup> Children with CP demonstrate a gait pattern of coactivation of leg muscles that is very similar to that described in automatic walking observed in newborns. Automatic walking in newborns can be elicited when the infant is vertically suspended and weight is taken through the lower extremities from the support surface. As the baby is leaned forward, it will spontaneously respond with well-organized reciprocal movement of the lower extremities.<sup>15</sup>

It is speculated that the gait pattern of a child with CP does not become more refined secondary to the abnormal spinal influences in combination with the peripheral motor system's early structural changes. Regulation of muscle stiffness during the step cycle is achieved by the interplay of the tension produced by muscle activation and the contractile viscoelastic properties.<sup>16</sup>

However, in the absence of any orthopaedic, neurological, or other clinical signs of abnormal tonus, sensory, or reflex changes, the diagnosis would be ITW. Idiopathic toe walking is an entity, which is also manifested with an equinus gait, but often referred to as a diagnosis of exclusion. In the late 1970s, there were 2 studies<sup>1,17</sup> presenting toe walking in association with very specific developmental disorders: autism and mental retardation. The common thread with these studies was the acknowledgment of sensory integration issues and its effect on the development of movement patterns. It is a possibility that sensory integration dysfunction may contribute to the clinical manifestation of toe walking in children without clearly defined pyramidal sign.

For clarity, it would be beneficial to review the theory of sensory integration. Sensory integration is the reg-



**Figure 1. 5-year-old with spastic diplegic cerebral palsy. (A) Independent standing posture. (B) Forward progression: increased hip internal rotation and internal tibial torsion. (C) Posterior view: shortening on weight-bearing side and center of gravity is anterior resulting in a toe-toe gait. (D) Side view: forefoot weight bearing with knee flexion.**

istration and modulation of sensory input for the execution of motor output. The sensory systems that are registering input in order to produce sensorimotor results include tactile, visual, vestibular, proprioceptive, auditory, olfactory, and gustatory. Exploring each system is beyond the scope of this monograph. However, it would be prudent to touch upon 2 systems that contribute to the development of the skill of motor planning. These are the somatosensory system, consisting of tactile and kinesthetics, and the vestibular system.

There are dual systems for mediating tactile input. One is phylogenetically older, responding to stimuli that may be harmful and of a crude or diffuse nature. This is called the protopathic system. The second system is the epicritic system. This is described as a phylogenetically newer system that responds to fine tactile discrimination.

There are 2 functional mechanisms of sensory integration. The first functional mechanism is found within the spinothalamic system, which may be equivalent to the protopathic system. The spinothalamic system is mediated through the spinoreticular, spinotectal, and spinothalamic tracts to the posterior thalamic nuclei. The spinothalamic system perceives peripheral stimuli including, but not limited to, pin prick and deep compression which is considered destructive input. Neuronal firing will also occur from light touch or skin pressure, displacement of hair, and vibratory or auditory input. The result of the stimulation is generalized and can result in an attempt to escape or alter emotions. The second functional system is the lemniscal system, which may be like the epicritic system. The lemniscal system is mediated through the dorsal columns, medial lemniscus, and ventrobasilar complex of the thalamus. Located in the ventrobasilar portion of the thalamic nuclei, this system is discriminative as well as specific to input and responds to various stimuli including proprioception, light, and touch.

There may be sensory integration issues that result in toe walking. Children with tactile defensiveness may

have an imbalance between the spinothalamic and lemniscal systems. If the spinothalamic system has an overpowering effect on the overall system, toe walking may result in an effort to balance the systems.

Another explanation offered for toe walking has to do with hypotonia and an associated hyporesponsive vestibular system. It is possible that a positive support reaction is used to enhance tactile and proprioceptive input into the lower extremities as a form of facilitated support. The mechanism of sensory integration, in particular the vestibular system, provides input to the reticular formation via the medial and lateral vestibulospinal tracts. The lateral vestibulospinal tract sends impulses to the lateral vestibular (Deiter) nuclei, which in turn affects the motor neurons of the spinal cord and, subsequently, the extensor muscles of the lower extremities, resulting in an equinus posturing of the foot and, ultimately, toe walking.<sup>17</sup>

In describing the toe-walking gait pattern of children diagnosed with autism, Weber<sup>1</sup> determined that it was due to a fixation from early development that was held over. A developmental lag of the central nervous system was felt to contribute to the delay or absence of development of individual functional areas.<sup>1</sup> More specifically, the areas of sensorimotor, cognition, or language could be at risk.<sup>1</sup>

In 1989, Accardo and Whitman<sup>18</sup> determined that one third of children with autism are known to walk on their toes. The possible association between toe walking and disorders of language may have roots in the model for autism. Accardo et al<sup>19</sup> credit Ornitz for dividing autism into 3 categories based on functional symptoms. The first is related to people and objects. The second is related to language and communication. The third is related to sensory modulation and motility. Along with the hand-wringing behavior that is often associated with autism, toe walking may be in the third category as a result of sensory integrative dysfunction in registration and modulation for motor execution.

In addition, Accardo et al<sup>19</sup> found that the persistence of toe walking is apparently consistent with the severity of language impairment. In one study of 799 children with known delayed development, toe walking was found to be prominent in the population diagnosed with autism as well as in the children with less severe language delay and communication disorders in the general pediatric population.<sup>18</sup> The purpose of the more recent study by Accardo et al<sup>19</sup> was to correlate toe walking with possible lower language skills. Of the 166 children seen for routine checkups, 24% were identified as persistently walking on their toes. Screening for language performance was administered, resulting in scores that were consistently lower in the children who were toe walking versus their peers who were not toe walking. The children walking on their toes scored 85% for deficient language skills with a sensitivity of 32%. The researchers determined that the incidence of language disorders associated with toe walking may not be insignificant, but the results were not impressive enough to warrant an explicit diagnosis.<sup>18,19</sup>

Montgomery and Gauger<sup>17</sup> described toe walking with a very strong regard for sensory integration dysfunction found in children with mental retardation. These children tended to be hypotonic and hyporesponsive to vestibular input as determined by nystagmus testing. It was theorized that toe walking counterbalanced these conditions by prolonging the stance phase and intensifying the proprioceptive input to the tarsal metatarsal joints and group IIA afferents from the muscle spindle via tonic muscular contractions. Therefore, the continuous input to the Dieter nuclei could stimulate the lateral vestibular tract to increase extensor activity of the lower extremities. In addition, it was speculated that toe walking in children with mental retardation was secondary to sensory defensiveness, especially the pressure elicited at heel strike.<sup>17</sup> Ironically, the increased pressure and weight bearing on the forefoot were not mentioned as having an adverse effect.

Since the mid 1990s, developmental specialists began to assimilate their clinical findings of individuals who were thought to be idiopathic toe walkers. The results were found to be beyond the boundaries of merely a single possible factor. In a study by Shulman et al,<sup>20</sup> there were 13 children between 1.6 and 6.8 years, with a mean age of 3.9 years. They were evaluated by a developmental team, which consisted of a developmental pediatrician, pediatric neurologist, speech-language pathologist, occupational therapist, and physical therapist. The subjects had been referred to the team due to concerns about toe walking. The purpose of this study was to determine if children with a normal neurological examination who toe walked had developmental delays in the areas of language development, visual motor function, sensory integrative function, gross and/or fine motor skills, or evidence of behavioral problems. Since there were no focal neurological signs, it was hypothesized

that the toe walking was secondary to tactile defensiveness, persistence of the positive support reaction, vestibular dysfunction, or sensory integrative dysfunction. The study determined that 75% of the children were found to have significant language delays and to a lesser extent a latency in fine motor, visual motor, and gross motor skills.<sup>20</sup> However, over 60% of the subjects had suspicious prenatal and birth histories that cannot justify being included in a population with developmental issues of unknown etiology.

## **Gait**

### **Development of normal gait**

In the normal development of humans, locomotion evolves from quadruped to biped. The assumption of an upright posture is dependent upon stabilizing the center of mass while simultaneously balancing over the base of support in order to advance the body forward with the use of repetitious lower limb sequences of movement. These repetitive sequences of movement are referred to as gait cycles, which are further subdivided into phases. Perry<sup>21</sup> defined 8 phases of gait as follows: initial contact, loading response, midstance, terminal stance, preswing, initial swing, midswing, and terminal swing. Each of these phases of gait are designated as having specific biomechanical functions.<sup>21,22</sup>

In motor control theory, the innate spinal cord contains the central pattern generators that are responsible for infant stepping. It has been suggested that ontogeny may be related to the phylogeny in humans that ultimately results in the plantigrade gait pattern. Neural circuits that are highly specialized for human development evolve late in ontogeny, transforming the original non-plantigrade pattern to a plantigrade motor activity. The functions of independent human plantigrade gait develop from the initiation of walking gradually into the second year of life. This efficient bipedal pattern is an organizational movement unique to man.<sup>23</sup>

The innate locomotor rhythm seen in human stepping may have a genetically coded neural network, organized at or below the brainstem. The maturational process of the central nervous system is geared toward a gradual transformation of motor output to achieve a plantigrade gait pattern. However, this is not always the outcome, and there are 4 alternatives to consider. One would be production of a locomotor pattern taken over by new rhythm generators. A second is when the original network becomes rewritten. A third is when the central pattern generators become altered by peripheral feedback. The fourth is when the output becomes modified by the influence of a new central system. This is an example of a supraspinal input occurring during development where the plantar reflex of the foot is transformed into an extensor response as seen in the Babinski sign.<sup>23</sup>

From a neuromaturational perspective, it is stipulated that the assumption of an upright posture initiates from prone to quadruped and then to bipedalism via maturation and myelination. There may be a dopaminergic



effect on the central nervous system, which assists in the transformation of a digitigrade to plantigrade gait pattern, along with the maturational process. Independent upright ambulation is the most energy efficient in the mature human. The bipedal human gait evolves from digitigrade to plantigrade to heel strike. Heel strike is a phase in gait unique to humans along with the entirety of the gait cycle.<sup>24</sup>

Early independent, unsupported walking is defined by asymmetrical step lengths, a wide base of support characterized by relatively excessive hip flexion and abduction, and a decreased stride length to compensate for the highly anticipated yet unstable single limb stance (Figures 2A to D). Within 2 years, the base of support narrows from the increase in the width of the pelvis, and more competent balance skills appear. In addition, at this point there is a decrease in the hip and knee flexion during stance, which is displayed in a digitigrade gait. Furthermore, the ankle develops movement independent of the knee, as seen with dorsiflexion in combination

with knee extension. This combined movement at the termination of swing fosters the transition to a plantigrade gait pattern.<sup>24</sup>

In addition to the aforementioned, the normal development of gait supports the cephalo-caudal progression of central nervous system control. Here the movement of the proximal joints is more refined than the movement at the distal joints. This is recognized as a known disorganization in new walkers during the swing to stance transition. This lack of refinement may correlate with the lack of nervous system control of muscle coordination. In ambulatory children younger than 18 months of age, there is an immaturity of the cerebral cortex, cerebellum, corticospinal tract, and motor end plate region. The areas of the cerebral cortex and spinal cord that lend control to the lower extremities are least advanced. Sometimes with new walkers, they are able to execute mature patterns of movement more rapidly to gain increased stability and decrease the need for lateral stability.<sup>25</sup>



**Figure 2. A new walker. Early independent, unsupported walking is defined by asymmetrical step lengths; a wide base of support characterized by relatively excessive hip flexion and abduction; and decreased stride length to compensate for the highly anticipated yet unstable single limb stance. (A) In almost constant dorsiflexion. (B) With well-aligned posture and shoulders over hips. (C) With elongation on the weight-bearing side and shortening on the non-weight-bearing side; appreciate the wide base of support. (D) Side stepping.**

Berger et al<sup>26</sup> conducted a study on 50 children, 6 months to 7 years of age, utilizing EMG while being tested on a treadmill. The results described 3 patterns: an early infancy pattern, a mature pattern, and mature locomotion as related to age. These could be interpreted as the initial, transitional with growth, and final end product.

There are 3 parts that were considered in the initial or early infancy EMG pattern. First was coactivation in the distal lower limb. The gastrocnemius muscles were activated prior to ground contact on the metatarsal heads of the foot and silent during the swing phase. The tibialis anterior was activated throughout the gait cycle. Second, there were large solitary biphasic potentials in the gastrocnemius muscles per the EMG. At the beginning of the process of learning to walk, the feet were usually slightly plantarflexed, in a digitigrade posture. However, the position of the trunk and center of gravity were noted to usually be anterior, and this could have contributed to the digitigrade contact. Third was the magnitude as recorded on EMG. It was determined that the magnitude of the activity of the tibialis anterior during swing was equivalent to, or more than, the gastrocnemius during stance. The early stage of muscle co-contraction may be related to maintaining equilibrium. Therefore, maintenance of equilibrium is crucial for early walking. Since the vestibular system functions from birth, this may contribute to the early coactiva-

tion pattern and, later, the conversion to the sequencing of the tibialis anterior and gastrocnemius in the gait cycle.

The second EMG pattern was the maturation of gait that starts at 2 years of age and continues to 5 or 6 years of age. From 2 years of age, the magnitude of the gastrocnemius per EMG increased until about 4 to 5 years of age, when maximum strength was attained. This was significant for the commitment of the gastrocnemius control of the lower leg from midstance to toe-off.

In the final EMG pattern, there was a high activity level in multiple muscle groups displayed that was consistent with the EMG pattern found in mature locomotion. It was determined that from quadruped up to bipedal locomotion, the initial coactivation pattern eventually converted to reciprocal organization with the development of walking and running.<sup>26</sup>

Sutherland et al<sup>27</sup> studied the gait of 186 nonimpaired children, 1 to 7 years of age, to determine normal gait patterns and performance standards. Five important parameters of mature gait were determined: duration of single limb stance, walking velocity, cadence, step length, and ratio of pelvic span to ankle spread. The duration of single limb stance gradually increases from 32% to 38%, most rapidly before 2½ years of age and with reduced variability. The velocity of walking increases primarily before 3½ years of age, but with no lessening of the variability. Cadence, the step rate per minute, was found to decrease with age along with the variability. The step length, defined as the distance between the initial point of contact by 2 feet, was found to increase at a rapid rate until 2½ years and continue to increase but at a slower rate. The pelvic span is the width of the body at the level of the anterior superior iliac spine. The distance between the center of the left and right ankle joints during double limb support time is called the ankle spread. The ratio of pelvic span to ankle spread has a rapid increase until 2½ years of age, increases at a slower rate for the next 3½ years, and remains fairly constant until age 7.

This age group was chosen because the gait of 1 year olds vastly differs from the gait of 7 year olds, since the gait changes with age are appreciable. The gait patterns of 2 year olds were understandably more mature than those of the 1 year olds. The pelvic tilt, hip abduction, and external rotation were decreased from the younger counterparts. A knee flexion wave was present where the knee goes into greater flexion after foot strike and then extends before toe-off. There was a decrease in a relative foot drop during the swing phase. Approximately 75% of the sample of 2 year olds displayed a reciprocal arm swing. The gait of 6 to 7 year olds was considered to closely resemble a mature adult gait. The most notable difference was the increased cadence, decreased walking velocity, and increased pelvic rotation, hip joint rotation, and hip abduction.<sup>26,27</sup>

What might be deduced from this information is that there is a relatively short period of time for the maturation of gait. At 1 year of age, stance phase knee flexion was present with prolonged quadriceps activity. Heel strike was seen at an early age before the maturational development of cadence, step length, and walking velocity. There should be a consistent heel strike by 18 months of age, within the range of 3 to 50 weeks after the onset of independent ambulation. By 22 months from the onset of independent walking, heel strike and arm swing should be constant and initially appreciated by 18 months of age. In a more mature bipedal pattern of gait, knee extension in the stance phase is due to the deceleration of the forward movement of the tibia over the talus controlled by the ankle plantarflexors and the extraneous forces of inertia and gravity.<sup>27</sup>

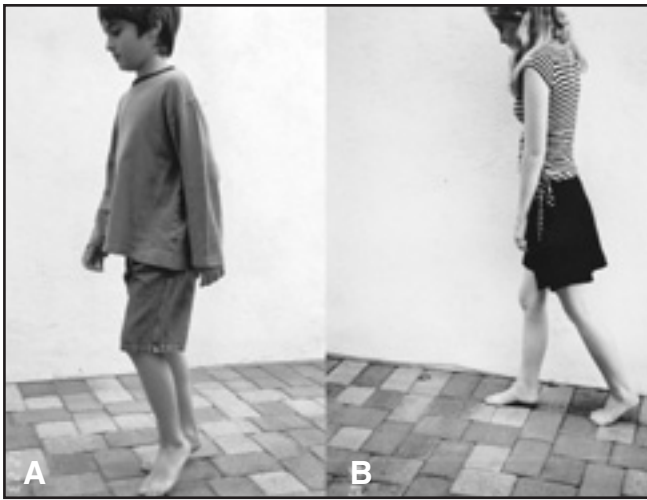
### **The toe-walking gait**

Why is it that some children go on to develop a heel-toe gait while others assume a toe-toe gait? In the literature, toe walking is considered an acceptable component of normal development, which is seen from 3 to 6 months after the onset of independent walking and ceases or resolves spontaneously by age 7 without neurological or orthopaedic sequelae.<sup>28</sup> It has been determined that the usual developmental sequence does not include consistent or persistent toe walking and that a normal gait eventually progresses to a heel strike by 18 months with a heel-toe gait by 3 years.<sup>26,29</sup>

One can appreciate that toe-walking characteristics are similar to those seen when testing for positive support in an infant. This is where the child is vertically suspended, a stimulus is placed to the plantar aspect of the feet, and the newborn spontaneously takes support more on the forefoot. Furthermore, it may be considered within normal limits that children walk on their toes in the initial 3 to 6 months of walking. The sequence may first be toe-toe, then toe-heel and finally heel-toe. It has been speculated that toe walking was due to the lack of strength of the plantarflexor muscles. In supported early walking with the hand held, there is a toe-heel sequence with the trunk more forward and an anterior pelvic tilt. With early independent walking, both supported and unsupported, the feet are in a plantigrade position upon initial contact.<sup>24</sup>

Intermittent toe walking may be seen in normal development, but it is those children who consistently walk on their toes from the inception that may be considered for the diagnosis of ITW in the absence of neurological or orthopaedic problems. There is no confirmation in the literature that ITW is a normal variant of an early gait pattern. However, even intermittent toe walking may be considered for the diagnosis of ITW, which does not account for other developmental diagnoses that may have toe walking as a characteristic (Figures 3A and B).

As previously stated in this monograph, the most common cause of toe walking is CP. In researching the literature, ITW is most often compared and contrasted to



**Figure 3. Examples of individuals who may be considered for the diagnosis of idiopathic toe walking in the absence of neurological or orthopaedic problems. (A) 9-year-old ZJ; walks on toes 70%; has a short stride length. (B) 14-year-old MK; walks exclusively on her toes.**

CP for the purpose of differentiating the diagnosis. In addition, the comparison of ITW to unaffected peers walking on their toes has also frequently been studied. In the following sections, all 3 scenarios will be explored through clinical gait analysis, EMG, and kinematic analysis.

### Clinical Gait Analysis

Sobel et al<sup>8</sup> completed a study that included 60 children, 1 to 15 years of age, all known to be toe walkers. There were 33 boys and 27 girls, excluding diplegia, hemiplegia, unilateral toe walkers, and those with no known surgeries. The participants were divided into 2 groups based on their passive ankle ROM of dorsiflexion. One group was considered the equinus toe walkers and had dorsiflexion at 0° or less. The second group was considered the habitual toe walkers and had 0° or more of dorsiflexion. In the latter group, only 25% constantly walked on their toes and 75% had an intermittent heel-toe gait.

All the parents who brought their children to the clinic knew that they toe walked, with 85% of the parents complaining of associated clinical signs. These included, but were not exclusive to, the following: falling, intoeing, pain, fatigue, flatfoot, limping, poor balance, and bunions. Thirty percent had a positive family history for toe walking. The mean age for initiation of walking was 11.14 months; 87% walked on their toes from the inception and the remainder assumed some degree of equinus within 6 months of walking.

The overall clinical findings of the subjects were as follows: 88% could voluntarily walk heel-toe; 90% had a plantigrade stance; 68% were intermittent toe walkers; 61% toe walked in shoes; and 46% had limited ROM of the Achilles tendon. On the whole, there was an ankle dorsiflexion average of 6.2°. Only 11 participants had

symmetrical ROM in dorsiflexion from right to left with a mean difference of 7.7°. Intermittent toe walkers averaged 8.08° of dorsiflexion versus the constant toe walkers who averaged 1.94°. The children who toe walked with ankle equinus averaged -5.18° of dorsiflexion; the children who were considered to be habitual toe walkers averaged 16.9° of dorsiflexion. Ninety-five percent of habitual toe walkers would walk voluntarily with a heel-toe gait, whereas only 68% of the equinus toe walkers had that ability. Ninety-six percent of the habitual toe walkers were able to plantigrade, whereas 71% of the equinus toe walkers had that ability.

From the above-mentioned study,<sup>8</sup> it was determined that ankle dorsiflexion decreased with age. More specifically, in 1 to 2 year olds, there may be 12° of dorsiflexion, which gradually decreased to -4° in 6 to 15 year olds. In addition, equinus increased proportionally with age: 35% in 1 to 3 year olds; 71% in 4 year olds; and 100% in 5 year olds. Sobel et al<sup>8</sup> hypothesized that limited dorsiflexion in some individuals that resulted in toe walking was secondary to Achilles tendon contracture which developed over time. In most habitual toe walkers with normal dorsiflexion, symptoms resolved spontaneously by early childhood. Younger children who did not improve were found to progressively develop a contracture of the Achilles tendon.<sup>8</sup>

### Electromyography

This section will address the results of EMG studies for the following groups: children serving as controls considered to be normal while voluntarily walking on their toes; children considered to be idiopathic toe walkers; and children with the diagnosis of mild CP.

Electromyography patterns of normal 4-year-old children walking on their toes frequently showed solitary biphasic potentials in the preactivated gastrocnemius.<sup>26</sup> Compared to EMG activity while not voluntarily toe walking, the presence of biphasic potentials was interpreted as the result of muscle yielding and preactivation potentials of the gastrocnemius. A transient and slight dorsiflexion of the foot was also recorded at ground contact. This was interpreted as the result of a stretch to the triceps surae. Similarly, in normal 6 year olds voluntarily toe walking, the gastrocnemius was also activated at ground contact. However, in these subjects, the gastrocnemius was preactivated prior to ground contact with such domination it discouraged any tibialis anterior activity.<sup>25</sup> This could be interpreted as a strength and maturation factor. In younger subjects who voluntarily toe walk, the gastrocnemius has neither the strength nor endurance as seen in older peers.

There are a number of studies that have used EMG for the purpose of differential diagnosis. One study<sup>3</sup> was conducted using EMG to differentiate the diagnosis of an upper motor neuron lesion, as seen in CP, from ITW. It should be clarified that subjects considered to be idiopathic toe walkers were interchangeably referred to as

congenital shortened tendo calcaneus subjects, but there were no limitations in ROM documented at birth that would confirm actual congenital shortening of the heel-cords. All subjects were able to volitionally walk with a heel-toe gait. It was a small study with only 4 subjects. While walking at free and fast speeds, EMG was recorded via foot-switch gait analysis. Electromyography was recorded while at rest, during manual muscle testing, and with a passive, quick stretch. Data were obtained from the gastrocnemius, soleus, tibialis posterior, tibialis anterior, peroneus longus, and peroneus brevis via myoelectric signals. One subject had markedly prolonged activity of the gastrocnemius, tibialis posterior, and peroneus longus into swing phase, and the other had prolonged activity of the gastrocnemius and soleus in swing phase. Clonus of the soleus was present with a quick stretch, evidence of an upper motor neuron lesion. The authors of the study, Papariello and Skinner,<sup>3</sup> felt that even with such a small sample, dynamic EMG was useful in differentiating between ITW and mild CP.

Kalen et al<sup>28</sup> studied similarities among children with ITW, children with the diagnosis of CP, and children considered to be the unaffected peers who were used as controls while voluntarily walking on their toes. The purpose of this study was to determine the timing of the gastrocnemius and tibialis anterior muscle contraction during the gait cycle. There were 18 subjects with ITW, 13 subjects with the diagnosis of mild CP, and 14 control subjects. The physical examination of the subjects with ITW was normal, and they began walking at 9 to 18 months. With the knee extended, the ankle ROM measured an average of -10°, with the actual values between -3° to -5°. All of these subjects had normal creatine phosphokinase levels.

Miniature surface electrodes were used on the gastrocnemius and tibialis anterior for EMG activity and transmitted with an 8-channel telemetry package. In each group, all of the children walked on their toes, even the control group. The findings are summarized in the Table below.

This study demonstrated that there were similarities between the ITW group and patients with CP and a dif-

**Table. Percent of Gait Cycle for Muscle Activity\***

Description	Muscle	% of Gait Cycle
Normal timing†	gastrocnemius	15%–50%
Normal timing†	tibialis anterior	55%–15%
Idiopathic toe walking	gastrocnemius	92%–52%
Idiopathic toe walking	tibialis anterior	53%–3%
Controls on toes	gastrocnemius	80%–40%
Controls on toes	tibialis anterior	69%–8%
Mild cerebral palsy	gastrocnemius	92%–53%
Mild cerebral palsy	tibialis anterior	59%–18%

\*Data from Kalen et al.<sup>28</sup>  
†Normal gait, not on toes.

ference with the control group. The results were possibly because the control group was found to use increased plantarflexion to maintain equinus. The authors felt that the outcome of this study did not necessarily support the use of EMG for establishing the diagnosis of ITW.<sup>28</sup>

Rose et al<sup>30</sup> performed a study of 8 children with ITW, 8 children with CP, and 10 unaffected peers used as controls. They measured the speed of walking; energy expenditure index; ankle position at stance; EMG activity of quadriceps, gastrocnemius, and tibialis anterior muscles during walking; and EMG activity during knee extension activity during sitting. Gait EMG was not found to be consistent or reliable to differentiate between ITW and mild CP. Differences between the gait of subjects with CP and subjects with ITW included: less pronounced plantarflexion in stance in subjects with CP, confirming the previous findings of Hicks et al,<sup>31</sup> and, in the subjects with CP, the onset of gastrocnemius activity occurred later in swing compared to in the subjects with ITW and the control toe walking group. On the other hand, the most consistent differences between ITW and CP were found during active and active-resistant exercise in sitting. This was felt to be enough to differentiate between a diagnosis of ITW and a diagnosis of spastic CP.<sup>30</sup>

Policy et al<sup>32</sup> utilized EMG in an attempt to differentiate between the diagnosis of mild CP and the diagnosis of ITW. The authors felt that, contrary to previous studies, the differentiation between CP and ITW required more information in addition to the family history and physical examination. The study assessed obligatory coactivation during voluntary contraction of the quadriceps or gastrocnemius. Both groups, ITW and CP, demonstrated premature firing of the gastrocnemius before heel strike, unlike the control subjects. There was also a failure to distinguish CP from ITW in the presence of clonus. Subjects with mild spastic CP were found to score exceptionally low on the Ashworth scale, reinforcing the limitations of the evaluative value for this tool. The authors determined the most effective way to differentiate between mild CP and ITW was with EMG testing during voluntary contraction of the quadriceps, more specifically with resistance to isolated knee extension and a quadriceps set. This resulted in a significant increase in coactivation of the gastrocnemius in the subjects with mild CP compared to the control group or the group with ITW. The rationale was that, since both the quadriceps and the gastrocnemius are biarticulate muscles, the activation of the former would cause a stretch reflex in the latter. However, the reverse was not found to be true. Voluntary activation of the gastrocnemius did not produce coactivation of the quadriceps on EMG. An example was in standing, where the gastrocnemius muscles were active in midstance and the quadriceps muscles were not. It was theorized that the resisted movement of the quadriceps took more effort, apparently creating an overflow effect, hence the coactivation of the

gastrocnemius muscles. Therefore, the authors concluded that the use of a 2-channel surface EMG would be useful in the differential diagnosis of ITW from mild CP while administering resistance to isolated knee extension and a quadriceps set.<sup>32</sup>

What could be surmised from the previous EMG studies is that in normal gait there is reciprocal movement activity between the gastrocnemius-soleus complex and the tibialis anterior. When children with ITW were compared to their unaffected peers walking voluntarily on their toes, in both patterns there was a premature onset of gastrocnemius activity at end of the swing phase, abnormal timing of tibialis anterior activity, and an overlapping of gastrocnemius and tibialis anterior activity. When the children with ITW were compared to children with CP, they were found to have more similarities than with the control group. In addition, subjects with ITW and subjects with CP had similar gastrocnemius activity, however, it was considered abnormal. On the other hand, the tibialis anterior activity was more like a normal gait pattern than typically developing children simulating toe walking.<sup>4</sup>

### **Kinematics**

Since EMG has not been conclusive in diagnosing ITW, other forms of assessment have been employed either jointly or as an independent tool. There are several studies that explored ITW from a kinematic perspective. Kinematics is the science of motion that utilizes various parameters, such as joint angles, displacements, velocities, and accelerations, to assess patterns of movement. It is often used along with kinetics, which describes motion in terms of ground force reactions, joint moments, and powers.<sup>21</sup>

Kelly et al<sup>33</sup> assessed sagittal plane kinematics in 50 children, divided into 3 groups. One group was children with ITW. Clinically they were found to have a normal neurological examination with limited dorsiflexion, on average, of +5°. Children in the second group had mild spastic diplegia with increased tone and decreased dorsiflexion (average of -5° dorsiflexion). Children in the third group were considered unaffected peers but were asked to walk on their toes. These children averaged 20° or more of dorsiflexion.

Almost 60% of the children with ITW, in addition to the unaffected peers who volitionally toe walked, demonstrated the following kinematic patterns. The knee displayed maximum extension at ground contact, and the ankle during initial contact was in plantarflexion, which forfeited the first rocker. The first rocker refers to the controlled plantarflexion created by an eccentric contraction of the dorsiflexors that occurs from heel strike to the foot flat phase of gait. In the swing phase, the ankle would initially move toward dorsiflexion but suddenly plantarflex at the midpoint.

The kinematic patterns of the group with spastic diplegia were abnormal at the knee and ankle. The knee was flexed at initial (ground) contact, without a loading

response, and underwent extension at midstance or late stance, where maximum extension was achieved. The ankle was in plantarflexion at initial contact and progressively dorsiflexed throughout the swing phase.

Based on the findings of this study, data from the sagittal plane kinematics, and not the absolute values for the ankle joint, permitted the differentiation of the diagnosis of ITW from toe walking due to spastic diplegia CP.<sup>33</sup> There are additional similarities when comparing and contrasting ITW and CP. For example, both groups lacked heel strike but for different reasons. In both CP and ITW, the initial contact is made with increased plantarflexion and toe strike or foot flat. In CP, there is a high repetition of movement patterns between gait cycles and stereotypical, predictable patterns of movement typically found in the presence of extrapyramidal lesions.<sup>34</sup> The gait pattern for individuals with mild spastic diplegic CP demonstrates sufficient dorsiflexion but a diminished stride. This is due to the activation of the hamstring muscles, as seen with greater knee flexion at terminal swing, thus preventing heel strike. In the individuals with CP, static as well as dynamic hamstring muscle restrictions are common.

For individuals with ITW, a varied ankle motion pattern is present using either a toe-toe or a heel-toe throughout the gait cycle. Kinematic findings for individuals with ITW demonstrate a limitation of the forward movement of the tibia in midstance with increased knee extension from the pairing of plantarflexion with knee extension. Two mechanisms have been described that permit the substitution for the decreased forward progression of the tibia. First, the foot is externally rotated approximately 6°. This, in turn, shortens the lever arm of the plantarflexors, which decreases the knee extension phase that is caused by the foot at that angle. With growth over time, the increased foot external rotation, along with tibial torsion, can cause a heel to surface contact in the presence of tight plantarflexors. Second, the femur moves over the tibia, causing an average of 7° knee hyperextension at midstance. These findings have fostered the development of the theory that ITW is eventually outgrown because bodyweight and size cannot be supported by the triceps surae. An increase in external tibial torsion can also diminish the ITW as the individual assumes a more plantigrade or heel-toe gait.<sup>4,31</sup>

### **EVALUATION OF IDIOPATHTHIC TOE WALKING**

The patient evaluation should include at least 3 parts. At the very least, the evaluation should include a clinical intake, physical examination, and gait analysis. Occasionally, this information can be streamlined to a screening tool (Appendix 1).

The first part of the evaluation, the clinical intake, should include information pertinent to prenatal, perinatal, and postnatal history. The developmental milestones of gross motor and cognitive-communicative skills should also be noted. Included in this part would be medical history, including information on seizures, allergies, and latex sensitivity.

The second part of the evaluation is the physical examination, which should assess the areas of structure, gross motor skills, tone, and sensory functioning. The examination should begin with a postural assessment for spinal alignment in forward flexion while bench sitting and standing. This would be used to determine a possible spinal asymmetry, which may be indicative of scoliosis or a leg-length discrepancy. Leg lengths should be measured from both the anterior superior iliac spine and the umbilicus. Range of motion of the hips, knees, and ankles should also be performed. To measure the ankle range, the subtalar joint needs to be neutral before the ankle is dorsiflexed. If not, the Achilles tendon may slip medially and result in eversion at the subtalar joint with pronation of the foot. The ankle range should be done with the knee straight to assess the gastrocnemius and with the knee bent to assess the soleus.

Along with the assessments of posture, range, and leg lengths, strength should be examined. Depending on the developmental status of the child, it may be expedient to perform a manual muscle test to assess the strength of hip extensors, hip abductors, quadriceps, and especially the tibialis anterior, either against gravity or with gravity eliminated.

Another area that needs to be assessed is the objective measurement of muscle tone, the presence of clonus, or increased deep tendon reflexes. The Modified Ashworth Scale is a readily available tool to assess muscle tone (Appendix 2). Previous authors have noted that the Ashworth scale was more effective in detecting hypertonia than spasticity.<sup>35</sup> Although this may be a weakness of the scale, it is relatively objective, easy to administer, and accessible.

The evaluation may also include an assessment of sensory functioning. The Sensory Profile is an effective tool to assess sensory function.<sup>36</sup> This is a caregiver questionnaire applicable for toddlers, children, and adolescents that explores sensory processing with respect to their activities of daily living. The 3 main areas that are assessed are sensory processing, modulation, and behavioral and emotional responses.

A number of tools can be used for gait analysis by the clinician, even in a small clinical setting. The first is the tread mat, which is a simple, inexpensive technique to record an individual's footprints to determine the gait pattern. It consists of dark surfaced paper and a chalk-like substance. The chalk is placed on the plantar aspect of the feet, and the child is to walk on the dark surface. The result is a display of the gait pattern, contact surface, stride length, and lower leg angulation (ie, in-toeing and out-toeing). Two other methods that are readily available to the clinician to assess gait are the Pedograph and the WriteStep. The Pedograph was developed by Marjorie Adams, PT, MS (9528 Shoreland Drive, Bellevue, WA, 98004, 425/454-0506, mmadamspt@aol.com, ©MAAdams 1997), to record measurable parameters and monitor change. The limitation of the WriteStep (Abilitations, Norcross, Ga) is it does have a minimum

weight requirement of at least 30 pounds to achieve an imprint.

Videotape analysis can be used for documenting patient information, especially gait. The video data can be kept longitudinally with repetitive follow-up visits. Videotape analysis permits both slow-motion and stop-frame viewing options. If possible, the child should be videotaped outdoors in addition to in the clinic with their shoes on. If the child tends to *clinic walk*, have the child intermittently run and walk. The same method should be used in the clinic with and without shoes.

Sawatzky et al<sup>37</sup> have described a severity index system developed to assess toe walking based on referral for 1 of 3 specific interventions. The interventions corresponded with the recommended interventions, from least to most involved. The interventions and level of severity were described as no treatment, orthotics, surgical, or surgical and Botox.<sup>37</sup>

## INTERVENTIONS

There are a number of treatment approaches to address ITW. An obvious choice is to do nothing and not intervene. This is frequently an option, as some professionals feel that if there is no evidence of neurological or orthopaedic issues and no ROM limitations, then the child will most likely outgrow the toe-walking gait pattern.<sup>31</sup> On the other hand, there are clinicians who strongly believe that ITW requires intervention. The following sections will present interventions from the least to most invasive.

### Physical Therapy

Physical therapy intervention should be multifaceted and include passive and active ROM exercises with emphasis on the ankles, strengthening, gait training or gait retraining, and a home exercise program. In addition, the physical therapist will be involved in many aspects of the following interventions as well.

### Footwear, Casting, and Orthotic Interventions

This section will discuss various shoe modifications, casting, and orthotics including night splinting, that have been utilized to alleviate or remediate ITW. Two types of footwear modifications that can be used together or independently are a gait plate and heel lifts. A gait plate in a shoe with high counters is thought to force the child to develop a heel strike. It is possible that one could still be in equinus yet appear to be making heel contact. To ensure contact, the therapist should place a piece of putty between the heel and the shoe and have the patient walk. If the patient is making contact, the heel will flatten the putty. However, it should be noted that this flattening can occur in a plantigrade gait as well as a heel strike gait. Another intervention is a heel lift that is placed in the shoe to raise the surface of the heel of the shoe to support the equinus position. The heel lift height would be gradually reduced to accommodate increased dorsiflexion ROM. A heel lift may also play a significant

role in the population with sensory integration issues by providing support in a posturally insecure situation while promoting a progressive stretch.<sup>10,38</sup>

The second intervention is the use of serial casting to provide a prolonged stretch over time to increase ankle dorsiflexion ROM in an attempt to alter the toe-walking gait pattern. Griffin et al<sup>7</sup> conducted a study of 6 subjects from 1973 to 1976. Following 6 weeks of casting, all of the subjects displayed an increase in dorsiflexion ROM and an alteration in the muscle synergy pattern on EMG, suggestive of normalization in the outcome.<sup>7</sup> In 1984, Katz and Mubarak<sup>39</sup> performed a study with 8 subjects that described a specific type of short leg cast designed to allow dorsiflexion yet prevent plantarflexion. They reported that after 6 weeks of casting, all subjects demonstrated a heel-toe gait. In a follow-up assessment 2 years later, they found that 5 subjects had what the authors described as a normal heel-toe gait and the remaining subjects were improved but occasionally walked on their toes.<sup>39</sup>

Pertinent to the latter study, Eastwood et al<sup>40</sup> determined that when there was no intervention, 50% of the subjects would show spontaneous improvement. This was consistent with the casting intervention where 50% showed improvement. The authors concluded that the casting did not change the potential outcome.<sup>40</sup>

Brouwer et al<sup>41</sup> stated that the goals of serial casting for the treatment of ITW were to increase the ankle ROM and improve the gait performance. Following the serial casting, there was an increase in plantarflexor muscle extensibility, which permitted greater dorsiflexion passive ROM. They also noted that the optimal length of the plantarflexors to generate force was with the ankle in neutral or slightly dorsiflexed, whereas the shortened position generated less force.<sup>41</sup>

When performing serial casting, there are several points that should be considered, including length-associated alterations in the muscle physiology and muscle biochemistry. First, in terms of muscle physiology, it has been determined in studies<sup>42</sup> using older animals that when a muscle is immobilized in a lengthened position, the number of sarcomeres will increase. When the immobilization ceases, the muscle will resume its normal length and number of sarcomeres. When young animals were studied,<sup>42</sup> immobilization in the lengthened position increased the length of the tendon, decreased the muscle belly length, and reduced the number of sarcomeres. Conversely, immobilization in the shortened position resulted in a decrease in the number of sarcomeres by as much as 40%. This effect appears to be age related. In the studies<sup>42</sup> with young animals, the number of sarcomeres decreased; in the studies<sup>42</sup> of adult animals, there was a complete loss of the sarcomeres. Upon cessation of the mobilization, this condition was found to reverse. This is significant because at the normal full-length resting state of the sarcomere, the muscle is able to generate its greatest power. The normal full-length

resting state of the sarcomere is defined as when the actin filaments fully overlap the myosin filaments and are just beginning to overlap themselves.<sup>42,43</sup>

The second consideration is the biochemical changes within the muscle. If a muscle is maintained in a lengthened state for over 4 weeks, muscular weight will increase. This increase in weight is due to the protein content of the submolecular structure of the muscle fiber. The clinical implications of muscle length-associated changes in children support the importance of maintaining a normal resting length. When a child's muscle is stretched, the tendon can be affected without an adaptive response in the muscle proper, resulting in a weaker muscle. When the muscle is placed in a shortened position, the muscle adapts, resulting in an even weaker state.<sup>42</sup>

If casting is to be used with the goal of increasing joint ROM, the alignment of the foot and ankle in the cast should also be considered. More specifically, the individual should be casted in a subtalar neutral position. The subtalar neutral position is important for 3 reasons. First, neutral is considered the positional midpoint of the subtalar joint, neither inverted nor everted. Second, subtalar neutral is for maximum congruency of the ankle joint and hence optimal for stability in weight-bearing activities. Third, the subtalar neutral joint position is important to enhance biomechanical alignment of the ankle and foot.<sup>44</sup>

The goal of any orthotic intervention should be to enhance biomechanical alignment and to support the dynamic arches of the foot. In the podiatric medicine literature, a recommendation was made to use knee-ankle-foot orthoses in order to immobilize the knee and ankle.<sup>10</sup> Otherwise, the literature offers limited recommendations for orthotic intervention with ITW; hence, anecdotal experiences will be cited.

Two types of orthotic interventions will be presented. Like serial casting, it is advisable to utilize the subtalar neutral concept when positioning for devices. Ankle-foot orthoses (AFOs) are used when the goal of treatment is to allow dorsiflexion but limit plantarflexion. Depending on the ROM of the child's ankles, the style would be determined. If full ankle ROM is present and it is determined that the ITW is sensory based, supramalleolar orthotics with (Figure 4) or without (Figure 5) a posterior strap can be used to enhance a heel-toe gait. If there is a limitation in active and passive dorsiflexion, then a short plantarflexion stop AFO would be recommended (Figure 6). This type of AFO would allow free dorsiflexion and stop plantarflexion in an effort to ensure a heel-toe gait while providing a more active and aggressive stretch to the gastrocnemius-soleus complex and the Achilles tendon. Both AFOs should not interfere with running, jumping, or climbing activities. From a cosmetic perspective, they are easily hidden when the sock is rolled down over the top. In addition, both of these AFOs can be used in conjunction with a knee immobi-



**Figure 4. Supramalleolar orthotic with a posterior strap.** Reprinted with permission from Cascade DAFO, Inc. Available at: [http://www.dafo.com/products.asp\\_Q\\_pagenumber\\_E\\_157\\_A\\_dirid\\_E\\_18\\_A\\_subnavid\\_E\\_26](http://www.dafo.com/products.asp_Q_pagenumber_E_157_A_dirid_E_18_A_subnavid_E_26). Accessed February 15, 2005.



**Figure 5. Supramalleolar orthotic without a posterior strap.** Reprinted with permission from Cascade DAFO, Inc. Available at: [http://www.dafo.com/products.asp\\_Q\\_pagenumber\\_E\\_157\\_A\\_dirid\\_E\\_18\\_A\\_subnavid\\_E\\_26](http://www.dafo.com/products.asp_Q_pagenumber_E_157_A_dirid_E_18_A_subnavid_E_26). Accessed February 15, 2005.

lizer as a night splint. For a more aggressive stretch, there is an adjustable AFO designed specifically for a night splint (Figure 7).

Another type of orthotic intervention is based on the progression of ITW. Upon clinical observation, as the patient who formally toe walked transitions from heel strike to midstance, there is an apparent transverse motion at the subtalar joint that promotes out-toeing. To address this dynamic distal malalignment, low-profile foot orthoses with a forefoot treatment to decrease out-toeing have been used. This forefoot treatment provides a lever arm from midstance to toe-off in the gait cycle, which brings the forefoot more toward the midline while the dynamic arches of the foot are well aligned and supported throughout the gait cycle (Figure 8).



**Figure 6. Plantarflexion stop ankle-foot orthotic.** Reprinted with permission from Cascade DAFO, Inc. Available at: [http://www.dafo.com/products.asp\\_Q\\_pagenumber\\_E\\_157\\_A\\_dirid\\_E\\_18\\_A\\_subnavid\\_E\\_26](http://www.dafo.com/products.asp_Q_pagenumber_E_157_A_dirid_E_18_A_subnavid_E_26). Accessed February 15, 2005.



**Figure 7. Adjustable stretching night splint.** Reprinted with permission from Cascade DAFO, Inc. Available at: [http://www.dafo.com/products.asp\\_Q\\_pagenumber\\_E\\_157\\_A\\_dirid\\_E\\_18\\_A\\_subnavid\\_E\\_26](http://www.dafo.com/products.asp_Q_pagenumber_E_157_A_dirid_E_18_A_subnavid_E_26). Accessed February 15, 2005.





**Figure 8. Low-profile foot orthotic with forefoot treatment to decrease out-toeing (right side).**

### Modalities

There are 3 modalities that may be helpful in the treatment of ITW. The first is taping, utilizing Kinesio-tape. Kinesiotape is a cotton tape with an acrylic backing that was designed by Dr Kenzo Kaze, a chiropractor from Tokyo, Japan. Dr Kaze designed the tape for the geriatric and athletic populations, yet pediatric clinicians have found it to be kid friendly. As in all taping procedures, a skin tolerance test should be administered. To address the toe-walking gait, a dorsiflex assist pattern could be applied in an attempt to enhance a heel strike.<sup>45</sup>

The second modality that could be used in the treatment of ITW is auditory biofeedback. Auditory biofeedback can be used to elicit feedback at heel strike, which would increase the likelihood of occurrence of the desired behavior in the gait cycle. In one study, augmented auditory feedback was used with a foot switch in the shoe that produced a burring sound with pressure, but only on 1 side.<sup>2</sup> After 3 months, all subjects made improvements, even on the untreated side, because the child had to reduce his walking speed to receive auditory feedback. The authors of this study suggest the population who would benefit from this intervention was selective and could not include those children with an ROM less than neutral or those who were under the age of 4 years old.<sup>2</sup>

Another form of biofeedback is electrical stimulation. Electrical muscle stimulation can be administered at either a sensory level or at a level to assist in muscular contraction. Threshold electrical stimulation is a form of sensory-level electrical stimulation. According to the

protocol described by Pape,<sup>46</sup> it should be used at night while an individual is sleeping to specifically address disuse muscle atrophy. Neuromuscular electrical stimulation, or functional electrical stimulation, is used to elicit the active contraction of the tibialis anterior. In order to stimulate the tibialis anterior from midstance through the loading response phases of gait, either a heel switch or a hand-held switch can be used. The use of the switches required for electrical stimulation is not without drawbacks. One drawback is that switches may not be reliable, making it difficult to coordinate the timing of the stimulation during gait. Second, muscle stimulation using switches can be used on only 1 extremity at a time. If the problem is bilateral, then electrical stimulation can be attempted using a continuous mode.<sup>38</sup> This use of continuous stimulation may be justified since it has been shown that the EMG activity of the anterior tibialis demonstrates a pattern of continuous firing in young infants who are starting to walk independently.<sup>26</sup>

### Botulinum Toxin Type A

The use of botulinum toxin type A, more commonly referred to as Botox or BTA, as a treatment intervention for ITW has been the focus of more recent publications. Botulinum toxin type A is used to decrease the muscle activity of the gastrocnemius, which is the primary factor in ITW. By inhibiting the gastrocnemius, the tibialis anterior might be able to activate, thereby preventing casting or surgical intervention.<sup>47</sup>

The biochemical effect of BTA is to inhibit the neurotransmitter at the peripheral cholinergic nerve terminals. There are 4 steps to this presynaptic blockage. First, BTA binds to the receptors on the unmyelinated presynaptic membrane. The second step is endocytosis, which is the uptake of the toxin into the nerve terminals. The third step is the translocation of the toxin across the endosome membrane. The final step is exocytosis or the inhibition of the transmitter from the presynaptic terminals. While the mechanism of cessation of the botulinum toxin is not known, a greater duration of action with type A in comparison to type B has been shown.<sup>48,49</sup>

Bishop and Senesac<sup>50</sup> studied the use of BTA with physical therapy in 12 children, ages 3 to 7, with the diagnosis of ITW. Using video analysis and EMG, the subjects demonstrated an early onset of gastrocnemius firing with brief activity of the tibialis anterior resulting in toe strike. Subjects received BTA to the gastrocnemius, and physical therapy intervention began 3 weeks later. Physical therapy continued until the subjects demonstrated a normal gait, confirmed by video and EMG, pre- and posttreatment. The authors reported an increase in heel strike at initial contact posttreatment. The firing pattern of the gastrocnemius and the tibialis anterior muscles was consistent with a normal gait. Follow-up was over 12 to 30 months. The authors concluded that the combined modalities of BTA and physical therapy were found to successfully alter the ITW gait pattern, thereby enhancing their function.<sup>50</sup>

## Surgical Intervention

The earliest studies in the literature appear to be biased toward an all or nothing approach regarding surgical intervention for ITW. Between 1958 and 1964, Hall et al<sup>5</sup> reported on 20 patients, 15 boys and 5 girls, who underwent surgical intervention for ITW. They were described as having no neurological signs, appeared normal but walked on their toes with contractures of the calf muscular, measuring 30° to 60° from neutral, with varying symmetry. Neutral was defined as 0° when the long axis of the foot is at a 90° angle to the long axis of the leg. All patients underwent surgical lengthening of the calcaneal tendons without a posterior capsulotomy of the ankle. The surgeons found that the tendons were short with an extension of the muscular tissue of the gastrocnemius muscles; however, the histology was normal. Following surgery, each subject was casted below the knees for 6 weeks. For the first 3 weeks, they were non-weight bearing, followed by 3 weeks of weight bearing. According to the authors, it took approximately 12 months for the presence of what was considered a normal gait and muscle strength. Based on a 3-year average follow-up, the authors reported that all patients had a heel-toe gait, but the older children had an occasional toe-toe gait, which was determined to be habit.<sup>5</sup>

This was challenged almost immediately by Tachdjian,<sup>51</sup> who disagreed with a surgical approach to management of this condition. He recommended passive stretching, gait training, and serial below-knee casting for at least 1 to 2 trials. If after 1 to 2 trials serial casting is not successful, then surgery might be beneficial. Tachdjian was adamant about surgery being the very last resort for children with ITW.<sup>51</sup> Furthermore, some surgeons were found to be more concerned with overlengthening the tendo Achilles and the subsequent debilitating results, such as a calcaneal gait. The triceps surae is a major power generator in gait and is at risk with surgical overlengthening. A calcaneal gait is characterized by overdorsiflexion during midstance, thereby interfering with the generation of power. This type of crouched gait can be quite deforming and difficult, if not impossible, to remediate.<sup>52</sup>

In 2001, Kogan and Smith<sup>53</sup> reviewed the cases of 15 children managed with percutaneous lengthening of the Achilles tendon. It was determined that all the parents were satisfied with the surgical outcome and there was no calf weakness or painful scarring. Two of the subjects had episodes of recurring Achilles tendonitis, which was treated with anti-inflammatory medications. Therefore, the authors concluded that this surgical intervention simplified the management of ITW.<sup>53</sup>

When considering a treatment strategy, it would be prudent to recognize that there are both nonsurgical and surgical options for the treatment of ITW. In addition, the clinician has a number of options to use individually or in combination to establish changes in the gait pattern of an individual with ITW.

## CASE REPORTS

### Case Report 1

ZJ is a 9-year-old boy born at 40 weeks gestation via planned cesarean section, the product of an uncomplicated pregnancy. He sat at 7 months and walked independently at 15 months. From the inception, he walked on his toes. His pediatrician noticed it and repeatedly mentioned it to the parents. The parents were not interested in seeking intervention and chose to change pediatricians. There is a familial history of toe walking, as his father also intermittently walks on his toes. ZJ did not come to the clinic for an evaluation or treatment. However, ZJ and his mother agreed to be a case study for this monograph, although they were clearly not interested in intervention.

The mother stated that developmentally ZJ initially had some language delay, as he did not speak until he was more than 3 years old. He did receive speech therapy services for a year, which fostered his language development. ZJ's performance in school is very good and he was tested for the gifted and talented program in the third grade.

Although ZJ was not formally evaluated for sensory integration issues, from taking information from the mother, it was apparent that he may demonstrate significant indications. For example, he has difficulty with loud noises, overloading on auditory input. He also does not like fast movements such as spinning or swinging, which tend to disorient him, a possible sign of gravitational insecurity secondary to a hyperresponsive vestibular system.

Physically, ZJ has limitations in his ROM at his ankles (Appendix 3). More specifically, he is limited in active dorsiflexion with his knees straight and passive dorsiflexion when in subtalar neutral, with his knee straight and bent, right greater than left side. Although ZJ is beginning to demonstrate asymmetry in the ROM in his ankles, his spine was symmetrical in forward flexion in short sitting and standing, and there was no leg-length discrepancy. In standing, his feet made full contact with calcaneal valgus, midfoot pronation, and external tibial torsion of 30° (Figures 9A and B).

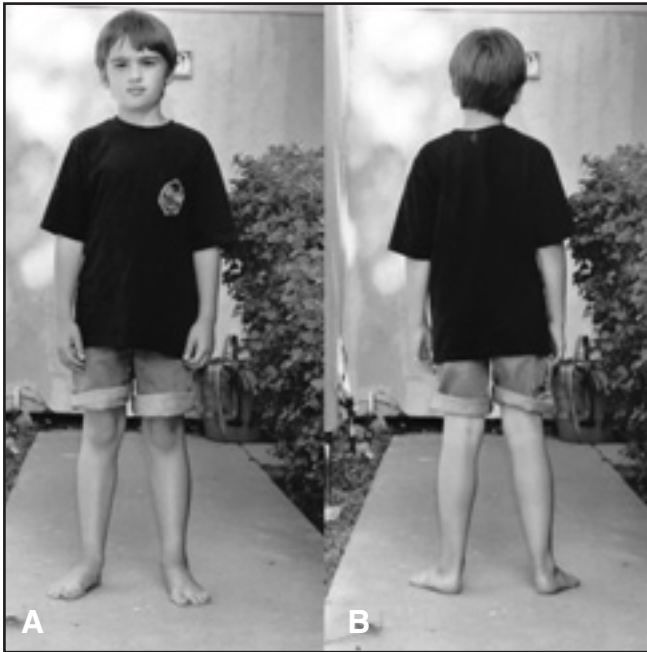
ZJ ambulates independently utilizing a digitigrade pattern approximately 70% but is able to ambulate with both a plantigrade as well as a heel-toe gait, especially if he knows he is being observed. This was seen when ZJ was asked to walk on the WriteStep, a 300-meter tread mat. He consistently walked utilizing a heel-toe pattern 100% of the duration. This was felt to be due to the visual feedback he received from his footprints on the WriteStep.

### Assessment

ZJ is a 9-year-old boy who walks on his toes without a known etiology; however, he has a history of language delay and possible sensory integration dysfunction.

### Plan of care

With respect to the parents' wishes, there will be no intervention. However, several options were discussed:



**Figure 9. Case report 1. ZJ's static standing posture. (A) Front view; note the external tibial torsion. (B) Back view; note the calcaneal valgus.**

1. Utilizing wedges under ZJ's heels in his shoes to provide a tactile surface in an attempt to bring his heels down.
2. Utilizing Kinesiotape in a dorsiflexion assist pattern.
3. It may be possible to use functional electrical stimulation or biofeedback for gait retraining, but it is doubtful whether ZJ would tolerate this intervention. More specifically, it has been found that individuals who have auditory sensitivity are usually tactile defensive. If this is true, it would be extremely difficult for ZJ to tolerate electrodes on his skin, let alone the actual electrical stimulation.

The issues that are important to consider are ZJ's present functional status; his parents' lack of interest for intervention; and his sensory issues, which may limit the possibility of altering his gait at this time. Last but not least there is a very real possibility of ZJ spontaneously coming down on to his heels secondary to growth and weight with the inability of his calf muscles to hold him on his toes. From the looks of his static standing posture in plantigrade, he is beginning to develop the frequently referenced limitations in the ROM at his ankles along with external tibial torsion.

### Case Report 2

MK is a 14-year-old girl who was born the product of a full-term pregnancy and delivered via cesarean section. There is no history of toe walking in her family. She is an honors student in a private school and has no history of learning disabilities or language delay.

Developmentally, MK met all of her milestones within normal limits. She began to walk on her toes from the inception, at 1 year old. The parents were told by their

pediatrician not to worry about it. Therefore, the parents felt that this was not anything that needed to be addressed. Upon examination, MK has no structural or postural limitations except at her ankles where she lacks active and passive dorsiflexion (Appendix 4). The only minor concern was her forefoot alignment in static standing: slight pronation with dorsiflexion of the first ray bilaterally and emerging hallux valgus (Figures 10A and B). Her rear-foot alignment was found to be relatively acceptable in rectus.



**Figure 10. Case report 2. MK's lower-extremity alignment in static standing. (A) Back view; fairly rectus calcaneus. (B) Front view; slight hallux valgus.**

For MK, toe walking is not something that has interfered with her life or ability to participate in sports. She is well aware of her limitations and has chosen to address them by wearing high-heeled shoes (Figures 11A and B). Her mother reported that MK used to wear



**Figure 11. Case report 2. (A) MK's toe walking without shoes. (B) MK's accommodation of toe walking with 3-inch heels.**

3-inch heels but now wears mostly 1.5-inch to 2-inch heels. For sports and gym class, she wears flat gym shoes and, for the most part, she is on her toes.

### CASE STUDY

AG is a 9½-year-old girl who was first evaluated at the age of 6 for persistent toe walking since 1 year of age, when she began walking. She was referred by her orthopaedic surgeon for a physical therapy evaluation and recommendations because she was found to be developing shortening of her calf musculature and her parents were adamant about immediately addressing and remediating this situation. There is no family history of toe walking; however she was receiving occupational therapy services for sensory integration issues (Appendix 5).

During AG's initial evaluation, her gait was videotaped both outside and in the office. She was found to spontaneously toe walk approximately 80% during walking. At that time, it was felt that she would benefit from the use of bilateral AFOs with plantarflexion stop. Three weeks later, AG's bilateral AFOs were issued. At that time, a videotape of AG's gait documented immediate remediation of her toe walking to a heel strike gait.

Sixteen months later, a phone conversation with AG's mother provided an update of her progress. Reportedly, she had been out of the AFOs for approximately 6 to 7 months. Apparently her gait had improved so remarkably that her occupational therapist advised taking a break and AG never resumed wearing them. Now that she has been out of the AFOs for 6 to 7 months, she is again toe walking.

Ten days after the above-mentioned conversation, AG was again videotaped both outside and in the office. A

physical examination was also performed. Outside AG was walking with wedged flip flops, thus there was no record made of her while running. In the office, she was videotaped without her shoes. It was apparent that AG was still toe walking, again, approximately 80% of the time. She would, when concentrating, perform a heel contact gait, but due to the limited ROM of her ankles, it could not be considered a heel strike gait.

### Physical Examination

#### Range of motion

In supine, the following measurements were recorded. AG's popliteal angle measured 85° bilaterally. With her knee extended, her dorsiflexion measured 0° (gastrocnemius). With her knees flexed, her dorsiflexion increased to 10° (soleus). With the norm for dorsiflexion being 20°, this suggests that there is limited ROM in the gastrocnemius muscles more so than the soleus muscles, but the soleus lacks 10° as well.

#### Strength

Given the prolonged dynamics of AG's toe-walking gait, the strength of her tibialis anterior muscle was tested. In sitting with knee flexion, she was asked to actively dorsiflex her foot. Her strength was determined to be 3/5 on the right and 3+/5 on the left.

#### Postural and structural status

AG's postural and structural status was assessed. Her posture was found to be in alignment with symmetry at both her shoulders and pelvis. Her spine was symmetrical in forward flexion during short sitting and standing. Her leg lengths on both the right and left were: anterior superior iliac spine to malleolus, 27 inches; umbilicus to medial malleolus, 29.25 inches. In foot-flat standing, AG demonstrated bilateral genu valgum, left greater than right; pronation of the midfoot bilaterally; plantarflexed first rays bilaterally; and hallus valgus bilaterally.

#### Initial Assessment

At the time, AG was a 7½-year-old girl with a known history of ITW. It was quite apparent that she made tremendous gains with the use of orthotic intervention. However, it was unfortunate that the intervention was discontinued prematurely resulting in the loss of ROM and strength at her ankles and the return of the toe-walking behavior.

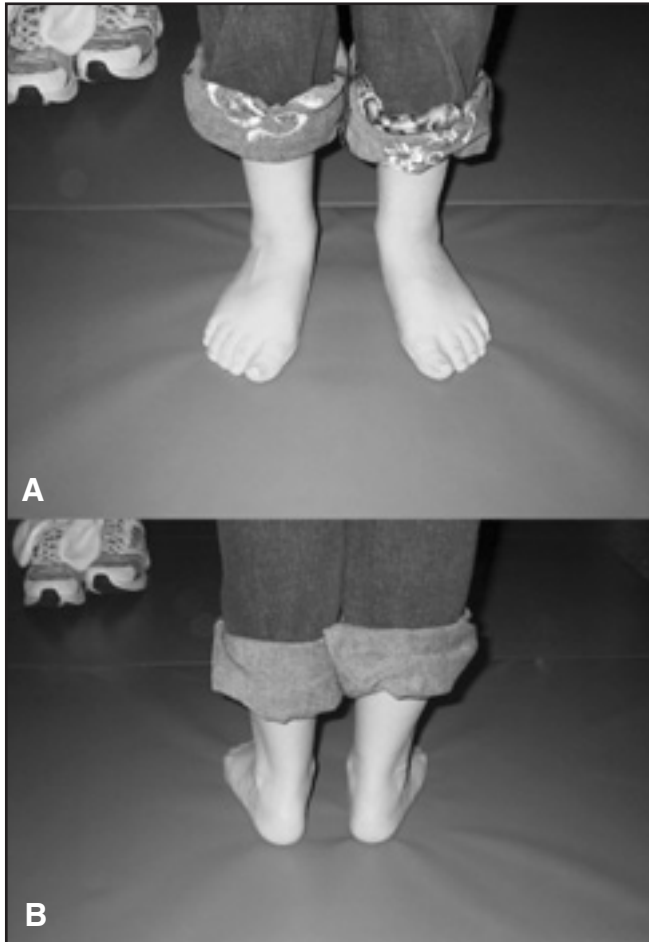
#### Recommendations and Follow-up

The following recommendations were made for AG:

1. Bilateral AFOs with plantarflexion stop.
2. Home exercise program to stretch the heel cords: active assist to recruit and strengthen the tibialis anterior muscle.

3. Recheck in 6 months to videotape, assess follow through with the home exercise program, and evaluate the use of the devices.

AG's mother called 2 years later for a follow-up appointment. Evidently AG, who was now 9½ years old, was no longer toe walking, but she was flat footed and pronated (Figures 12A and B). She was also having a difficult time with her shoes as she was getting blisters, particularly around her first metatarsal heads and the medial border of her heels.



**Figure 12.** Case study. (A) AG, front view. (B) AG, posterior view.

AG was seen for a follow-up appointment 2 months later. The screening tool was administered and she was videotaped. At that time, it was determined that she could benefit from low-profile foot orthoses with a fore-foot treatment to decrease out-toeing. This was to address the external tibial torsion in addition to what can be seen as a transverse motion at the subtalar joint in the mid-stance position when walking. The orthotics were issued one month later and there was a noticeable decrease in out-toeing in her gait with the devices in her shoes.

#### **Follow-up Assessment**

AG is a 9½-year-old girl with a history of ITW. It is difficult to determine if using the AFOs was helpful since she did not wear them for any length of time and the fol-

low-up was inconsistent. As stated in the literature, with maturation, weight, and age, the child may develop a plantigrade or heel-toe gait, along with external tibial torsion and pronation of the midfoot. AG appears to have followed this sequence. Furthermore, the initial video documentation of her walking with the low-profile foot orthoses appears to be promising.

#### **CONCLUSION**

The purpose of this monograph was to provide information and an overview of ITW. Until more recently, ITW was clinically addressed primarily by the orthopaedic sector and regarded as a diagnosis of exclusion or habitual in nature. In the presence of a normal neurological examination, ITW was seen as an entity of musculoskeletal origin that frequently had, and still has, surgery as an intervention of choice. Surgery may be a last resort if any intervention is done at all. Frequently, it is the pediatrician who may be the first to actually notice that a child is walking on the toes. Hopefully therapists and other health care practitioners will be able to appreciate that ITW may have its etiology beyond the realm of musculoskeletal disorders or may be a clinical manifestation of a developmental marker. Not totally unrelated is the situation where toe walking is a part of the clinical picture or characteristic of the developmentally impaired population, which may be a major area of concern. In these situations, toe walking could challenge the balance of these individuals so that, as they grow and go through puberty, their ability to walk could be impaired. It is much easier to care for this population when patients are ambulatory. This maintenance of independent ambulation is imperative.

On the other hand, with true ITW there is no documented long-term effect that interferes with an individual's life.<sup>9</sup> Even after intervention, a residual percentage remain walking on their toes intermittently or periodically. Without intervention, and as determined by observation, toe walking persisted but improved by 50%.<sup>40</sup> Furthermore, as health care practitioners, we may need to recognize that there is a very functional population of individuals who walk on their toes without the presence of a neurological condition and have accommodated to this type of gait without negative repercussions. In one study, 85% of parents complained of their children falling, limping, or having flat feet, poor balance, and bunions.<sup>8</sup>

As physical therapists, we may see patients who have developed issues as a consequence of a toe-toe gait pattern. With this in mind, the clinician has been presented with a number of treatment options to address this gait disorder when there has been early clinical identification. In conclusion, unless the choice is to continue to treat the clinical presentation, there needs to be additional research to determine if toe walking from ankle equinus is truly idiopathic, a primary condition, or a result from congenital contractures.

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**APPENDIX 1: SCREENING SURVEY FOR IDIOPATHIC TOE-WALKING CASE REPORTS AND CASE STUDY**

Name: \_\_\_\_\_

Date of Birth: \_\_\_\_\_

Date: \_\_\_\_\_

Age: \_\_\_\_\_

**I. Birth/Family History:**

II. Developmental Milestones: sitting \_\_\_\_\_(months) walking \_\_\_\_\_(months)

III. Known Speech/Language Delay: Y \_\_\_\_\_ N \_\_\_\_\_

Known Learning Disabilities: Y \_\_\_\_\_ N \_\_\_\_\_

**Clinical Intake**

Gait Observation:

\_\_\_\_\_ % on toes

Able to plantigrade? \_\_\_\_\_ heel-toe? \_\_\_\_\_

	<b>Right</b>	<b>Left</b>
Active ankle range of motion with knee extended: dorsiflexion		
Active ankle range of motion with knee extended: plantarflexion		
Active ankle range of motion with knee flexed: dorsiflexion		
Active ankle range of motion with knee flexed: plantarflexion		
Passive ankle range of motion, dorsiflexion with subtalar joint inversion: Knee extended Knee flexed		
Leg lengths: Anterior superior iliac spine to medial malleoli Umbilicus to medial malleoli		
Extrapyramidal signs: Ankle clonus Increased deep tendon reflexes		
Tibial torsion		
Spinal asymmetry: yes _____ no _____ If yes, describe/sketch:		





**APPENDIX 3: SCREENING SURVEY FOR CASE REPORT 1**

Name:   ZJ  

Date of Birth:   9/15/95  

Date:   9/21/04  

Age:   9   years

**I. Birth/Family History:**

40 weeks; planned cesarean section. Positive family history as father intermittently walks on his toes.

II. Developmental Milestones: sitting   5   (months) walking   15   (months)

III. Known Speech/Language Delay: Y   X   N       

Known Learning Disabilities: Y        N   X  

**Clinical Intake**

Gait Observation:

  70   % on toes

Able to plantigrade?   Yes   heel-toe?   Yes  

	<b>Right</b>	<b>Left</b>
Active ankle range of motion with knee extended: dorsiflexion	-7°	90°
Active ankle range of motion with knee extended: plantarflexion	>180°	>180°
Active ankle range of motion with knee flexed: dorsiflexion	+4°	90°
Active ankle range of motion with knee flexed: plantarflexion	>180°	>180°
Passive ankle range of motion, dorsiflexion with subtalar joint inversion: Knee extended	-10°	-10°
Knee flexed	-5°	0°
Leg lengths: Anterior superior iliac spine to medial malleoli	27 <sup>3</sup> / <sub>8</sub> "	27 <sup>3</sup> / <sub>8</sub> "
Umbilicus to medial malleoli	30"	30"
Extrapyramidal signs: Ankle clonus	No	No
Increased deep tendon reflexes	No	No
Tibial torsion:	External 30°	External 30°
Spinal asymmetry: yes <u>      </u> no <u>  X  </u> If yes, describe/sketch:		

**APPENDIX 4: SCREENING SURVEY FOR CASE REPORT 2**

Name:  MK

Date of Birth:  7/01/90

Date:  9/16/04

Age:  14 years

**I. Birth/Family History:**

Full term, delivery by cesarean section. No family history of toe walking. Has walked on toes since 1 year of age.

**II. Developmental Milestones:** sitting  6 (months) walking  12 (months)

**III. Known Speech/Language Delay:** Y   N  X

Known Learning Disabilities: Y   N  X

Exceptional student, top of her class at private school.

**Clinical Intake**

Gait Observation:

100  % on toes

Able to plantigrade?  Yes  heel-toe?  No

	<b>Right</b>	<b>Left</b>
Active ankle range of motion with knee extended: dorsiflexion	0°	0°
Active ankle range of motion with knee extended: plantarflexion	>180°	>180°
Active ankle range of motion with knee flexed: dorsiflexion	+5°	+3°
Active ankle range of motion with knee flexed: plantarflexion	>180°	>180°
Passive ankle range of motion, dorsiflexion with subtalar joint inversion: Knee extended	-7°	-10°
Knee flexed	0°	0°
Leg lengths: Anterior superior iliac spine to medial malleoli	33"	33"
Umbilicus to medial malleoli	36 1/2"	36 1/2"
Extrapyramidal signs: Ankle clonus	No	No
Increased deep tendon reflexes	No	No
Tibial torsion:	External 15°	External 15°
Spinal asymmetry: yes <u> </u> no <u> X </u> If yes, describe/sketch:		

**APPENDIX 5: SCREENING SURVEY FOR CASE STUDY**

Name: AG

Date of Birth: 3/25/95

Date: 10/12/04

Age: 9 1/2 years

**I. Birth/Family History:**

Full term, 40 weeks, uncomplicated, vaginal delivery. No history of toe walking. Has walked on toes since 1 year of age.

**II. Developmental Milestones:** sitting 5 (months) walking 12 (months)

**III. Known Speech/Language Delay:** Y  N

Known Learning Disabilities: Y  N

**Clinical Intake**

Gait Observation:

5 % on toes

Able to plantigrade?  Yes  heel-toe?  Yes

	<b>Right</b>	<b>Left</b>
Active ankle range of motion with knee extended: dorsiflexion	3°	3°
Active ankle range of motion with knee extended: plantarflexion	165°	165°
Active ankle range of motion with knee flexed: dorsiflexion	+10°	+10°
Active ankle range of motion with knee flexed: plantarflexion	>180°	>180°
Passive ankle range of motion, dorsiflexion with subtalar joint inversion: Knee extended Knee flexed	0° +5°	0° +5°
Leg lengths: Anterior superior iliac spine to medial malleoli Umbilicus to medial malleoli	30" 32 1/2"	30" 32 1/2"
Extrapyramidal signs: Ankle clonus Increased deep tendon reflexes	No No	No No
Tibial torsion:	External 25°	External 25°
Spinal asymmetry: yes <input type="checkbox"/> no <input checked="" type="checkbox"/> If yes, describe/sketch:		

## NOTES

*Idiopathic Toe Walking: A Diagnosis of Exclusion or a Developmental Marker*

REVIEW QUESTIONS

- In a more mature gait pattern of children, the most notable differences from their younger counterparts were the increase in cadence, the decreased walking velocity, and the increase in pelvic rotation, hip joint rotation, and hip abduction. Upon electromyography, this is found to be consistent with the gait pattern of an adult. What is the earliest age this adult-like pattern of gait emerges?
  - 18 months old.
  - 2½ years old.
  - 6 years old.
  - 10 years old.
- There is detailed enzymatic and histochemical information suggestive of a neuropathic entity contributing to idiopathic toe walking or toe walking in the absence of a neurological disorder. In the gastrocnemius, there is an increase in type I muscle fibers. Type I muscle fibers contain the most mitochondria of the 3 major muscle fibers in human skeletal muscle. Characteristics of type I muscle fibers include being dependent on oxidative phosphorylation and having more blood capillaries than type IIA and type IIB muscle fibers. Additional characteristics of type I muscle fibers include:
  - fast contracting and not resistant to fatigue.
  - fast contracting and resistant to fatigue.
  - slow contracting and not resistant to fatigue.
  - slow contracting and resistant to fatigue.
- There may be sensory integration issues that result in toe walking. Children with tactile defensiveness may have an imbalance between the spinothalamic and lemniscal systems. If the spinothalamic system has an overpowering effect on the overall system, toe walking may be a result in an effort to balance the systems. Another explanation offered for toe walking has to do with:
  - hypertonia and an associated hyperresponsive vestibular system.
  - hypertonia and an associated hyporesponsive vestibular system.
  - hypotonia and an associated hyperresponsive vestibular system.
  - hypotonia and an associated hyporesponsive vestibular system.
- There may be a dopaminergic effect on the central nervous system that transforms the immature gait pattern to a mature gait pattern, which is upright and, for the most part, more energy efficient. The bipedal human gait evolves from:
  - digitigrade to heel strike to plantigrade.
  - digitigrade to plantigrade to heel strike.
  - heel strike to plantigrade to digitigrade.
  - plantigrade to digitigrade to heel strike.
- In mature bipedal gait, knee extension in the stance phase is due to the deceleration of the forward movement of the tibia over the talus controlled by which muscle group?
  - adductors.
  - gastrocnemius.
  - peroneals.
  - quadriceps.
- In comparing the normal gait cycle to volitional toe walking, toe walking due to mild cerebral palsy, and idiopathic toe walking utilizing surface electrodes and electromyography, which statement describes the findings?
  - gastrocnemius activity in the gait cycle of idiopathic toe walking and mild cerebral palsy was not similar.
  - gastrocnemius activity in the gait cycle of idiopathic toe walking and mild cerebral palsy was similar.
  - gastrocnemius activity in the gait cycle of idiopathic toe walking and the control group volitionally toe walking was similar.
  - gastrocnemius activity in the gait cycle of mild cerebral palsy and normal gait was similar.
- In 1980, Sutherland et al made a tremendous contribution with their article on the maturation of gait. There they described 5 parameters of mature gait, which are:
  - duration of single limb stance, walking velocity, cadence, step length, and ratio of pelvic span to ankle spread.
  - duration of single limb stance, walking velocity, skipping, running, and jumping.
  - heel strike, foot flat, midstance, roll over, and toe-off.
  - swing, initial contact, foot flat, midstance, and toe-off.

8. Botulinum toxin type A is used to hinder or weaken gastrocnemius activity in idiopathic toe-walking gait, thereby permitting more spontaneous activation of the tibialis anterior. There are 4 steps in the biochemical effect of botulinum toxin type A on a muscle. They are binding, endocytosis, translocation, and exocytosis. Endocytosis is the:
- fusion of the receptors on the unmyelinated presynaptic membrane.
  - inhibition of the transmitter from the presynaptic terminals.
  - mechanism of cessation of the botulinum toxin.
  - uptake of the toxin into the nerve terminals.
9. Whether casting is prescribed for the purpose of prolonged stretching, as in serial casting, or for orthotic intervention, a subtalar neutral position is recommended. The subtalar neutral position is when the subtalar or talocalcaneal joint is neither:
- dorsiflexed nor plantarflexed.
  - inverted nor everted.
  - supinated nor pronated.
  - varus nor valgus.
10. Which type of orthotic would allow free dorsiflexion and stop plantarflexion in an effort to ensure a heel-toe gait, while providing a more active and aggressive stretch to the gastrocnemius complex as well as the Achilles tendon?
- a knee-ankle-foot orthotic.
  - a low-profile foot orthotic.
  - an ankle-foot orthotic.
  - an inframalleolar orthotic.

## ANSWERS

1. c
2. d
3. d
4. b
5. b
6. b
7. a
8. d
9. b
10. c