Orthotic Treatment of Idiopathic Toe Walking with A Circular Lower Leg Orthosis

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Abstract

Background: There is no universally accepted treatment standard for idiopathic toe walking patients (ITW) in the current literature. None of the established methods provide homogenous satisfying results. In our department we treat ITW patients with lower leg orthoses with a circular foot unit for a total of 16 weeks. In this study we reviewed our database to evaluate the success of our treatment protocol for 24 months.

Results: 22 patients were included in the study. Age at the beginning of treatment was 7.0 years $\pm$ 2.9 (range 2.5-13.1). Percentage of ITW at the beginning of treatment according to the perception of the parents was 89% $\pm$ 22.2 (range 50-100). Immediately after the treatment with our device, percentage of ITW dropped to 11% $\pm$ 13.2 (range 0-50). After 12 months, 73% of the patients (16/22) walked completely normal or showed ITW less than 10% of the day. After 24 months, 64% of the patients kept a normal gait (14/22).

Conclusion: This study provides evidence that the treatment of idiopathic toe walking with lower leg orthoses with a circular foot unit results in satisfying long-term results in two thirds of the patients.

Introduction

Idiopathic toe walkers (ITW) are children, who habitually walk on their toes at an age when they usually should show a physiological gait pattern. Neurologic, neuromuscular or biomechanical reasons have to be excluded. Prevalence among five to six year olds is around five percent[1]. Males are slightly predominant[1]. Structural changes might develop if the habit persists for an extended period of time [2-5]. Furthermore, the walking pattern might become socially stigmatizing for older children.

Validation often relies on the perception of the symptoms by the parents, complemented by the clinical observation of a physician[6]. Gait laboratory investigations are significant but can be flawed because children sometimes tend to disguise the tip toe walking pattern and show their "best gait" for the observational period [7, 8].

Today, a variety of treatment options of ITW are used, including stretching exercises, serial casting, orthotic treatment, and operative procedures – all of them optional in combination with botulinum toxin injections into the calf muscles[9]. Furthermore, motor control interventions and auditory feedback methods are optional [9]. Results of these methods vary broadly and are often dissatisfying, leaving a significant proportion of "non-responders" up to 88% after twelve months [2, 6, 8, 10, 11].

In our clinic we have been treating ITW patients with a lower leg orthosis with a circular foot unit for several years. This construction is internationally unique because the supplying company held patents on crucial elements of the orthosis until recently. The most important feature of the orthosis is a circular foot unit, that is attached to a lower leg unit with hinges. The orthosis fulfils all functions of a cast[12]. Compulsory health insurance in Germany has acknowledged the orthosis and substitutes its costs.

The aim of this study is to provide a retrospective evaluation of the treatment of ITW with the circular lower leg orthosis at our clinic. The primary outcome parameter was the perception of a normal walking gate from the parents' point of view. Secondary outcome parameters were ankle joint dorsiflexion capacity in a straight leg position, recurrence of toe walking gait and adverse side effects.

Methods

We searched our in-house-database for the ICD codes "gait impairment (R26.8)", "equinus (M21.62; Q66.8)" and "contracture of muscle/joint in lower leg/foot (M62.46; M62.47)" from 2014 to 2018 and identified patients treated with lower leg orthoses with a circular foot unit. Patients had to be at least two years old at the beginning of treatment and the duration of toe walking had to exist at least six months prior to the diagnosis. Minimum follow-up was set to be two years.

Orthosis

All patients were treated with a lower leg orthosis with a circular foot unit. This unit is ring-shaped, slides over the foot from the front and is closed over the heel by a cap (figure 1). A liner worn under the orthosis reduces pressure points and provides padding of contact areas. An elevated toe plate in the liner shoe elevates the second to forth toe. The foot is encompassed in the circular foot unit with a maximum area of contact, comparable to a mounted cast. Correctional pressure forces are applied over a wide area. Therefore, a displacement of the foot in the orthosis becomes less likely.

The lower leg unit is stabilized by a three-point fixation. Two lay-on points are fixed, the third one is a closing cap at the tibial tuberosity to complete the fixation. Similar to the idea of Sarmiento in 1972, the lower leg experiences an additional stabilization of the lower leg unit with an activation of muscles [13]. If desired, ear-shaped mouldings at the condyle level of the femur provide additional rotational stability. (figure 1 & 2).

The orthosis is custom-made from a 3D-scan or a plaster cast. Its body consists of fibre-reinforced material and is therefore very rigid. The sole is more flexible due to incorporated aramid fibres. The liner is made of Tepefoam.

Hinges at the ankle joint allow for approximately 15° of dorsiflexion, plantarflexion is blocked in a neutral position (figure 3).

Treatment

All patients were examined by a senior consultant specialized in neuroorthopedics (MS) to rule out underlying neurologic disorders before the orthotic treatment was initiated. Prior to treatment the ankle joint mobility was measured in a straight leg position for both legs using a goniometer. Differences in passive ankle joint mobility between the right and left leg were rare and only of a small amount if they did exist. We averaged their values.

During the first six weeks of treatment patients were instructed to wear the orthosis 23 hours a day. It was only taken off for hygienic procedures and during sports/physiotherapy. The next four weeks, the orthosis was trained off during the daytime. For the last six weeks the orthosis was only worn at night-time. This point of time was defined as “end of treatment”. Beyond that period of 16 weeks, patients were free to adopt the wearing time of the orthosis to individual needs.

Physiotherapy treatment was continued if participants had already received it prior to orthotic treatment.

During every visit the orthosis was checked for the appropriate fitting. Patients were examined for pressure sores or skin breakdown. In addition, they were asked if it was painful to wear the brace or if they perceived pain while walking without the orthosis. Ankle joint mobility was examined as specified before. The proportional amount of time spent toe walking was estimated by the caregivers. Five groups corresponding to 0-25-50-75-100 percent were defined and patients allocated accordingly (figure 4). If toe walking recurred and orthotic treatment resumed (either with a new or the existing orthosis) patients were transferred into group 6 (recurrence group).

Statistical analysis

The distribution of quantitative data was described by mean, standard deviation and range. Hypothesis testing of group differences was performed by Mann-Whitney-U Tests. Qualitative data was presented by absolute and relative frequencies and compared between groups using Fisher's exact test. The correlation of quantitative data was explored by Spearman's rank correlation coefficient and the respective z-Test. A linear regression model was used to simultaneously assess the conditional effects of age and sex with respect to the improvement of toe walking. The latter was defined as the difference between the follow-up measurements at 12 or 24 months (as indicated) and the baseline measurement of the parent reported toe walking frequency of the patient. Hypothesis testing was performed at exploratory two-sided 5% significance levels. Analysis was conducted using R 3.6.1 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

From 2014 to 2018 we identified 224 patients with an ankle equinus. 192 were excluded from this study due to a causative congenital or a neurological disorder. Two of the remaining 32 patients were under the age of 2 years at the start of the treatment and were excluded consequently. Five patients were excluded because the follow-up time was less than 24 months, three children moved and consequently did not participate in the follow-up. The remaining 22 patients (8 f, 14 m) were included in the study.

Mean age at the beginning of treatment was 7.0 $\pm$ 2.9 years (range 2.5-13.1). Mean percentage of toe walking during a day was 83% $\pm$ 22.2 (range 50-100) according to the parents' perception (table 1).

Allocation into groups according to percentage of toe walking

Table 1: Parents were asked to estimate the time their child spent tip toeing when walking. The grouping was performed accordingly. When children were reequipped with orthoses after a treatment-free interval it was graded as recurrence (group 6).

	Percentage of toe walking
Group 1	0-15%
Group 2	16-35%
Group 3	36-65%
Group 4	66-85%
Group 5	86-100%
Group 6	Recurrence

Before the beginning of the treatment, one patient was classified into group 3 (50%_ITW), five patients into group 4 (75%_ITW) and sixteen patients into group 5 (100%_ITW). No patients were allocated into group 1 and 2 at the beginning of treatment (for patients' details see table 2).

Patients' details

Mean wearing time of the orthosis was 23 weeks +/-14.5 (range 8-73).

At the end of the treatment, mean toe walking time dropped to 11% +/-13.2 (range 0-50). One patient developed recurrent ITW (70%) after eight months and restarted wearing the orthosis. This patient was classified into group 6 (recurrence group). All patients (including the recurrence case) improved their gate pattern after twelve months (figure 4).

At that point (12 months), 14 patients (64%) were classified into group 1 (0%_ITW), two (9%) patients into group 2 (25%_ITW), three (14%) into group 3 (50%_ITW) and one (5%) into group 6 (recurrence_ITW).

Deliberate night-time bracing was continued in our study group by 9 patients (41%) for an average of 18.9 weeks +/-15.2 (range 4.6-56.7).

During the second year follow up three patients suffered a recurrence and were equipped with an orthosis again. Two years after the end of the treatment 14 patients (64%) remained in group 1 (0%_ITW), one patient in group 2 (25%_ITW) and seven patients (32%) in the recurrence group (figure 5). At this point, the average age of our patients was 9.1 years +/-2.9 (range 4.5-13.1).

After twelve months, a moderate positive correlation of toe walking improvement with age at the beginning of treatment ($r=0.38$; $p=0.08$) was seen. Looking at the multivariable linear regression, we recognized the adjusted effect that boys improved more (9.2%) than girls of the same age ($p=0.35$).

Within the sexes we found that older patients improved more (figure 6). Statistically, the toe walking time at the 12 months follow-up was reduced by 2.5 percent with every year of age at the beginning of treatment ($p=0.13$).

In seven patients the toe walking gate recurred within 24 months. Four of them were males (24% of all boys) and three females (38% of all girls). Four 5-year-old patients at the beginning of treatment had to restart orthotic treatment within 24 months. The other three patients were between seven and eight years old. Our results did not show any correlation between age and toe walking recurrence ($p=0.70$).

The mean ankle dorsiflexion (DF) in an extended knee position was $3^{\circ} \pm 7.5$ (-10° to 30°) at the beginning, improved to $16^{\circ} \pm 4.8$ (10° to 30°) at the end of treatment (or after treatment) and remained $14^{\circ} \pm 7.5$ (0° to 30°) after twelve months (table 3).

Table 3: %ITW = percentage of idiopathic toe walking. *one child (ID 12) developed recurrence shortly before the 12-months follow-up (%ITW_12_months). For statistical reasons, the last score of percentage of ITW and dorsiflexion before retreatment was applied.

Patients' data at 12 months follow-up				
Patients (m/f)	22 (13/9)			
Mean age (yrs; range)	7,0 (2,5-11,2)			
Wearing time of orthoses (months)	22 (8-48)			
	Mean %ITW	Mean Dorsiflexion	Mean Grouping	Equal or less 50% tip toe walking (% of all patients)
Before treatment	83%	2.7°	4.7	n=1 (5%)
0 months (end of treatment)	11%	16°	1.3	n=22 (100%)
12 months	14%*	14° *	1.6	n=21 (95%)

During orthotic treatment, six patients suffered mild pressure sores that did not result in an interruption of the treatment. None of the patients complained of pain while walking during the observation period. Other adverse effects were not reported.

Discussion

12 months after the treatment with the lower leg orthoses with a circular foot-unit following the Baise/Pohlig design, 73% of our patients (16 of 22) showed no or just sporadic idiopathic toe walking (less than 10% of time spent walking). After 24 months, 64% of the patients (14 of 22) had a normal walking gait.

These results are quite favourable compared to previously published ones. In 2013 Engström et al. provided 51 idiopathic toe walkers with a lower leg cast for four weeks and additionally randomized 21 patients to botulinum toxin injections into the calf muscles beforehand. After twelve months, only 12% (cast) and 30% (cast + botulinum toxin) of their patients showed a normalized gait pattern in parents' perception [10]. Sättilä et al. (2016) treated 30 children with stretching exercises for one-year, indoor shoes with solid heel caps and night-time splints made of a softcast, which had to be worn at least five nights a week. 16 of these patients received botulinum toxin injections into the calf muscles additionally. After 12 months, 28% (conservative group) and 56% (cons. + botulinum toxin) walked normally, after 24 months 54% and 50%, respectively [8]. Only Jack et al. were successful by completely seizing toe walking in all of their 10 children observed after 12 months using a combination of botulinum toxin, 1-3 weeks of walking cast and night-time bracing[11].

Surgical interventions to correct muscular shortening have been investigated with heterogeneous results. Eastwood et al. showed that only 22% of surgically treated patients (Baker type of aponeurotic lengthening of the Achilles tendon; 10/46) showed a normal gait after 7.9 years (range 2-22). McMulkin et al. 2016 showed that after surgical lengthening of the gastrocnemius/soleus muscle after five years six out of eight patients had a normalized gait pattern [2].

To date, classical AFOs could not be proven to provide proper treatment of ITW so far[14]. Herrin et al. investigated the effect of classical AFOs compared to carbon insoles in a cohort of 18 patients (figure 7) [7]. Parents did not find an improvement in their walking pattern after six weeks

We are convinced, that the ring-type design of the orthosis subject of our investigation is well capable of correcting the position of the foot and in this situation especially of the talocalcaneal complex regarding to the tibia. With the widely-used classical ankle foot orthosis (AFO), being a dorsal half-pipe with Velcro-straps at the foot and lower leg (figure 5-A), we did observe that the heel and the hindfoot can move inadequately in an equinus situation within the orthosis, especially while walking. In 2005 on the other hand Baise and Pohlig demonstrated for the first time in 260 patients suffering cerebral palsy that an equinus position can be corrected in 84% using a lower leg orthosis with a circular foot unit [15]. In a previous study with paediatric clubfoot patients our research group showed that the orthosis is capable of controlling the foot in all three planes [12]. The position of the foot in the orthosis cannot or merely be altered by evasive movements, like being held in a cast.

According to the Cochrane Paper by Caserta and Williams (2019), orthotic treatment of ITW patients should facilitate better ankle movement. It should include walking treatment, modulation of sensory processing or enhancement of motor control [9].

Ankle mobility does improve with muscular stretching of both the soleus and the gastrocnemius muscles. The single articulated soleus muscle is stretched during the pre-swing phase of the walking cycle, when the foot is brought into dorsiflexion (possible in our orthosis because of the hinges). Furthermore, knee extension will stretch the double articulated gastrocnemius muscle in mid stance (facilitated in our orthosis by prevention of plantarflexion).

Previous groups have shown, that cast treatments can normalize toe walking gait patterns for a few weeks[19, 20]. Because our orthosis works similar like a walking cast, we assumed that the impact on the motor control should be comparable. The use of the orthosis while walking could thus possibly restructure the walking pattern and improve dyspraxia[16-18].

Deliberate night-time bracing was continued in our study group by 41% of the patients for an average of 19 weeks and seemed to have a positive influence on the gait pattern during daytime. This might be explained by the sensory processing modulation taking place via stimulation of proprioceptive and tactile receptors during subconscious movements while sleeping. A dysfunction of sensory processing has been associated with ITW in multiple studies in the past [21-25]. Williams et al. (2014) found a connection between partial dysfunction and hyposensitivity to tactile stimuli due to an immature or mild impaired cerebellum or motor cortex in ITW [26]. Consequently, we added a toe elevation plate from the second to the fourth toe to enhance stimulation of the tendon receptors by enhancing pretension of the flexor tendons.

The assumption exists that younger children may benefit more from serial casting [27]. Contrary to previous results, older patients suffered less recurrences than younger ones in our small group of 22 patients.

We decided to choose the parents' perception of ITW as a primary outcome parameter. Because children tend to show their "best walking" under examination and intentionally suppress the toe walking in the gait laboratory or when feeling observed. Both would confound objective examinations. Other groups reported similar observations [7, 8]. This point of view is not shared by all groups examining ITW [28]. Smart wearables, for example insoles or socks with pressure receptors could be useful additions in future studies.

We are cautious to combine orthotic treatment with botulinum toxin. We do not think that the literature does sufficiently prove advantages of this measure [10, 18].

Limitations of the study

Retrospective observations could be confounded in general. The information value of our study is limited by the small number of cases and the absence of a control group.

Declarations

Ethics approval, consent to participate:

Ethical approval was obtained by the Ethics Committee of the technical University Munich (ref. number 435/18s).

Informed consent was obtained from a parent and/or legal guardian from all subjects, as subjects were under 18.

All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication:

Consent for publication is given by all authors.

Availability of data and materials: Not applicable.

Competing interests:

Two authors (NB, MS) received payments for presentations by a third party involved in an aspect of this work.

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Authors' Contributions:

N.B. and M.B. collected the data, wrote the main manuscript text and prepared all the figures and tables apart from figures 4 and 6, which were prepared by A.H. A.H. performed the statistical analysis. A.H. and P.P. helped with structural considerations. All authors reviewed the manuscript.

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Tables

Due to technical limitations, table 2 is only available as a download in the Supplemental Files section.

Figures

Figure 1

(A) The component parts are the circular foot unit (1), closed by a heel cap as seen in (B), the lower leg unit (2) and the liner (3). The foot is held in a slightly external, physiological rotational position (D). Plantarflexion and dorsiflexion can be blocked or allowed by lateral hinges, as desired (C, E).

Figure 2

A-J: Putting-on of the Pohlig lower leg orthosis: (A+B) A stocking is put on the leg before the liner is applied, then the stocking is pulled over the liner (C+E) Now the lower leg unit is slipped over the foot and fixed (F) The foot unit is slipped over the foot and the heel cap is closed (G) The foot unit is fixed to the lower leg unit by screws. (H) The mounted orthosis fixes the foot in a neutral dorsiflexion position and physiologic amount of external rotation (I+J). 5–10° of dorsiflexion are allowed by hinges when walking in the orthosis.

Figure 3

ROM of the foot unit. The lower leg orthosis in neutral position (plantarflexion is blocked); A) and maximum dorsiflexion of slightly above 10° (B).

Percentage of toe walking before treatment and at 12 months follow-up.

Figure 4

Boxplots showing the percentage of toe walking gait at beginning of treatment and changing in percentage of ITW after 12 months.

Grouping of patients according to percentage of idiopathic toe walking

● group1_0%, ● group2_25%, ● group3_50%, ● group4_75%, ● group5_100%, ● group6_recurrence

Figure 5

Twenty-two patients (o = 1 patient) have been grouped according to percentage of toe walking gait. Patients were reprovided with orthoses and allocated into the recurrence group.

Correlation between age and percentage of idiopathic toe walking.

Figure 6

The multivariable linear regression shows a better improvement regarding percentage of ITW in the 12-months-follow-up for increased age at the beginning of treatment.

Figure 7

Classical Ankle foot orthosis, as used by Herrin et al. Herrin et al. provided nine patients either with classical AFOs (A) or carbon insoles (B-C)[7]. After six weeks, parents did not report improvement of the toe walking gait in any of the patients.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Table2.JPG](#)