Postural Analysis of Idiopathic Toe Walking in Children: A Systematic Review

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ABSTRACT

Background: Approximately 5% of children aged 5 to 15, regardless of gender, are diagnosed with Idiopathic Toe Walking without a medical cause, when the condition persists for more than six months. These Children often display coordination issues and biomechanical disturbances during dynamic movements. Kinetic, kinematic and electromyography data are crucial for understanding these adaptations to clarify the neurophysiological processes that regulate posture. Authors have also developed classifications based on clinical, morphological, or kinematic parameters. **Objective**: This systematic review aims to analyze postural adaptation in children with Idiopathic Toe Walking by examining kinetic and kinematic parameters, as well as muscle activity. **Method**: Articles were selected following PRISMA guidelines, considering relevance to the research question and methodological quality. A comprehensive search strategy was employed across four databases. Article screening and data extraction were independently conducted by two reviewers to ensure methodological rigor. The methodological quality of the trials was assessed in using the Newcastle-Ottawa Quality Scale. **Results**: The searches yielded a total of 681 results, and 6 articles were included in this systematic review. Electromyographic analyses revealed atypical muscle activation patterns in children with idiopathic toe walking, including premature gastrocnemius activity during swing phase and increased coactivation during resisted tasks, indicating altered neuromuscular control. Kinematic assessments identified reduced passive ankle dorsiflexion and early heel rise, quantified by a specific index (HR32), reflecting impaired gait stability. Kinetic findings showed increased plantar flexion moments and early-phase ankle power absorption, highlighting biomechanical adaptations consistent with equinus gait. **Discussion**: Measured activations of gastrocnemius and soleus during Idiopathic Toe Walking could be interpreted as dictated by equinus biomechanics rather than by pathology alone. The kinetic and kinematic approach allows practitioners to understand postural compensations related to equinus in Idiopathic Toe Walking and determine classifications and treatments based on ankle movements and force moments. **Conclusion**: These results emphasize the importance of early physiotherapeutic intervention before the age of six to address postural adjustments in relation to the child's ontogenetic motor development. Descriptions of lower limb muscle activity in this gait help physiotherapists determine exercise intensity to manage muscle fatigue.

KEYWORDS: biomechanics, ITW, muscular activity

Introduction

Over the years, gait analysis has become increasingly important in clinical research to better understand motor disorders. Walking is a complex motor activity acquired very early in life, between the 8th and 18th month [1], allowing the growing child to transition from the four-legged position (quadrupedal) to an upright stance (bipedal) to adapt to the surrounding environment. The work of Assaiante et al. [2] highlighted the postural strategies involved in various locomotor tasks. Their study emphasizes the role of lower limb stability and muscle activity in postural control in children, particularly focusing on the evolution of postural strategies organized feet to the head between 14 months and 6 years, in line with ontogenetic motor development. According to the authors,

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conditions such as Idiopathic Toe Walking (ITW), Cerebral Palsy (CP), or autism may disrupt typical postural development, underlining the need for a better understanding of these mechanisms. Postural adaptation refers to the body's ability to maintain balance in different environmental conditions and respond to both internal and external disturbances through postural adjustments [2, 3]. Body support allows upright posture against gravity mainly by the action of trunk and lower limb extensors [4].

The percentage of single limb support duration increases with age (from 32% at 1 year to 35% at 3 years, 38% at 7 years, to 39% in adults, associated with improved balance). Speed and step length increase, and cadence and double support phase duration decrease [5].

In some children, the typical heel-strike pattern may not develop or may be lost during the maturation of walking [6]. These children may walk on their forefoot throughout all phases of the gait cycle, or the heel may only touch the ground later in the cycle with potential compensations [7]. According to a Cochrane systematic review conducted in 2019 [6], Idiopathic Toe Walking (ITW) is a commonly applied exclusion diagnosis that describes a child with limited or absent heel strike during the contact phase of the walking cycle, without any neurological or orthopedic medical reasons. In bilateral toe walking, strength, reflexes, and sensation are normal. It is estimated that 5% of children aged 5 to 15 years, regardless of sex, receive a diagnosis of idiopathic toe-walking when the condition persists for more than 6 months [6] or after the age of 2 years [8]. Children with ITW may present postural difficulties, such as static standing, and may have coordination problems with biomechanical disturbances, along with reduced dorsiflexion during slow, passive evaluation [9, 10, 11, 12]. It is these shared factors that prompt parents to seek consultation with a medical doctor, pediatrician, rehabilitation doctor, neurologist, pediatric orthopedic surgeon, or physiotherapist when their child is diagnosed with ITW [6, 8]. This represents a consultation issue, accounting for approximately 1% of visits to pediatric orthopedics [13].

Many studies have noted a high prevalence of neurodevelopmental disorders in this group [13, 14, 15, 16]. Around 8% of children with Autism Spectrum Disorders (ADHD) exhibit toe-walking, potentially explained by the need to reduce sensory contact with the sole of the foot [13]. Some researchers have identified various atypical gait patterns that distinguish children with ADHD from their typically developing peers. In children with ADHD, backward walking was marked by slower speeds, wider step width, and increased stepping cadence [17]. Sensory processing dysfunction could also lead to toe-walking in children without a diagnosis of associated neurodevelopmental disorders [18]. The explanation is that the integration of the vestibular system, proprioceptive, and tactile systems does not provide adequate cortical or subcortical information [19, 20].

To facilitate this examination, Pomarino et al. described a series of 5 clinical tests, easily performed by a healthcare professional, combining walking performance tests, passive joint range of motion measurement of the talocrural joint, and measurement of lumbar lordosis. Children with ITW may exhibit an increased lumbar lordosis angle than children with physiological walking. These authors also described a classification system that classes ITW into 3 types based on morphological characteristics of the foot, Achilles tendon, and calf assessed during a clinical examination [8]. However, these measures are subjective and there is a need for a classification based on objective measures such as temporal movement evaluation and muscle activity [21, 22]. In addition to Pomarino et al.'s investigation [8], a classification based on kinetic and kinematic parameters of this walking pattern is required.

Alvarez et al. delineated three specific gait analysis parameters: the presence of a first ankle "rocker", the presence of a third early ankle "rocker", and a first ankle moment predominantly in extension [23], and three stages (mild, moderate, and severe). Type I (mild) is distinguished by the presence of only a first ankle rocker, Type II (moderate) by the presence of both first and early third ankle rockers, and Type III (severe) by the presence of early third ankle rockers and predominant first ankle moment [23, 24].

Quantitative Gait Analysis provides an objective postural analysis of walking by providing kinematic, kinetic, and electromyographic data during different phases of the gait cycle. Kinematic analysis of the walking cycle focuses on movements and joint positions that occur during different phases of walking, and quantifies spatiotemporal parameters such as stride length, cadence, speed, and duration of gait phases, which are important for assessing gait symmetry and balance [21, 25, 26, 27, 28]. The analysis of the kinetics during the gait cycle focuses on ground reaction forces during different phases of gait and balance and stability parameters [21, 25, 28]. With its high temporal resolution, EMG allows detailed analysis of muscle activation timing and levels, making it possible to evaluate the contributions of different muscles, including antagonistic muscles and synergies, to motor tasks [29, 30].

In summary, postural adaptation and adjustments are intrinsically linked to biomechanics and kinematics. Kinetic and kinematic data are essential for understanding these adjustments, while EMG provides detailed insights into the muscle activity required for them, shedding light on the underlying neurophysiological processes that regulate posture [27].

Several authors have argued that ITW tends to resolve spontaneously by the age of 5 to 10 years; however, this assumption may underestimate the potential consequences of persistent ITW on postural control, gait coordination, and ankle range of motion. Given its possible influence on motor development and functional stability, a systematic investigation of postural mechanisms in ITW, together with the evaluation of physiotherapeutic strategies, is warranted. Advancing research in this field is crucial to distinguish self-limiting cases from those at risk of long-term impairment and to establish evidence-based guidelines for clinical management.

Considering these elements, we propose to conduct a systematic review to synthesize knowledge on Quantitative Gait Analysis in children with ITW compared to typically developing children. We will attempt to determine whether ITW is a postural adaptation characterized by disturbances in kinetic and kinematic parameters and whether it results in increased muscle activity in the lower limbs.

To address this, we will investigate whether muscle activity of the quadriceps, soleus, gastrocnemius, and tibialis anterior is higher in children with ITW than in typically developing children during gait cycle. Additionally, we will examine whether ankle dorsiflexion associated with ITW results in compensatory joint movements in the ipsilateral knee, compared with children with normal gait patterns. To better understand these concepts, we will focus specifically on the data during the heel rocker and second ankle rocker phases of gait.

Methods

The research question was formulated using the PICOS method. The protocol was registered on the international database of prospectively registered systematic reviews in health care, PROSPERO, under the number 498493 and the review is reported according to the PRISMA guidelines [31].

Eligibility criteria

Eligible studies included observational, cross-sectional, and case series designs. They had to focus on kinetic, kinematic, or electromyographic analyses of idiopathic toe walking in children aged 5 to 15 years regardless of sex. Idiopathic toe-walking had to have been diagnosed at least 6 months previously and had to persist after the age of 2 years. The analysis of idiopathic toe walking had to be compared to physiological walking. We considered publications up to February 2024, with no restrictions on publication date or language. We excluded gray literature, longitudinal studies, qualitative studies, therapeutic studies, and studies involving adult participants, those with neuropathy, hydrocephalus, or describing treatments such as foot orthoses, botulinum toxin, or lower limb surgery.

Information sources

A comprehensive search strategy was employed across 4 databases: PubMed, Google Scholar, Science Direct, and Cochrane.

Search strategy

A search equation was formulated using boolean operators and keywords such as "idiopathic toe walk*, gait analysis, walking analysis, biomechanics, movement pattern, electromyography, muscular activity".

Selection process

A first screening based on title and abstract was conducted independently by two reviewers. In case of disagreement, consensus was taken based on full-text reading.

Data collection process

The data collection process was conducted by the two reviewers independently. Each reviewer completed the extraction sheet, and a synthesis was written at the end of the extraction.

Data item

The following information was extracted for each article: author and year of publication, ages of participants, description of the "intervention" criterion in the group of children with idiopathic toe-walking, and description of the "comparison" criterion in the group of children with physiological walking; measurements of outcome (kinetic, kinematic, and EMG analyses).

Study risk of biais

The methodological quality of the trials was assessed using the Newcastle-Ottawa Quality Scale (Table 1). The assessment was conducted independently for each article. If a disagreement arose, a discussion among the reviewers was held until a consensus was reached.

Effect measures

The measures used for each outcome, including gait parameters and electromyographic data, are summarized in Table 2 and detailed in Appendix 1. This appendix outlines the specific variables and measurement approaches applied in the synthesis of results.

Results

Study selection

The searches generated a total of 681 results, with 176 from PubMed, 496 from Google Scholar, 8 from Science Direct, 1 from Cochrane. The flow diagram (Figure 1) illustrates the selection process [32]. After removing 482 duplicates, 246 titles and abstracts were screened. From there, 152 articles were excluded due to mismatched titles, and 26 due to lack of relevance of the abstract. Subsequently, 21 articles were selected for full reading. Fifteen articles were excluded based on eligibility criteria: nine were outside our specified age range or lacked age information across all study groups, and six did not meet our eligibility criteria for using the Newcastle-Ottawa Quality Scale. Among these six studies, four did not meet the "intervention" criterion, and two did not meet the "outcome" criterion. Ultimately, six studies underwent thorough examination for this systematic review [21, 29, 30, 33, 11, 34].

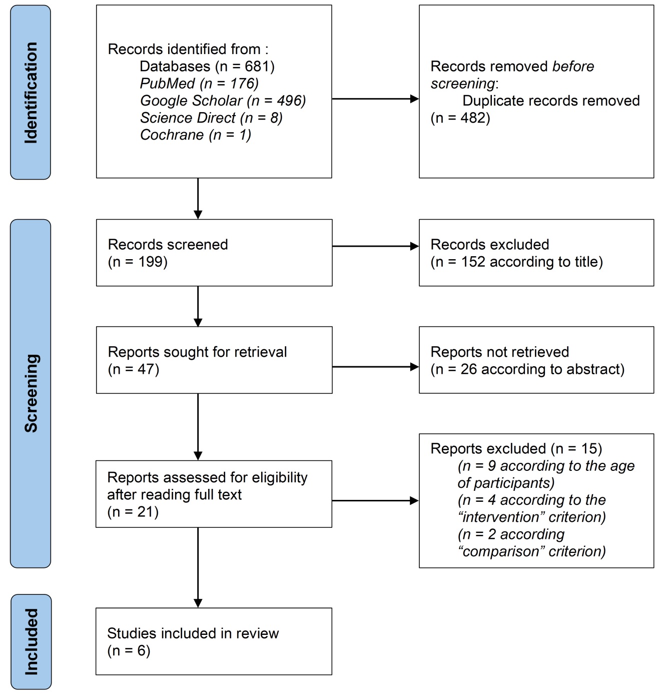

Figure 1 Flowchart depicting the selection of scientific articles [32]

Study characteristics

The included studies focused on postural analysis using kinematic and kinetic parameters or surface electromyography to assess muscle activity. The variables extracted for comparison between the two populations (ITW and physiological walking), as well as the quality assessment using the Newcastle-Ottawa Scale, are all presented in Table 1. The results of individual studies are summarized in Table 2 and detailed in Appendix 1.

Most studies demonstrated good methodological quality, with adequate representativeness of cohorts, clear case definitions, and consistent assessment of outcomes. The cohort studies by Habersack et al. [21], Fanchiang et al. [34], and Kelly et al. [11] obtained the highest scores, reflecting appropriate selection and follow-up procedures as well as satisfactory control for confounders such as age, sex, and anthropometric characteristics.

The case control studies by Rose et al. [30] and Policy et al. [33] also achieved good overall quality, particularly in terms of case definition and comparability between groups, although minor limitations were noted in the selection of controls and in the reporting of non-response rates.

Only the early study by Kalen et al. [29] presented lower methodological quality, mainly due to incomplete description of the control group and limited control for potential confounders.

Synthesis of findings

Our findings underscore the relevance of kinetic, kinematic, and electromyographic analyses in characterizing ITW. This synthesis is based on a cohort of 83 children with ITW (mean age 6.8 years) and 64 children with physiological gait (mean age 7.2 years), allowing for a comparative understanding of gait and postural control parameters.

EMG activity

Electromyographic analysis was employed in four of the selected studies to differentiate ITW from other gait disorders. Kalen et al. [29] used surface EMG to measure gastrocnemius and tibialis anterior activity in children with ITW, but initial findings lacked sufficient discriminatory power. Rose et al. [30] reported an earlier and greater activation of the

Table 1 Quality of studies

QUALITY CRITERIA	NEWCASTLE-OTTAWA SCALE	CRITERIA	Electromyography of Idiopathic Toe Walking (Kalen et al.1986)	Kinematic and Kinetic Gait Parameters Can Distinguish between Idiopathic and Neurologic Toe-Walking (Habersack et al. 2022)	The Effects of Walking Surface on the Gait Pattern of Children With Idiopathic Toe Walking (Fanchiang et al. 2016)	The Kinematic Patterns of Toe-Walkers (Kelly et al. 1997)	Electromyographic Differentiation of Diplegic Cerebral Palsy from Idiopathie Toe Walking (Rose et al. 1999)	Electromyographic Test to Differentiate Mild Diplegic Cerebral Palsy and Idiopathic Toe- Walking (Policy et al. 2001)
		COHORTE						
		SELECTION			=4	=3		
		Representativeness			A (1)	B (0)		
		Selection non-exposed			A (1)	A (1)		
		Ascertainment			A (1)	A (1)		
		Outcome not present			A (1)	A (1)		
		COMPARABILITY			=2	=1		
		Control for confounders			A+B (2)	A (1)		
		OUTCOME			=3	=3		
		Assessment outcome			A (1)	A (1)		
		Follow-up long enough			A (1)	A (1)		
		Adequacy follow-up			A (1)	A (1)		
		QUALITY:			GOOD	GOOD		
		CASE-CONTROL						
		SELECTION	=3	=1			=4	=3
		Case definition	A (1)	B (0)			A (1)	A (1)
		Representativeness	A (1)	A (1)			A (1)	A (1)
		Selection Controls	B (0)	C (0)			A (1)	B (0)
		Definition Controls	A (1)	B (0)			A (1)	A (1)
		COMPARABILITY	=2	=2			=2	=2
		Analysis control	A+B (2)	A+B (2)			A+B (2)	A+B (2)
		EXPOSURE	=2	=1			=2	=3
		Ascertainment	A (1)	B (0)			A (1)	A (1)
		Same method	A (1)	A (1)			A (1)	A (1)
		Non-Response rate	B (0)	B (0)			B (0)	A (1)
		QUALITY:	GOOD	POOR			GOOD	GOOD

quadriceps during the active phase of knee extension in idiopathic toe walkers compared to controls. However, these findings were based on a small sample and were not specifically interpreted in the study. Further comparison with data from other studies is therefore warranted.

Policy et al. [33] reported that, compared with control subjects who showed minimal gastrocnemius activity during quadriceps contraction, idiopathic toe walkers exhibited markedly greater levels of co-activation, indicating a partial deficit in reciprocal inhibition. In addition, children with ITW demonstrated premature gastrocnemius activation during the swing phase, with a prolonged duration of co-activation (20–35% of the gait cycle) compared with controls (0.4–3%). Moreover, they showed that soleus EMG activity is higher and occurs just before ground contact in ITW, whereas it remains inactive during the rest of the gait cycle. In contrast, during normal walking, the peak soleus EMG is lower and occurs 180 ms after ground contact, with tibialis anterior activity just before heel strike [35, 36]. These findings suggest EMG can identify altered neuromuscular control in ITW.

Kinematic parameters

Kinematic parameters were investigated in the studies by Kelly et al. [11] and Fanchiang et al. [34]. Kelly et al. reported that children with ITW presented a limitation in passive ankle dorsiflexion (+5º on average) compared to typically developing children (20º) [11]. In contrast with typically developing children who exhibited progressive dorsiflexion during the swing phase, children with ITW had a sudden plantarflexion at mid-swing, indicating an altered control of ankle motion throughout the gait cycle [11].

Fanchiang et al. developed the HR32 index. They measured heel height at 32% of the gait cycle, and found it to be significantly higher in children with ITW, reflecting earlier heel rise and altered stability [34]. They concluded that the HR32 is a useful measure to distinguish toe walking patterns [34].

The study by Rose et al. [30] found no significant difference in the popliteal angle between ITW and normal walking.

These findings suggest that specific kinematic features can be used to characterize and differentiate ITW from physiological gait.

Spatio-temporal parameters

Kelly et al. [11] reported no differences in spatiotemporal parameters such as walking speed, cadence, or stride length, whereas Rose et al. [30] found a slightly slower gait speed in ITW (58 $\pm$ 16 m/min) than in typical walking (69 $\pm$ 15 m/min), but without statistical significance. However, Rose et al.'s study had a small sample size, and the participants in Kelly et al.'s study were not strictly comparable in age and gait characteristics, which may limit direct comparison of their findings.

Kinetic parameters

Kinetic gait parameters were analyzed by Habersack et al. [21] who found that children with ITW displayed significantly greater plantar flexion moments during loading and mid-stance (0–30% of the gait cycle), reduced

Table 2 Summary of Results from Selected Articles Regarding Studied Parameters

Study Title	Outcome	Parameters / Results
Electromyography of Idiopathic Toe Walking (Kalen and al. 1986)	EMG activity (tibialis anterior, gastrocnemius, soleus)	Surface EMG: no clear distinction ITW vs controls; further studies needed
Kinematic & Kinetic Gait Parameters (HABERSACK and al. 2022)	Ankle, knee, hip position, length of stance during swing phase; dorsiflexion, plantarflexion, moments	ITW: Greater plantarflexion moment (0–30% gait cycle), reduced knee extension moment (30–60%), absorption high (10%), energy generation greater (20–40%) compared to controls. Maximum knee flexion similar to normal
Walking Surface & Gait (Fanchang and al. 2016)	Velocity, cadence, step length/width, effective pre-positioning heel (HR32)	HR32 (heel rise measure) higher in ITW compared to controls
Kinematic Patterns of Toe-Walkers (Kelly and al. 1997)	Speed, cadence, stride length, ankle dorsiflexion	Normal children: 20º dorsiflexion ITW: around 5º dorsiflexion (reduced passive ankle dorsiflexion) ITW: altered control of ankle motion throughout the gait cycle
Walking (Rose and al. 1999)	Differentiate diplegic CP, normal, ITW	Popliteal angle similar Walking speed ITW (58±16 m/min) not significantly different from controls (69±15)
Electromyographic Test (Policy and al. 2001)	Differentiate mild CP vs ITW (coactivation tests)	Premature gastrocnemius firing in swing (ITW) Duration of gastrocnemius coactivation: ITW (20–35%) vs controls (0.4–3%) In ITW, soleus activation occurs earlier and is greater just before ground contact, whereas in controls it appears later and with lower amplitude after heel strike

knee extension moments during terminal stance (30–60%), and increased ankle power absorption early in the gait cycle (around 10%). These children also exhibited energy production patterns similar to physiological gait in late stance (20–40%). These results underscore the biomechanical adaptations present in ITW and support the use of kinetic profiling in differential diagnosis.

Discussion

The analysis of the selected studies highlights distinct biomechanical and neuromuscular features associated with idiopathic toe walking (ITW). Across the literature, alterations have been consistently reported in ankle range of motion, gait stability [34], and muscle activation timing. Kinematic evaluations revealed reduced ankle dorsiflexion at initial contact and earlier heel rise in children with ITW [11], suggesting a modified gait strategy compared to typically developing peers. Kinetic analyses indicated increased plantar flexion moments and altered energy absorption and generation patterns throughout the stance phase [21].

Electromyographic assessments identified atypical patterns of activation in both static and dynamic conditions, with evidence of premature gastrocnemius and soleus firing during gait [29, 30, 33].

These observations open the discussion of a broader motor control dysfunction, as several studies suggested that children with idiopathic toe walking exhibit difficulties with postural control during tasks such as standing and walking, and may also have impaired coordination [12]. Our aim in this review was to determine whether ITW in children is a postural adaptation characterized by disturbances in kinetic and kinematic parameters, leading to greater lower limb muscle activity than in typically developing children with physiological gait [37]. Findings from the reviewed studies indicate that the average duration of gastrocnemius coactivation is higher in children with ITW than in those with physiological gait. Pomarino et al. [8] found that this coactivation was accompanied by hyperactivity of the adductor magnus in the children with ITW.

Additionally, De Pieri et al. [38] demonstrated that during equinus gait, the gluteus maximus contributes more to the extension moment during the initial stance phase (0–2% and 8–17% stance time), than to normal walking similarly to the adductor magnus (11–21% stance time). The hamstrings contributed less to knee flexion but in a more sustained manner during the loading response than normal walking (decreased during 0 to 3% stance time and increased during 8 to 18% stance time). This was counterbalanced by a synchronous positive contribution from the gluteus maximus and the adductor magnus [38].

Following the work of Policy et al. [33], and as emphasized by Lorentzen et al. [39], an important question remains: is the greater EMG activity observed in the ankle plantar flexors during toe walking due to stretch- or force-sensitive afferent activity, or to central anticipatory mechanisms? These findings by Lorentzen et al. [39] suggest that the timing of this EMG burst is consistent with an increase in the spinal reflex excitation of motoneurons resulting from ground contact that causes stretching of the plantar flexor tendon [39]. Rossi et al. [40] found varied neurophysiological abnormalities in the soleus H-reflex in a subset of idiopathic toe walkers, suggesting heterogeneity in the etiology of ITW. They attributed the observed EMG activity of the soleus during toe walking to anticipatory control mechanisms and suggested that sensory feedback mechanisms play a minimal or negligible role in muscle activation and the resulting stabilization of the ankle and foot during the early stance phase in toe walking [39, 40].

Musculoskeletal modeling approaches have also been used to characterize the different contributions of lower limb muscles to body support and propulsion during equinus gait, showing that not only the ankle plantar flexors but also the knee extensors, knee flexors, and hip extensors exhibit altered function during idiopathic equinus gait [38]. Although the number of participants was relatively small in this initial study by Rose et al. [30], other findings [11, 21, 37, 38] support their results by affirming that ITW is characterized by significantly greater muscle forces exerted by the quadriceps on the patella and prolonged force transmission through the Achilles tendon during the support phase than physiological gait. Similarly, prolonged force transmission through the Achilles tendon in plantar flexion may be associated with tendon shortening and contractures.

Altered activation of gastrocnemius and soleus at heel strike seems necessary to maintain a balance of forces transversely to the leg axis during ITW [38].

Regarding kinetic and kinematic parameters, Policy et al. [33] suggested that reduced ankle dorsiflexion is compensated for by knee hyperextension at mid-stance to shift the body vector in front of the knee, inducing non-muscular knee extension by coactivation of the gastrocnemius-soleus complex and quadriceps muscles [37, 38].

The results of kinetic and kinematic studies, combined with simultaneous dynamic electromyographic activity, confirm the hypothesis that increased plantar flexion moment during ITW is associated with increased plantar flexor muscle activity.

Some authors interpret the gastrocnemius and soleus activation during ITW as dictated by equinus biomechanics rather than by pathology alone [39, 38]. Such muscle activations, which directly correspond to the measured kinematic pattern, can also be predicted using musculoskeletal modeling [35]. Similar gait patterns would be expected to lead to similar predicted activation patterns in healthy and pathological subjects. Lima

et al. [41] investigated the acute effects of unilateral ankle plantar flexor static-stretching on surface electromyography and the center of pressure during a single-leg balance task in both lower limbs.
The question thus remains for future research whether EMG activity in the ankle plantar flexors in ITW is due to stretch-sensitive or force-sensitive afferent activity, supported by central mechanisms and corticospinal anticipation, or altered sensory influx from these muscles [35, 39, 42]. Studies based on perception-action coupling supported by functional imagery could enlighten this question [43].
Concerning the walking speed parameter described in the studies by Rose et al. [30]. and Kelly et al. [11], the absence of significant differences and the methodological limitations of both studies highlight the need for further research with larger and more homogeneous samples to obtain reliable data on walking speed and other spatiotemporal parameters in ITW.
Considering the postural control findings across the selected studies, the kinetic and kinematic approach enables clinicians to understand postural compensations related to equinus in ITW and determine objective classifications based on ankle movements and force moments. Clinicians can associate this data with morphological observation and the specific ITW tests described in the introduction of this review. The primary treatment goal is to counteract equinus deformation by increasing ankle dorsiflexion, as described by Kelly et al. [11]. Referring to the classification by Alvarez et al. [23], Type 3 walkers, who present with a severe form of toe-walking, show reduced ankle mobility both passively and during active walking. They also exhibit an abnormal ankle rocker and abnormal kinetics, which require intervention. Treatments based solely on physiotherapy or casting have not proven to be sufficiently effective, leading to incomplete corrections and a high risk of recurrence [44]. However, surgery has shown better outcomes, though complications are frequently observed [23]. An alternative treatment that has demonstrated improvements in abnormal walking patterns is botulinum toxin type A [45]. For children classed as type 2 (moderate) or type 1 (mild), the management approach differs. In mild cases with a slight reduction in ankle mobility remaining within normal ranges and normal gait parameters based on the classification, treatment is not recommended [23]. Similarly, children classed as type 2 generally do not require treatment but should be regularly monitored with repeated gait analyses. In conclusion, children classed as type 3 are primarily treated with botulinum toxin A injections, serial casting, bracing, physiotherapy, or tendon lengthening (for older children).
According to the systematic review conducted by COCHRANE in 2019 [6], addressing restricted ankle dorsiflexion is a common approach to managing children with ITW. However, there is insufficient evidence from randomized controlled trials to confirm the effectiveness of interventions for ITW.
Recommendations include integrating postural rehabilitation based on anticipation, including targeting corticospinal, vestibular, and proprioceptive pathways [35, 39]. Descriptions of muscle activity in lower limb muscles in ITW can guide the physiotherapist in determining exercise intensity to regulate muscle fatigue.
Within the limits of our work, we remain cautious when interpreting the conclusions of the studies, as not all of them provided a full description of Quantitative Gait Analysis or surface EMG acquisition protocols. Surface EMG does not record electrical activity from deep muscles, a key limitation in selecting muscles. Moreover, most included studies did not assess the same set of variables, and diagnostic criteria for idiopathic toe walking were inconsistently defined, potentially contributing to the variability in participant characteristics.
The most relevant studies for our review compared idiopathic toe walkers with typically developing controls, but some also included children with cerebral palsy, which may have confounded interpretation. Although sex was generally balanced across samples, the age range (5–15 years) may have introduced differences related to the ontogenetic evolution of postural strategies in children.
The conclusions of this review should therefore be interpreted in the light of the variable methodological quality of the included studies. Although most studies had a low to moderate risk of bias, several limitations, such as small sample sizes, incomplete control of confounding factors, or partial selection of control groups, may restrict the generalizability of the findings. These methodological discrepancies likely account for some of the variability observed in kinematic and spatiotemporal results. Nevertheless, the consistency of the main trends, particularly regarding muscle activation profiles and kinetic adaptations, supports the overall validity of the conclusions while emphasizing the need for future, well-designed, standardized studies to strengthen the reliability of current evidence.

Conclusion

Quantitative Gait Analysis has revealed that ITW in children aged 5 to 15 increases ankle joint constraints and prolongs force transmission through the Achilles tendon during the support phase. This gait pattern also increases the quadriceps muscle forces exerted on the patella.
The literature does not yet describe effective physiotherapy treatment for children with ITW. Nevertheless, the kinetic and kinematic approach increases physiotherapists' understanding of the postural compensations associated with ITW, informing the use of specific tests and classifications tailored to this condition in their assessments. This enables better assessment of the role of lower limb stability and muscle activity in children's postural strategies, with particular emphasis on the development and orientation of postural strategies organized feet to the head between 14 months and 6 years of age.
The imperative therapeutic goal of addressing equinus must be coupled with an approach that respects the sensory aspects and acknowledges the muscle fatigue inherent in ITW. The observed corticospinal influence and the evolving understanding of the predictive internal model, albeit not fully described in ITW, suggest a promising trajectory in the management of this condition.
A deeper understanding of the energy demands associated with ITW could pave the way for the early establishment of preventive intervention strategies targeting muscle fatigue and mitigating lower limb joint deformities. This holistic approach aims to enhance the overall quality of care and outcomes for individuals with ITW.

Statement and declaration

Authors' contribution

F.M. conceived the study and designed the methodology. F.M. and E.M. collected and analyzed the data. F.M. drafted the manuscript. All authors critically revised the manuscript, responded to reviewers, approved the final version, had full access to the study data, and take responsibility for the integrity of the data and the decision to submit the manuscript for publication.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Supplemental material

The method was registered on the international database of prospectively registered systematic reviews in health care, PROSPERO, under the number 498493.

Competing Interests

The authors declare not to have any conflicts of interest that may be considered to influence directly or indirectly the content of the manuscript.

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