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IMPROVEMENT OF GAIT PATTERN FOR CHILDREN WITH INFANTILE CEREBRAL PALSY AND DYNAMIC PES EQUINUS AFTER TREATMENT WITH HINGED SUBTALAR CIRCULAR LOCKING ANKLE-FOOT-ORTHOSES

İNFANTİL SEREBRAL PALSİ VE DİNAMIK PES EKİNUSU OLAN ÇOCUKLARDA EKLEMLİ SUBTALAR SİRKÜLER KİLİTLİ AYAK-AYAK BİLEĞİ ORTEZİ İLE YÜRÜME PATERNİNİN GELİŞMESİ

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SUMMARY

Aim: Dynamic equinus gait in children with cerebral palsy (CP) is treated in different ways (physiotherapy, injections, casting and orthotic-device). Therapy with hinged subtalar circular locking ankle-foot-orthoses (AFO) allows maximal stretching of the muscle-tendon-complex as well as intra-articular reduction of the bone. The aim of this study is to show the effects of the therapy with this AFO on kinematic and kinetic gait data in children with CP and dynamic equinus.

Methods: 16 children with CP were analyzed during walking before and after orthotic-device therapy. Lower body kinematics and kinetics were measured barefoot using an 8 camera Vicon-MX-system and two AMTI-platforms and analyzed using the Newington-Model. Plantar pressure distribution was measured with the emed-x/R platform.

Results: After therapy the affected leg showed a significant higher ankle dorsal-flexion-angle in terminal stance, a higher maximum ankle-angle during swing, a higher amplitude of movement in stance and swing, a reduction of the first peak in the ankle-moment and of peak power at the ankle during loading response as well as more contact area and higher peak pressure under the heel. However there is still a too high plantar flexion angle at initial contact (IC).

Conclusion: The results show that the therapy with an AFO with hinged subtalar circular locking is an efficient therapy to treat dynamic equinus gait without any BTX-A-treatment or surgery. The gait patterns show a more physiological and mechanically efficient gait. To improve the existing plantar flexion angle at IC the children should strengthening the dorsal-flexors.

Keywords: Gait analysis, Cerebral palsy, Pes equinus, Orthotic device therapy

ÖZET

Amaç: Serebral palsi (SP) tanısı olan çocuklarda dinamik ekin değişik yollarla tedavi edilir (fizyoterapi, enjeksiyonlar, alçılama ve ortotik-cihaz). Eklemli subtalar sirküler kilitli ayak-ayak bileği ortezi (AFO) kas-tendon bileşeninde maksimal gerimi uygularken eklem içi kemiği de azaltır. Bu çalışmanın amacı SP tanısı olan çocuklarda ve dinamik ekinde bu AFO ile kinematik ve kinetic yürüme verileri üzerine tedavinin etkinliğini göstermektir.

Method: SP tanısı olan 16 çocuk ortotik-cihaz tedavisi öncesi ve sonrası yürürken incelendiler. Alt vücut kinematik ve kinetikleri çıplak ayakla yürürken 8 kameralı Vicon-MX-sistemi ve iki AMTI-kuvvet platformu ile Newington-Modeli kullanılarak incelendi. Plantar basınç dağılımı emed-x/R platformu ile ölçüldü.

Bulgular: Tedavi sonrası etkilenen bacakta basma fazı sonunda daha fazla ayak bileği dorsal fleksiyon açısı, salınımda daha fazla ayak bileği açısı, basma ve salınımda daha yüksek amplitüdlü hareket, yüklenme sırasında ayak bileği momenti ilk tepe değerinde ve tepe güç değerinde azalma ve topukta daha fazla temas alanı ve basınç gözlendi. Ancak hala yere ilk temas (IT) anında fazla plantar fleksiyon açısı vardı.

Sonuç: Bulgular eklemli subtalar sirküler kilitli AFO tedavisinin BTX-A veya cerrahi bir tedavi olmadan dinamik ekin yürüyüşünü tedavi ettiğini gösterdi. Yürüme paternleri daha fizyolojik ve mekanik olarak verimli bir yürüme gösterdi. IT anında aşırı plantar fleksiyonun düzelmesi için dorsal-fleksör kaslar güçlendirilmelidir.

Anahtar kelimeler: Yürüme analizi, serebral palsi, pes ekinus, ortotik-cihaz tedavisi

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INTRODUCTION

Dynamic pes equinus is a common gait deviation in children with cerebral palsy (CP). If pes equinus is the primary gait deviation, its causes are prolonged and/or premature ankle plantar flexor activity, plantar flexor spasticity and/or plantar flexor contracture (1). Associated gait deviations in children with dynamic pes equinus include premature peak external dorsal flexion moments with excessive power absorption (2). Davids et al. (3) reported from increased knee flexion at initial contact (IC) and in mid stance (MSt). He also observed a delayed and diminished peak knee flexion in swing phase, a diminished hip extension at terminal stance (TSt) and an increased anterior pelvic tilt.

Dynamic pes equinus and calf tightness in children with cerebral palsy is treated by different conservative measures such as physiotherapy, intramuscular Botulinum toxin injections, serial casting and orthotic devices (4). Structural pes equinus interfering with function is treated by surgical lengthening procedures. There are positive effects on gait cycle parameters after surgical corrections in the literature (5, 6). However, there is a risk of recurrence or over lengthening. This may result in calcaneal deformity (7), crouch gait (8), and diminished strength for push-off (1).

Recently the treatment of spasticity with intramuscular Botulinum toxin injections has become very popular and a lot of studies have been published with positive outcome data (9-13). Though, each injection may cause side-effects (4). Furthermore, the positive effects after injections usually only last temporarily between 3-10 months (10).

The influence of different Ankle-Foot-Orthoses (AFO) constructions on gait or their effect against barefoot walking was shown in different studies (14-16), while there is a lack of controlling the treatment of equinus itself with hinged AFO (HAFO). Our type of HAFO with a circular subtalar locking support according to Baise and Pohlig (17) allows direct stretching of the plantar flexor muscle-tendon-complex (MTC) without destabilisation of the subtalar joint complex (midfoot-break). Similar lengthening effects of the MTC may be obtained by casting or solid AFO. However, these treatments have the disadvantage of immobilizing the joints of the ankle and foot. Consequently, walking with HAFO allows more normal ankle dorsal flexion motion at terminal stance (TSt) than walking with solid AFO (2). Baise and Pohlig (17) reported on the efficacy of this HAFO by qualitative analysis of 260 flexible spastic pes equinus deformities. The aim of this study was to evaluate the effects of the therapy using the HAFO with a circular subtalar locking support on gait variables in children with infantile CP and dynamic pes equinus.

MATERIALS AND METHODS

Concept, Treatment and Subjects

The subjects had instrumented 3D gait analysis just before and immediately after finishing treatment with HAFO with subtalar circular locking. During the therapy the subjects had to use the HAFO for 24 hours a day except for hygiene purposes. One attending doctor decided about the duration of the therapy. The treatment was successful and stopped, if the patient reached a heel-strike or a flat-foot at IC. The mean duration of therapy lasted about 11 weeks (SD 5 weeks).

Sixteen children with cerebral palsy (10 females and 6 males) with a mean age of 9yrs (SD 4yrs), a mean height of 1.33m (SD 0.23m), a mean body mass of 32.8kg (SD 17.5kg) and a mean leg length discrepancy of 0.5cm (SD 0.5cm) participated in the study. The children were randomized chosen but has to satisfy following inclusion criteria for participating in this study: a) possibility to move the foot passively into a neutral position while knee flexed and extended (17) (no fixed deformities), b) no previous surgical interventions. All patients` parents gave written consent for participation.

For interpreting the gait patterns more specifically a group consisting of 20 healthy children (14yrs SD 2yrs, 1.67m SD 0.09m height, 54.2kg SD 9.0kg mass) with a mean walking velocity of 1.27m/s SD 0.07m/s were investigated.

Hinged Subtalar Circular Locking Ankle-Foot-Orthoses

The orthoses development (Orthopädietechnik Pohlig GmbH, Traunstein, Germany) from Baise and Pohlig (17) consists of two parts (Fig.1). The first part pro-

Figure 1. Hinged AFO with subtalar circular locking according to Baise/Pohlig (2005, p.4).

vides an S-type calf-construction with condylar support. It is fixed to the shank below the tibial tuberosity with a Velcro strap. The second part is a circular foot support. By a rotational movement at the level of the rear foot it is possible to correct the rear foot alignment and fix it into the anatomical correct position. The heel is securely fixed. The two parts have to be connected with an adapting mechanism. This device allows an optimal stretching of the calf muscles. To improve adhesion and to enhance comfort a soft inliner supports the rear foot. The movement of the ankle joint for plantar flexion can be adjusted while dorsal flexion of the ankle joint is not restricted.

Data Collection and Analysis

Kinematics and ground reaction forces were recorded simultaneously while the subjects walked barefoot along the 10m walkway at self-selected speed. Three valid gait cycles were analysed for each subject and each leg. Three-dimensional lower body kinematics (200Hz) and kinetics (1000Hz) were measured using an 8-camera Vicon® motion analysis system (Vicon Mx-System, Oxford Metrics Ltd, Oxford, UK) and two AMTI force plates (Advanced Medical Technology Inc, Newton, MA, USA) and analyzed using the Newington-Model (18, 19).

Plantar pressure distribution was measured with the emed-x/R (Novel GmbH, Munich, Germany) platform with a resolution of four sensors/cm^2 and a sampling frequency of 100Hz. The children were measured with the first step method according to Peters et al. (20). A minimum of three steps per side were measured.

The three-dimensional coordinates were smoothed using a Woltring filter routine with a minimum mean squared error value of 15. The segmental masses and moments of inertia were calculated based on data reported by Dempster et al. (21). The threshold on the AMTI force platform for determining the first foot contact and foot-off was set at 20N. Joint power was calculated as the dot product of the net joint moment and the angular velocity. Joint moments and power were normalized to body mass, and all kinematic and kinetic data were time-normalized to the gait cycle. The parameters were chosen according to the functionally tasks of the separated gait phases (22).

Spatio-temporal gait characteristics, sagittal ankle, hip, knee and pelvis kinematics and kinetics were analysed for the involved leg. For each variable, data were averaged across three trials for each subject. Furthermore, group means were generated. If the pathological burst of the ankle angle or the ankle moment during stance disappeared after the therapy, the value from the curve was taken at the same time the burst appeared before the therapy.

From the pressure distribution data one representative trial for each subject was analyzed. The foot was divided into three masked regions: heel, mid foot and fore foot. Peak pressure and contact area of the masks were evaluated. Identical masks were used before and after therapy.

The shape of distribution of the present sample was checked using the Kolmogorov-Smirnov-test. Because a normal distribution was not completely confirmed in the present study differences of the parameter values before and after the therapy were checked using a paired sample test (Wilcoxon). Statistical significance was assigned to p-values ≤0.05.

RESULTS

Sagittal Plane Joint Kinematics and Kinetics

The temporal-spatial gait variables show no significant differences in walking velocity (v_{pre}= 1.06m/s SD 0.16m/s - v_{post}= 1.08m/s SD 0.14m/s), cadence (c_{pre}= 129.1steps/min SD 17.8steps/min - c_{post}= 129.6steps/min SD 13.3steps/min), single support-time (sst_{pre}= 346ms SD 98ms - sst_{post}= 334ms SD 75ms) and double support-time (dst_{pre}= 198ms SD 94ms - dst_{post}= 198ms SD 73 ms) before and after the treatment.

Fig. 3 shows the time-normalized ankle angle curves. The improvements can be seen in the significantly increased peak dorsal flexion angle in TSt, in the higher level of dorsal flexion amplitude in stance, higher peak ankle angle during swing phase and the significantly larger range of motion during swing. While the pathological external ankle dorsal flexion moment and the excessive ankle power absorption during loading response are significantly reduced or even disappear, no significant differences in the external dorsal flexion moments and in the ankle power generation during push-off can be observed. The results also (Tab.1) show a statistical trend (p=0.098) towards a better foot position at IC.

Table I

Mean ankle, knee kinematics and kinetics of the involved side before and after the therapy (SDs) (n=16)

	Involved side pre-therapy	Involved side post-therapy	p-value
Angle Initial Contact [°]	- 11.7 (10.5)	-7.5 (5.1)	0.098
Pathological Peak Angle (stance) [°]	3.6 (11.4)	6.2 (4.3)	0.730
Peak dorsal flexion angle terminal stance [°]	5.0 (19.2)	17.5 (6.4)	0.004*
Maximum dorsal flexion angle in stance [°]	8.4 (12.5)	12.54 (6.0)	0.006*
Range of Motion stance [°]	23.7 (5.6)	26.6 (5.3)	0.098
Peak plantar flexion angle (swing) [°]	-21.3 (14.3)	-14.7 (8.4)	0.079
Peak ankle angle (swing) [°]	-6.0 (9.7)	1.0 (4.9)	0.008*
Range of Motion swing [°]	17.5 (6.5)	20.2 (8.2)	0.034*
Pathological external dorsal flexion moment [Nm/kg]	0.87 (0.38)	0.52 (0.32)	0.005*
Peak external dorsal flexion moment terminal stance [Nm/kg]	0.92 (0.33)	0.90 (0.32)	0.642
Pathological peak ankle power absorption [Watt/kg]	-1.5 (1.0)	-0.6 (0.3)	0.002*
Physiological peak ankle power absorption [Watt/kg]	-0.6 (0.4)	-0.6 (0.4)	0.756
Peak ankle power generation [Watt/kg]	1.9 (1.0)	2.0 (0.9)	0.535
Knee angle initial contact [°]	17.3 (6.2)	16.0 (4.7)	0.326
Peak knee flexion in loading response [°]	23.3 (6.3)	23.6 (6.4)	1.000
Minimum knee angle in mid and terminal stance [°]	6.7 (7.7)	7.7 (4.2)	0.959
Range of motion stance [°]	20.5 (4.3)	22.0 (3.1)	0.215
Peak knee angle swing [°]	60.8 (6.9)	64.8 (6.4)	0.163
Range of motion swing [°]	44.5 (9.1)	49.1 (6.0)	0.044*
Peak external knee extension moment loading response [Nm/kg]	-0.15 (0.16)	0.07 (0.24)	0.015*
Peak external knee flexion moment loading response [Nm/kg]	0.23 (0.15)	0.52 (0.27)	0.003*
Minimum external knee moment in mid and terminal stance [Nm/kg]	-0.20 (0.20)	-0.03 (0.16)	0.020*
Peak external knee flexion moment during pre-swing [Nm/kg]	0.12 (0.14)	0.17 (0.13)	0.438
Peak knee power generation during loading response [Watt/kg]	0.5 (0.3)	0.5 (0.7)	0.796
Peak knee power absorption during loading response [Watt/kg]	-0.4 (0.3)	-0.8 (0.7)	0.098

The knee joint results (Table I) show a significantly lower external peak knee extension moment following a significantly higher external peak knee flexion moment during loading response as well as a significantly higher value of the external knee moment in mid and terminal stance. The peak knee power absorption during loading response does not change significantly, but it shows a trend towards normalization.

The variables at the hip joint as well as the pelvis show fewer differences after treatment than those seen at the ankle and knee. There are only significant differences in timing of the maximal hip extension during stance (t_{pre}=53% SD 2%, t_{post}=51% SD 4%) as well as in the timing of peak external hip extension moment during pre-swing (t_{pre}=48% SD 3%, t_{post}=46% SD 3%).

Plantar Pressure Distribution

Figure 2 shows an example of plantar pressure prior to (a) and after (b) treatment. The mean temporal-spatial gait parameters of plantar pressure distribution show a tendency towards a slower walking velocity (measured during the fifth step of walking) after the therapy (v_{pre}= 1.36m/s SD 0.33m/s- v_{post}= 1.15m/s SD 0.28m/s) but no significant differences in contact time (t_{pre}= 732ms SD 209ms- t_{post}=732ms SD 146ms). The results of the plantar pressure distribution show a highly significant extended contact phase of the heel (CA_{pre}=13.8cm^2 SD 8.8cm^2- CA_{pre}=21.9cm^2 SD 7.9cm^2 (p=0.001)) and the mid foot (CA_{pre}=16.7cm^2 SD 10.1cm^2- CA_{pre}=22.6cm^2 SD 7.5cm^2 (p=0.006)) and a significantly higher peak pressure under the heel (PP_{pre}=130kPA/kg SD 118 kPA/kg - PP_{post}=198kPA/kg SD 73 kPA/kg (p= 0.021)).

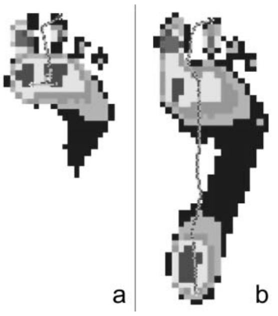

Figure 2. Example of plantar pressure distribution during gait prior to (a) and after (b) treatment with hinged AFO with subtalar circular locking.

DISCUSSION

Comparing the data (Fig. 3) with the sagittal classification from Rodda et al. (23) and the kinetic patterns from Lin et al. (24), the mean curves of our patients' pre-treatment show typical gait patterns of children with mild dynamic pes equinus. The children exhibit the premature peak external dorsal flexion moments with excessive power absorption as it was shown by other authors (2, 5, 23). The higher knee flexion in stance as reported by Davids et al. (3) could not be found. This can be explained by the mild spasticity of the children we examined. In contrast to Davids et al. (3) the mean curves of the children pre-treatment show a mild recurvatum in stance with a too low knee flexion angle at loading response, as it is also shown by Rodda et al. (23). Furthermore, an earlier appearance of the maximal knee flexion during stance can be determined. The pelvis of the patients also tilted anteriorly as reported by Davids et al. (3).

While walking velocity or cadence did not change significantly after the treatment, it could be assumed that the changes of kinematics and kinetics result from different gait techniques. After the treatment the corrected anatomical and physiological position of the foot, resulted in a normalization of the kinematic and kinetic data of the ankle data on the affected side.

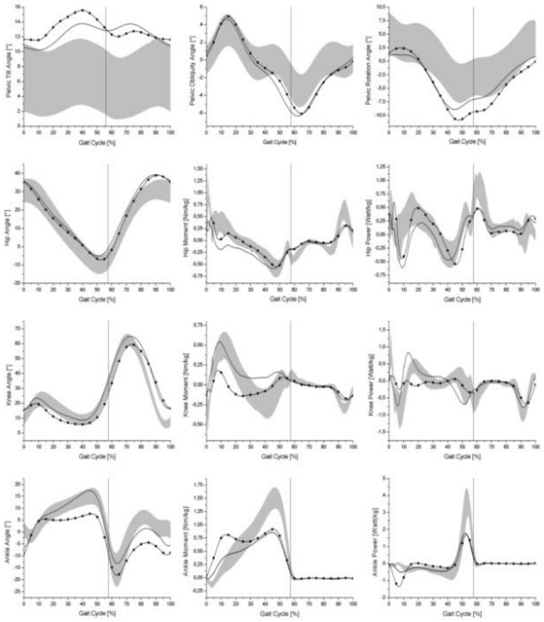

Figure 3. Mean angle, moment and power of the ankle-, knee- and hip joint as well as mean pelvic tilt, pelvic rotation and pelvic obliquity during the gait cycle of 16 children with CP and dynamic pes equinus before and after the therapy with orthotic device. The grey curves display the patterns from 20 healthy children.

The higher external knee flexion moment in loading response shows a better shock absorption. It can be explained by the better position of the foot at IC and the better roll-over process after therapy. Due to the improvement of the ankle ROM after treatment, the pathological plantar flexion-knee extension couple disappears. The therapy thus results in normal ankle and knee joint angles from the loading response to mid swing.

The lower external knee extension moment of the patients before and after the therapy in comparison to the normative data is caused by a more flexed knee position at IC in both conditions. It may be supposed that the knee was more flexed in terminal swing and at IC to place the contralateral leg closer to the ground (22). While the ankle position at IC shows a trend towards normalization it could be assumed that the results at IC would be better if the patient would have more time to adapt the joint angle position of the lower extremity to the new condition. Moreover, the patients show a lack of an external knee extension moment in TSt. A possible explanation for this difference in comparison to the normative data may be the slower gait velocity which has a great influence on the knee kinetics (25). Other reasons for the lacking external knee extension moment may be hyperactivity of the quadriceps, posterior trunk lean, knee valgus or weakness of the knee flexors. Their contribution needs to be proven in further studies.

The stretching of the MTC of the plantar flexors due to the HAFO-treatment led to a larger ROM of the ankle, which is shown in the enhancement in peak dorsal flexion angle in TSt, in the ROM of the ankle in swing phase and the tendency of a larger ROM in stance. Although the patients from Sutherland et al. (9) and Corry et al. (11) already had worse equinus than our patients and comparison is therefore difficult, the improvement of the maximal dorsal flexion in TSt in our study was better. The improvements at the ankle angle curves can be reached without the deficit of power generation in the ankle joint. In the study from Lyon et al. (6) where the children had an achilles-tendon lengthening, the loss of moment generation at the first 20% of gait cycle and the exaggerated dorsal flexion angle show the problematic of an over lengthening. It has to be considered if the patients from Rose et al. (5) also could have succeeded with the HAFO from Baise and Pohlig (17) without lengthening of the gastrocnemius fascia, because the ankle curves from Rose et al. (5) show similarities of gait deviations at the ankle with our patients. The reduction in ankle power absorption at loading response points towards a more physiological and mechanically more efficient gait pattern, which may be caused by a longer MTC of the plantar flexors with an improvement of ankle ROM during stance. Results from Singer et al. (26) with adult patients point out that the increased extensibility of the MTC led to a reduction in reflex excitability. This reduced excitability might be the reason for the reduced or disappeared pathological first peak in the external dorsal flexion moment.

The plantar pressure distribution shows the presence of initial heel-foot contact during the roll-over process of the foot after treatment, but the kinematic data shows that there is still a flat-contact without the first rocker of the ankle-joint. The absence of the first rocker was also reported from studies with treatment of pes equinus via botox (9, 11) and casting (11). It is maybe possible to improve the existing first rocker function of the ankle joint by strengthening the dorsal flexors during the treatment which might have still an unfavorable length for the force development just after therapy.

The treatment of dynamic spastic equinus deformity by a HAFO with subtalar circular locking led to improvements of the kinematics and kinetics of the lower extremity during the gait. Therefore it is an efficient method without side-effects.

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