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Functional Bandaging in Children with Idiopathic Toe Walking

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Background: Idiopathic toe walking (ITW) is a persistent gait pattern with no known etiology, which is characterized as premature heel-rise or no-heel contact. The aim of this study was to investigate the effects of functional bandaging in children with ITW on heel-contact during stance phase and gait quality.

Methods: Nineteen children, 4-16 years of age with ITW (mean±SD: 7.36±3.16) and ten age-matched healthy pairs (mean±SD: 7.30±2) were included in the study. Elastic adhesive

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bandages were applied to children with ITW to assist with dorsiflexion. Before bandaging (T0), immediately after initial bandaging (T1), and one week later with the same bandage (T2), the initial contact, loading response, and mid-stance sub-phases of gait were analyzed with video-based observational gait analysis (VBOGA) using light-pressure sensors and the Edinburgh Visual Gait Score (EVGS). Ten age-matched children with typical gait participated for comparison in T0. The data was analyzed by using Friedman and Wilcoxon signed-rank tests for within-group comparison and Mann-Whitney U tests for between-group comparison.

Results: In T0, for the ITW group, no heel contact was observed during stance. In T1, all the participants achieved heel contact at initial contact and loading response; and 56.8%, at mid-stance. In T2, all the heels continued contact at initial contact and loading response; and 54.3%, at mid-stance. The EVGS significantly improved. The Friedman test showed that there were noteworthy improvements between T0-T1 and T0-T2 in VBOGA and EVGS ($p < 0.001$), although no difference was found between T1-T2 in VBOGA ($p = 0.913$) and EVGS ($p = 0.450$).

Conclusions: In this study, for ITW children, dorsiflexion assistive functional bandaging was an effective tool to help achieving heel contact on the ground and improve walking quality for a short period of time after the application. Further studies with longer follow-ups and larger sample sizes are required to confirm the long duration therapeutic effects of this promising functional bandaging.

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Key words: Idiopathic toe walking, functional bandaging, heel contact, gait quality

Idiopathic toe walking (ITW) is a term used to describe the condition in which children walk with a toe-toe gait pattern in the absence of any known cause ^{1,2}. In the stance phase of gait, the heel is in contact with the ground at 3 of 5 subphases (initial contact, loading response, and mid-stance), and most of the gait pathologies are observed in these subphases ³. Toe walking is the inability to generate a heel strike at initial contact and the absence of full foot contact during stance phase; it is a common pattern observed in healthy, developing children before the age of 3 years old ⁴. Toe walking may gradually lead to ankle plantar flexion contracture over time ⁵. Furthermore, the natural history of persistent toe walking places children at risk of structural and functional abnormalities such as falling ⁶, permanent outward tibial torsion ⁷, and limitation on ankle mobility ⁸.

Gait assessment of children with ITW consists of determining the severity (how high the heels are from the ground) and extent (frequency) of toe walking. Severity is usually evaluated using computerized or observational gait analysis with additional physical measurements, which include ankle flexibility and manual muscle tests ⁹. Although, goniometric assessment of ankle range and computerized gait analysis are most commonly reported outcome measures in studies with ITW children ¹⁰, observational gait assessment is a quick, inexpensive method, which is efficiently performed by health professionals to assess patients' gait patterns and creates intervention plans to address the impairments

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and gait deviations ¹¹. However, different than in daily activities, children with ITW tend to modify their gait when they realize that they are being observed, which changes and usually delays the beginning of the treatments. In addition, the frequency and severity of toe walking may also vary depending on speed ¹².

The treatment of ITW includes active and passive stretchings of the calf muscles ¹³, botulinum toxin A (BoNT-A) injections ¹⁴, serial casting ¹⁵, surgery ¹⁶ and orthoses ^{17,18} the most common assistive treatment tool. However, the benefit of these treatments is still questionable ¹⁹ and the standard treatment protocol has not been established yet in clinics ¹⁷. In a recent review which discussed the effects of BoNT-A, footwear, exercises, and different types of orthoses in ITW, the authors concluded that the outcome data in the related studies were too limited to assess their effects. Besides the review revealed that it is not known whether treatment with BoNT-A injections and serial casting together is more effective than just serial casting in children with ITW ²⁰. Functional bandaging is an intervention tool utilized by health professionals to address impairments and activity limitations in people with musculoskeletal disorders to improve muscle strength, postural stability, and proprioception ²¹. No prior studies have been published assessing gait with dorsiflexion-assist bandage application to improve heel contact during gait for children with ITW. An alternative treatment intervention of adhesive bandaging may help increase heel-contact during stance, facilitate appropriate proprioception through the heel and

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hindfoot, preserve ankle range of motion (ROM), and therefore reduce the incidence of surgery to reduce a fixed contracture ²².

By comparing the gait of typically developing children, the aim was to evaluate the acute effects of dorsiflexion-assisted functional bandaging applied in children with ITW to achieve heel strike at initial contact, gain heel contact at loading response, prevent premature heel off at mid-stance, and investigate whether this application helps to improve gait quality, providing an alternative conservative intervention for children with ITW.

Methods

This is a basic longitudinal study that the children tested under 3 timepoints: Before bandaging (T0), immediately after initial bandaging (T1), and 1 week later with the same bandage (T2).

Participants

Nineteen children diagnosed as having ITW, whose ages ranged from 4 to 16 years (mean $\pm$ SD: 7.36 ± 3.16), who were followed up by Istanbul University, Istanbul Faculty of Medicine, Departments of Child Neurology and Orthopedics and Traumatology and 10 typically developing paired children (mean $\pm$ SD: 7.30 ± 2) participated in this study. All ITW participants were recruited to the study from Istanbul Faculty of Medicine Gait Analysis Laboratory who were diagnosed as having ITW by neurologists in the same university.

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The inclusion criteria included children demonstrating no heel strike at initial contact and observed premature heel off or no heel contact at the mid-stance phase bilaterally; no neurological, physiological, and orthopedic problems; and no previous interventions of any exercise program, BoNT-A injection, and orthopedic surgery.

Table 1 gives the characteristics including age, height, weight, the measurements of average bilateral leg length, and goniometric active and passive dorsiflexion range of motion (DFROM) with knee extended. All ankle DFROM measurements were performed three times, the average values were used in the data analysis for each side. All cases were evaluated with Silfverskiöld test which evaluates the ankle dorsiflexion in knee flexion and extension for detecting the isolate gastrocnemius tightness. For each participant, the same examiner performed the physical examination (goniometric joint ROM of ankle and leg-length measurements). Another physical therapist applied the bandages and analyzed the videos using tools, so the data analysis was performed by someone blinded to the clinical data intervention.

Toe Walking Tool (TWT) was used as a screening tool for ITW children. In order to diagnose toe walking was not caused by a medical condition and insure the diagnosis of ITW, all participants were evaluated by TWT which is a valid and reliable assessment tool. TWT includes four sections; demographics, indicators of trauma, indicators of neuromuscular influence, indicators of neurogenic influence²³. According to the TWT questionnaire, children with ITW in the present study have no neurogenic, neuromuscular

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or traumatic indicators. Although ankle flexibility is tested during the Lunge test in TWT, ankle dorsiflexion range was measured by goniometer in a non-weight bearing position in this study (Table 2).

Information about the study was provided to all the participants and their families through written, informed consent, and written permission was obtained for images provided by parents for the study to be published. The protocol of this study was in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethical Committee of Istanbul University (2012/1299-1171).

Measures

Video-Based Observational Gait Analysis

Participants' gait deviations were analyzed by video-based observational gait analysis (VBOGA) by allowing them to wear only their underclothes. The presence or absence of heel-contact was evaluated by using both a pressure sensor and VBOGA without shoes. The children with ITW were evaluated before (T0) and immediately after bandaging (T1), and at the end of the following week immediately with the same bandage (T2). VBOGA was the primary outcome measure in this study. The physical therapist who videotaped and analyzed the videos had worked more than 5 years as a physical therapist and had at least five years of experience in treating and analyzing gait deviations by means of an observational gait analysis.

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Edinburg Visual Gait Score

The Edinburg Visual Gait Score (EVGS) has been proven to be valid and reliable and helps to gain quantitative data on top of the typical qualitative data when observing gait^{24,25}. The quality of gait was also analyzed by EVGS for all participants which scores sagittal and coronal plane gait quality in 17 variables. In this study, all participants were evaluated with 12 sagittal plane variables of EVGS. Each of the variable can be scored by three-point scale (0 (normal), 1 (slight deviation) or 2 (severe deviation)) for each joint and each side²⁴. Although the EVGS has been primarily developed for children with CP, its reliability for the children with ITW has not been studied²⁵. The assessor was well trained and experienced in the evaluation and application of the EVGS with a senior physical therapist who had worked more than 10 years as a physical therapist in a motion laboratory and had experiences in video based observational and 3D gait analysis in children.

Toe Walking Frequency

Children with ITW, who have no fixed contracture in their plantar flexors, can often choose to walk with a heel-toe gait on request. The Visual Analogue Scale (VAS) was used to assess frequency of toe walking observed by the family recently. This frequency is a 10 cm long percentage (0% 'never walking', 100% 'walking continuously') frequency. For subjective comments we asked the parents frequency of toe walking in a community where the child is not aware of being observed and it is asked in T0 and T2. The question was 'How many points do you give as a percentage if you evaluate the frequency of toe walking'.

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Procedure

VBOGA and EVGS results were compared for the children with ITW and healthy pairs in T0, T1 and T2. In order to understand the differences between acute and one-week duration of the application, ITW children's scores were compared between T0, T1 and T2. In order to compare the heel contact between the subjects with ITW and typical gait, as well as to confirm the pressure sensors worked properly, ten typically developing children were recruited for this study (Fig. 1).

A switch-type pressure sensor (Fig. 2), which is designed to light up when the heel contacts with the ground, was placed on bilateral heels to define heel contact behavior at initial contact, loading response and mid-stance. The sensor consists of a durable 25 mm diameter membrane switch (1 mm thick and <1 g in weight, responds reliably to 200 g of load anywhere in the sensor area) with a 15 mm sensor area on a 100 mm flexible tail. The observed mean time between failure was 10,000 actuations. To find the precise location of heel contact, the bare heel was marked by ink, and the sensor was then placed on the ink mark. After the sensor was positioned, the participants were seated, and hand pressure was applied to the heel part by the same examiner to check proper sensor function. It was confirmed that every time pressure was applied, a LED connected to the sensor by a thin wire turned on. To help the camera see the LED easily, the LED was wrapped on the lateral shank by using a standard non-adhesive elastic bandage. This electronic sensor was used

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elsewhere to understand whether the heel was in contact with the ankle-foot orthosis (AFO) during walking and it worked well and was consistent ²⁶.

A digital video camera (Canon A2200, Japan) that can capture 30 frames per second and a triple video camera stand were used to record the participant's gait pattern. The camera was placed 3 m away perpendicularly from the middle of the 12 m walkway to record the natural way of walking by asking the participant to walk as they usually do outdoors.

Since gait speed can affect heel contact ^{27,28}, cadence was controlled for each condition using a metronome set for 80–100 beats per minute (bpm) to ensure consistent timing of steps. Before the video recording, the participants practiced for at least 3 minutes to adapt to the timing of the metronome beat. Adaptation to a specific cadence is difficult for young children, so when the participant caught a cadence range between 80–100 bpm for 3 minutes, the participant was assumed to have adapted to the cadence. We repeated trials until the child adapted to metronome. Parents, before the recording, also checked the walking pattern of their children, if they walk the way they usually walk outside. After each participant adapted to the proper cadence, five full gait cycles midway on the walkway were recorded on the left and the right in the sagittal plane, followed by video analysis.

Intervention

For T1, Tensoplast Sport, a latex-free elastic adhesive bandage 2.5 m long and 5 cm wide, was used to facilitate the ankle dorsiflexion during gait. The Tensoban foam is a foam wrap

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that prevents skin irritation were applied to each participant's shank and foot after spraying Tensosprey to prevent sliding of the Tensoban and Tensoplast Sport couple. According to the production company, there are no known complications about these bandage materials. To minimize risk of complications, such as discomfort or skin irritation, the parents were informed about the material properties of the bandage and were instructed to remove the child's bandage if the child expressed discomfort. With the hamstrings and gastrocnemius relaxed, each child was positioned in a comfortable sitting position with the lower legs and feet freely hanging. The ankle was passively set to 5° dorsiflexion by using a goniometer. Bandaging was applied by starting from the dorsal forefoot (one circular wrap) in parallel to the distal metatarsals, crossing the front-ankle region from the lateral foot to the medial half of the shank (one circular wrap again), and then wrapping was continued down likewise, crossing the front-ankle region to the distal metatarsals until using up all 2.5 m of bandage (Figs. 3a-b) ²⁹. Same therapist applied all the bandaging for all the subjects. After wrapping the bandage, the children couldn't achieve ankle plantar flexion even if they tried.

In T1, before the video recording, the participant's toes and comfort were checked verbally and visually to record comfortable barefoot walking without reduced blood circulation. After T1, an appointment 1 week later was set for each family to check the bandage for T2. During the 1-week period, the family was warned to keep the bandage on the child unless some unusual complications occurred, such as itching under the bandage,

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pain, or edema in the toes or lower legs. No exercise program was recommended and the bandages were never removed during the 1-week period. Children were allowed to continue their daily activities with the bandage, and the parents were instructed to let the children take a shower by covering the bandaged area with a waterproof material.

One week later, immediately after the third video recording, the bandage was removed with a solution called Leukotape Remover, which inactivates adhesive property.

There was no intervention to the children with typically developing children; they were just analyzed with the VBOGA and EVGS for gait comparison between the subjects with ITW.

Data analysis

The video records of each participant for each condition were analyzed with the VBOGA by using the frame-by-frame function of the video player software QuickTime 7.75.80.95. All video recordings for the ITW and typically developed children were also analyzed using the EVGS. VBOGA and EVGS analyzes were performed by the same physical therapist who applied the bandaging and perform the video records. The average scores of five gait trials for each side, corresponded to the center of the walkway, were used for statistics.

The VBOGA was used to analyze three gait subphases, namely 1, initial contact, defined as the instant the foot contacts the floor; 2, loading response, defined as the sole of the foot coming in contact with the floor; and 3, mid-stance, defined as the ipsilateral tibia rotating

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over the stationary foot (the instant the opposite foot crosses the stationary limb) by additionally using the pressure sensor (Figs. 4a–c).

To evaluate the effect of bandage application on heel contact in children with ITW, in T0 and T1, 570 subphases (19 children walked 5 times and 3 subphases of stance phase in each tour were analyzed for bilateral sides) were evaluated by using a light pressure sensor. After 1 week, in T2, the analysis was repeated for 420 subphases (14 children walked 5 times and 3 subphases of stance phase in each tour were analyzed for bilateral sides). None of the participants had heel contact at any of the subphases in T0.

All videos were analysed based on whether the sensor placed on the heels lightened or not in 3 subphases of stance, and scored it as 0 (light off) and 1 (light on). All the scores that light on were summed up and recorded for each children.

All statistical analyses were performed using a specific software (SPSS version 20.0, SPSS Inc. Chicago, USA) with a significance level of 5% in all tests. Mann Whitney U test were used for comparison of the age, height, weight, averaged leg length, bilateral active and passive dorsiflexion, EVGS score differences between the ITWs and typically developing children. Friedman test was used with post-hoc pairwise comparisons using Wilcoxon signed-rank test with a Bonferroni correction being utilised to account for increased Type I error associated with multiple pairwise comparisons in VBOGA and EVGS for T0, T1 and T2 conditions for children with ITW.

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Nineteen participants were above the minimum sample size needed to ensure 99% confidence level (significance level of 0.05 ($\beta = 0.2$)) by considering averaged changes in the interested parameters (VBGO (averaged: 80%) and EVGS (averaged: 84%) scores) as the effect size ($>80\%$) for the basis of prospective studies³⁰. With 5% error and 70% effect size 24 children could provide a power of 80%.

Results

The 19 children with ITW and 10 typically developing children were enrolled in the study. No statistically significant differences were found between groups on age, height, weight, averaged leg length and measurements of active and passive dorsiflexion with knee extended ($p > 0.05$) (Table 1).

According to the TWT questionnaire, children with ITW in the present study have no neurogenic, neuromuscular or traumatic indicators (Table 2). All the children with ITW achieved ankle dorsiflexion despite variable baseline ROM values between participants. Except for the six children, whose DFROM had slightly restricted (active: 6.16 ± 1.32 , passive: 11.5 ± 1.97), for all ITWs the Silfverskiöld test was negative for bilateral extremities, there was no isolate tightness for gastrocnemius muscle.

In this study, we measured the VBOGA and EVGS scores in pre (T0), post (T1) and 1 week later with bandaging (T2) of children with ITW and compared with typically

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developing. In T2, five of the 19 participants were excluded, because the bandage was removed before 1 week. Therefore, 14 of the 19 children with ITW participated in T2.

The total VBOGA scores (mean $\pm$ SD) in T0, T1, and T2 were as follows: 2.45 ± 5.87 , 24.24 ± 9.78 , and 23.81 ± 10.68 , respectively. In the VBOGA, the ITW children did not carry out heel strike in all the gait phases on their dominant and non-dominant sides without bandaging (T0), all the healthy participants made the lights on during all the sub-phases instance in T0. The children with ITW participants who could not make any heel contact (light off) in any subphases in stance under the T0 condition, made heel contact (light on) in initial contact and loading response after the bandage application. Although in mid-stance, the heel was in contact for 56.8% (108/190 steps) of the 190 subphases. In T2, the heel continued to contact during initial contact and loading response for all the phases in all the cases (Table 3). Although the percentage of heel contact in mid-stance was reduced from 56.8% (108/190 steps) in T1 to 54.3% (76/140 steps) in T2. Friedman test ($\chi^2(2) = 66.797, p < 0.001$) post-hoc Wilcoxon signed-rank test with a Bonferroni correction ($p < 0.05/3 < 0.017$) revealed a significant differences between T0-T1 and T0-T2 ($p < 0.001$). Although no difference was found between T1-T2 ($p = 0.913$).

In T1, 53.7% of the steps on the dominant side and 60% of the steps on the non-dominant side succeeded heel contact. In T2, the heel contact occurred 52.9% of the steps on the dominant side and 55.7% of the steps on the non-dominant side. In the number of

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heel contacts between the dominant and non-dominant sides, no statistical difference was found in T1 and T2 ($p = 0.232$ and 0.556 , respectively).

The total EVGS (mean $\pm$ SD) in T0, T1, and T2 were as follows: 7.32 ± 2.06 , 1.47 ± 1.88 , and 1.12 ± 0.95 , respectively (According to total sagittal plane items of EVGS scores 0 (normal), 12 (slight deviation) or 24 (severe deviation)). Friedman test ($\chi^2(2) = 23.231$, $p < 0.001$) post-hoc Wilcoxon signed rank tests with a Bonferroni correction ($p < 0.05/3 < 0.017$) revealed a significant differences between T0–T1 ($p < 0.001$). T0–T2 ($p < 0.001$). Although no difference was found between T1–T2 ($p = 0.450$).

The EVGS also showed a significant difference between the children with ITW and the typically developing children in T0 ($p < 0.001$). However, no significant difference was found between the two groups in T1 ($p = 0.054$) and T2 ($p = 0.063$).

According to the parent reported VAS before bandaging VAS score was 84.32 ± 12.11 , and 1 week later with the same bandage the mean score was changed to 38.34 ± 17.66 . There was significant difference between the duration of before bandaging and after 1 week with bandage ($p < 0.001$).

Discussion

This is the first study in the literature to evaluate the acute effects of functional bandaging in children with ITW. Dorsiflexion assistive functional bandaging is an effective tool to help achieve heel contact with the ground and improve gait quality for children with ITW.

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According to our results, immediately and 1 week after the application, functional bandaging was highly effective in providing the proper heel contact behavior in the early stance subphases (initial contact and loading response) and highly promising in the mid-stance phase of walking. For ITWs, EVGS scores were significantly higher (atypical walking quality) before the bandage application (T0), than typically developing children, but no significant difference was found between the two groups after the bandage application and after 1 week of wearing the bandage.

When detecting the gastrocnemius/soleus tightness and ankle hypomobility into dorsiflexion serial casting is mostly chosen as a conservative treatment^{22,31}. In our study all the children with ITW achieved ankle dorsiflexion despite variable baseline ROM values between participants. The bandaging probably will be less effective if the child has a fixed contracture. However after the serial casting process, the child is given AFOs for daytime use and AFOs set in dorsiflexion for night use for the alignment. After their desired range of motion and alignment is achieved, the children may need to continue to wear AFOs for years after casting³¹. As an assistive tool, functional bandaging seems to provide enough dorsiflexion moment to achieve proper heel contact at initial contact. AFOs are difficult to fabricate due to casting, take time to make them, and need to be modified as the child grows. In addition, parents need to purchase larger sizes of shoes to fit in the AFOs, and one shoe has to be larger than the other if the child uses the AFOs unilaterally. By using elastic bandaging, which is more tolerable than orthotics, we achieved similar foot contact

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behavior and gait quality as with orthotics^{21,32}. It may also be quite an alternative or assistive treatment tool for AFO usage to support the treatment programs ITW children and for children who do not like to wear AFOs or larger shoes for cosmetic reasons. As the bandage can be concealed under the socks and allows free choice of use, the child may agree to use the bandage over a longer period in daily life as an alternative to AFOs, which can enhance the benefits of exercise program and encourage the child to participate in the rehabilitation program.

After functional bandaging, in the initial contact phase, heel strike was achieved in all the children who could not attain a heel strike in T0. Even though none of the participants had heel contact to the floor at mid-stance in T0, 43.2% of the children in T1 and 45.7% in T2 demonstrated premature heel-off at the mid-stance phase. However, as the benefits of the bandage seem limited in mid-stance because the participants had no heel contact at loading response and mid-stance in T0, the premature heel rise in mid-stance was a noteworthy achievement. By incorporating functional bandaging to assist dorsiflexion, an exercise program in the present study could have been more effective in increasing the child with ITW's heel contact in mid-stance. Any exercise program, such as motor control intervention or stretching was not included in this study because i) the participation of the young children in an exercise program is sometimes difficult, ii) there are challenges with standardizing the amount of exercises in young children, and iii) advantages of verifying

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children with ITW by using the TWT and ruling out medical conditions contributing to toe walking has not been studied.

In our pilot study, Coban bandage, which is an elastic and nylon thread fabric with a structure containing latex, was used to gain assistive dorsiflexion ankle moment. However, it caused skin irritation and sensitivity on the applied area and thus was terminated immediately. On the basis of the preliminary results of the pilot study, because the other kinesiological tapes available on the market (Kinesiotape, Pinotape, etc) were not believed to have the strength to generate enough dorsiflexion moment at the initial contact and mid-stance phases, the impact of Tensoplast bandages are thought to be more promising to address lack of heel contact in toe walking. We believe that a comparison of the impacts of these two functional taping applications in future studies will be useful.

In our other pilot study, we attempted to control the fixed rhythm and walking speed range by using a metronome. Gait velocity differences cause various changes in gait pattern. Metronome is a tool to control the cadence and gait speed very commonly in literature for not only heel-toe walkers but also tip-toe walkers and for different gait patterns such as jump knee gaits, crouch gait, true equines^{33,34}. However, the older children adapted well to the cadence, but the young children had difficulty maintaining the same cadence. In the young children, controlling their walking speed by using a metronome caused changes in their walking patterns. Therefore, instead of forcing the children to a constant cadence, a specific cadence range (80–100 bpm) was used. The child's walking

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cadence was then monitored using a metronome to ensure that the child's cadence was within the specified range during the analysis. In future studies, to maintain the same walking speed for objective evaluation, the use of a treadmill or technical equipment such as photosensors is recommended.

In addition, in our study, the EVGS was used only in the sagittal plane on the dominant and non-dominant sides. Nevertheless, no specific video-based observational gait analysis methodology has been developed for children with ITW, although this was validated for CP children in the literature. We believe that the EVGS may be useful for evaluating the sagittal plane gait alterations in ITW, which are similar to those in mild spastic diplegia^{35,36}.

Because this is the first study correlating results of light sensors with VBOGA score and EVGS, this study, although not specifically analyzed using correlative statistics, shows EVGS is a promising tool to evaluate the gait deviations in ITW. For children with ITW, validity and reliability studies of the EVGS are strongly recommended.

The EVGS scores also showed the effects of the bandage applications on proximal segments. The VBOGA scores and EVGS revealed no statistically significant differences between T1 and T2. On the basis of the EVGS, although heel contact improved with the bandage application, 11 of 19 children showed moderate (6° – 15°) forward trunk posture in T0, and eight of them continued forward trunk lean in T1 and T2. Eight of the 19 children demonstrated increased pelvic rotation (pelvic protraction between 11° and 20°) at mid-stance in T1, and five of them continued this in T2. We observed that the children's gait

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postures approached normal with the bandage application, but some proximal gait alterations remained.

The bandage application in 5° dorsiflexion may have forced the child to bend the knee at first walking with the bandage. Accordingly, 11 of the 19 children showed increased knee flexion in stance (16°–25°) in T1, which continued in T2 in 5 children. Owing to the absence of previous literature for comparison, bandaging in 5° dorsiflexion position was chosen due to the elastic property of the bandage, which may resist the generated plantar flexion moment during stance. Although observational gait analysis is often used in clinical practice, three-dimensional gait analysis will provide more-accurate data and outcomes.

In order to distinguish the participating ITWs from neurogenic, neuromuscular influences and trauma which may affect the assistive bandage application by spasticity, motor control and sensation problems, TWT was utilized. Bandage application may have different effects on gait in children with medical diagnoses causing toe walking ²³. According to a study ³⁷ revealed normative reference values for lower limb range of motion in children with 4-16 years old, passive DFROM in knee extended is represented as 21.3±5.4. In our study six children with ITW had mildly restricted passive DFROM in knee extended (<20°).

Since we performed the evaluation of gastrocnemius tightness with goniometric measurement instead of Lunge test, we indicated this in the tool as non-weight bearing goniometric measurement. The ankle plantar flexor muscle tightness was found in six

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participants in the TWT test. However, in TWT test, the ankle flexibility is assessed by the Lunge test using an inclinometer in weight bearing condition ³⁸.

In clinical practice, pressure sensor placement on the heel might be a reliable, inexpensive, and easy tool to assess heel contact behavior during walking. The sensor is also promising for providing auditory feedback as a visual feedback for children and parents in home and clinic based treatment programs.

Limitations

Due to the fear of possible local allergic reactions, five of the 19 children felt uncomfortable and requested removal of the bandage. Despite the latex-free cotton and breathable fabric used, skin reactions such as itching and irritation occurred in five children. Because of the absence of T2 evaluations for these children, the statistical comparison was made between T1 and T2 over 14 participants. Therefore, the allergic reactions of the skin, that were observed as other bandages, should be monitored ^{39,40}. Besides, by dropping out of five participants, the confidence level of the study reduced in comparison between T1 and T2 which was among the limitations of our study.

The walking cadence of the participants in this study was controlled by metronome in which leg length, ethnicity and age are highly effective. For the future researches, walking analysis may be planned by allowing the children into self-direct their walking pattern in order to eliminate artificial bias.

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Only the acute effects of the bandage application were investigated in the present study which gives only a hint of its sub-acute and chronic effects. The influences of the dorsiflexion assistive bandage application on heel contact behavior and quality of gait should be investigated in the long term for children with ITW. For future studies, in order to understand the lasting of its functional benefits, investigating the effects of the bandage application after removing the bandage one or more weeks and comparing the VBOGA and EVGS scores would be useful.

This intervention was effective for the children who have at least neutral active dorsiflexion, but may not be appropriate if the child can't passively get his/her heel on the ground due to the tightness.

However, the ankle flexibility was measured in non-weight bearing condition by the goniometer which is one of the limitations of the present study.

Conclusions

This study shows that functional bandaging to assist dorsiflexion is effective for achieving heel strike at initial contact and maintaining heel contact in loading response. It is also promising for improving heel contact behavior in the mid-stance phase of gait. Walking quality improved after the bandage application, and the benefits continued to be observed after 1 week of bandaging.

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However, even though it is effective for short term in patients with ITW who can tolerate the tape and self-correct their gait, further studies with larger sample sizes and longer follow-up periods are needed for understanding whether the functional bandaging as an assistive treatment tool in the treatment options in long term. Additionally, the computerized gait analysis may help to detect the self-selected speed of gait variables more sensitively.

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Conflict of Interest: The authors declare that there is no conflict of interest.

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Table 1. General characteristics of the subjects

	Group 1	Group 2	
	(n=19)	(n=10)	
	mean ± SD	mean ± SD	p-value
Age (year)	7.36±3.16	7.30±2.00	0.960
Height (m)	1.43±0.77	1.25±0.19	0.590
Weight (kg)	31.50±7.14	27.20±6.97	0.270
Averaged leg length (cm)	63.3±9.95	64.00±8.21	0.970
Active DF with knee extended			
(R) (°)	11.40±2.18	14.26±3.46	0.240
Active DF with knee extended			
(L) (°)	12.31±3.4	14.05±3.37	0.480
Passive DF with knee			
extended (R) (°)	18.6±4.8	21.50±3.27	0.250
Passive DF with knee			
extended (L) (°)	18.9±5.2	21.50±3.37	0.450

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Table 2. Evaluation of ITW children (n:19) with TWT questions

Questions	Yes n (%)	No n (%)
Does the child toe walk	19 (100%)	0 (0%)
Does the child have a condition that you have sought medical assistance for and/or been diagnosed with a condition causing toe walking?	0 (0%)	19 (100%)
Does the child have a diagnosis of autism spectrum disorder?	0 (0%)	19 (100%)
Does the child have a diagnosis of cerebral palsy?	0 (0%)	19 (100%)
Does the child have a diagnosis of muscular dystrophy?	0 (0%)	19 (100%)
Does the child's family have a history of muscular dystrophy?	0 (0%)	19 (100%)
Does the child have a diagnosis of global developmental delay?	0 (0%)	19 (100%)
When the child was born, was their birth weight over 2500 g?	19 (100%)	0 (0%)
When the child was born were they over 37 weeks of gestation?	19 (100%)	0 (0%)
Was the child admitted to special needs nursery/neonatal intensive care after birth?	16 (84%)	3 (16%)
Did the child independently walk prior to 20 months of age?	19 (100%)	0 (0%)
Does the child have a family member that toe walks with no other medical condition?	8 (42%)	11 (58%)
Does the child toe walk on one foot only?	0 (0%)	19 (100%)

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Is the child toe walking in response to pain?	0 (0%)	19 (100%)
Did the child previously walk flat footed and only recently start to toe walk?	0 (0%)	19 (100%)
When you ask the child to walk on their heels are they able to?	19 (100%)	0 (0%)
On testing the ankle or hamstring range of motion is there a clonus and/or catch?	0 (0%)	19 (100%)
When asking the child to get up from the floor is there a positive Gower's sign?	0 (0%)	19 (100%)
Is there a normal knee jerk reflex?	19 (100%)	0 (0%)
Is there a normal babinski reflex?	19 (100%)	0 (0%)
Are the hip flexors tight for the child's age (Thomas test)?	0 (0%)	19 (100%)
Is the gastrocnemius and soleus tight for the child's age (Non-weight bearing goniometric measurement)?	6 (31,6%)	13 (68,4%)
Does the child have more than 2 significant delayed developmental milestones?	0 (0%)	19 (100%)
Does the child have limited eye contact, have strict rituals or ritual related behaviors, i.e., lining up toys, rocking or spinning	0 (0%)	19 (100%)

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Table 3. Evaluation of steps according to the phases in T0, T1, and T2. The calculation was performed over n=190 (19 participant x 5 trials for both sides) for T0 and T1, and n=140 (14 participants x 5 trials for both sides) for T2.

	T0			T1			T2		
	Ic	Lr	Mds	Ic	Lr	Mds	Ic	Lr	Mds
Light (+)									
(n)	0	0	0	190	190	108	140	140	76
(%)	0	0	0	100	100	56.8	100	100	54.3
Light (-) (n)	190	190	190	0	0	82	0	0	64
(%)	100	100	100	0	0	43.2	0	0	45.7

Note: T0: barefoot, T1: bandaged-acute, T2: bandaged after a week, (+): light on (heel contact), (-): light off (no heel contact), Ic: initial contact, Lr: loading response, Mds: mid-stance, n: total number of steps. %: The percentage of the light-on and off condition relative to n for each sub-phase.

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Figure 1. Flow chart of the study participants

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Figure 2. The light pressure sensor (a). The LED turned on a load of ≥ 200 g was applied on the sensor (b). The sensor is attached to the heel (c), and the LED is wrapped on the lateral shank by using a standard non-adhesive elastic bandage to help the camera see the LED easily (d).

Figure 3. Bandage application (a). The appearance of the shank after the bandage application was completed (b).

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Figure 4. Appearance of the LED connected to a switch-type pressure sensor on the heel at initial contact (a), loading response (b), and mid-stance (c).