Effects of carbon fibre spring orthoses on gait in ambulatory children with motor disorders and plantarflexor weakness

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A consecutive series of 17 children (six males, 11 females; mean age 11y 11mo [SD 4y 5mo]; range 3y 11mo–17y 4mo) with plantarflexor weakness was assessed to compare gait differences between a carbon fibre spring orthosis (CFSO) and participants’ regular orthoses. Twelve children had myelomeningocele, four children had arthrogryposis, and one child had neuropathy with peripheral muscle pareses. All participants underwent clinical examination and 3D gait analysis. Parents answered a questionnaire to assess subjective perceptions of the orthoses. Results from 3D gait analysis provided evidence that CFSOs enhance gait function in most participants by improving ankle plantarflexion moment (p<0.001), ankle positive work (p<0.001), and stride length (p<0.001). The CFSO did not suit all participants, which emphasizes the importance of analyzing each patient’s needs.

During gait, the plantarflexors contribute to knee and ankle stability, restrain the forward rotation of the tibia during stance phase, and conserve energy by minimizing vertical oscillation of the whole-body centre of mass. The positive work done by the plantarflexors during push-off adds to the potential and kinetic energy of the leg, thigh, and upper part of the body, and propels the body forward.

Children with various motor disorders exhibit weakness of plantarflexor muscles. Children with myelomeningocele (MMC) with neurological lesions at as low as the sacral and low lumbar levels are generally unable to stand still without external support, despite sufficient muscle strength in hip and knee muscles to walk independently. Extensive plantarflexor weakness results in kinematic alterations (such as increased knee flexion, anterior pelvic tilt, and trunk and pelvic rotation), increased vertical excursions, and is associated with an anterior trend in the centre of mass motion. In children with arthrogryposis multiplex congenita (AMC), equinovarus adductus foot is frequently observed, which is often associated with plantarflexor muscle weakness.

Due to the essential role of the plantarflexors in walking, orthotic substitutions are essential in patients with plantarflexor paralysis. In children with MMC at L4 and L5, ankle–foot orthoses (AFOs) have been shown to improve sagittal plane function by reducing excessive ankle dorsiflexion, increasing plantarflexor moment, and reducing crouch and associated knee extensor moments. In the authors’ experience, ambulatory children with AMC and unstable feet, ankle, and knee joints also benefit from orthoses, but no gait study has been found in this field.

One major challenge in the field of orthotics is to compensate for the plantarflexors’ propulsive function, namely, to sustain a plantarflexion moment and to allow simultaneous plantarflexion movement. The posterior-leaf spring AFO was tested in patients with cerebral palsy. While it allowed ankle dorsiflexion in midstance, it was not shown to augment ankle function through storage and return of mechanical or spring energy. Carbon fibre orthoses have been compared with posterior-leaf spring AFOs during walking; results showed a significantly improved third ankle rocker with greater ankle range of motion, angular velocity, and power generation at pre-swing with the use of carbon fibre orthoses.

In the authors’ clinical practice, carbon fibre spring orthoses (CFSOs) have been recently introduced to store energy with increasing dorsiflexion through spring tension, and to return energy at the end of stance phase for push-off. In the clinic, this type of orthosis is prescribed for children with plantarflexor weakness caused by various motor disorders, and it is currently used by approximately 35 children who attend the clinic. The authors previously reported findings of three participants during walking with both the new CFSO and their regularly used orthoses. The aim of the present study was to compare objective and subjective gait differences between the CFSO and participants’ regular orthoses (RO).

Method

PARTICIPANTS

Ethical approval for this study was obtained from the Karolinska University Hospital Ethics Committee. Written informed consent was obtained from all participants’ guardians.

A consecutive series of 22 children were recruited who were referred to an orthotist from the clinic’s paediatric orthopedic
department between June 2003 and March 2005 to receive a CFOS for the first time. Of the 22 participants, 17 participants (six males, 11 females; mean age 11y 11mo [SD 4y 5mo]; range 3y 11mo–17y 4mo) had their former orthoses available at the time of testing and agreed to participate in the study. Twelve children had MMC, four children had AMC, and one child had neurology with peripheral muscle pareses (Table I).

**CLINICAL EXAMINATION**

All participants underwent a physical examination by the same examiner (ÅB).

**Muscle strength**

Muscle function was tested with manual muscle testing.13 All 17 participants had normal knee extensor, hip adductor, and hip flexor strength. Muscle strength in plantarflexion, dorsiflexion, knee flexion, hip extension, and hip abduction for each participant is shown in Table I.

**Spasticity**

Children with MMC were assessed clinically by a physiotherapist according to spasticity types commonly found in this patient group.14 Three children displayed spasticity in the peroneal muscles, one of whom also displayed spasticity in the plantarflexors (Table I).

**Joint range of motion**

Presence of joint contractures in hip and knee extension, dorsiflexion, and plantarflexion was measured. One child had knee flexion restriction at 90˚ (Table I). External tibial rotation, measured as the foot–thigh angle in prone position, did not exceed 20˚ in any participant. One child had internal torsion of 10˚ in one limb.

**Orthoses**

Participants used either AFOs or knee–ankle–foot orthoses (KAFOs) with unrestricted knee flexion. All participants used the CFOSs routinely for 2 to 3 weeks before gait evaluation and had been instructed to use their former orthoses occasionally during this time. All orthoses were custom-made, and individual compensations in orthoses and shoes were made for each participant’s ankle contractures. Participants’ walking was tested in both orthoses, in either AFOs or a KAFOs corresponding to their regular orthoses. Participants were asked to walk at a self-selected, comfortable pace.

**Carbon fibre spring orthosis**

The CFOS and its construction have been described in detail in an earlier study.12 It has a polycentric mechanical ankle joint and consists of an L-shaped carbon fibre spring component that is embedded in a composite material and is attached to a supramalleolar section with a few millimetres’ distance between the carbon fibre spring and the foot section posteriorly. This construction allows dorsiflexion during the stance phase until the spring’s flexion is halted by the foot section. Proximally, the carbon fibre spring is attached to a calf section that extends to the femur condyles. The sole is made of a composite material and extends to the toes, and the material encompassing the foot extends to the fifth metatarsal head. For the KAFO a monolateral mechanical knee joint of titanium or steel (Spring Carbonfeder, Göttinger Orthopädie-technik GmbH, Zorneding, Germany) with one degree of freedom was used. Twelve children used carbon fibre spring AFOs, four used the carbon fibre spring KAFOs, and one child used one of each (Fig. 1). The same orthotist and a technician, who had been trained by the carbon spring manufacturer, made all orthoses. One larger shoe size was generally required to accommodate the spring component.

**Regular orthoses**

One child used a hinged AFO with a dorsiflexion limit at neutral and a 15˚ plantarflexion allowance. Eight children used

| Table I: Participant distribution of muscle strength, occurrence of spasticity, joint range of motion, and orthoses used in all participants according to diagnostic groups |
|---------------------------------|---------------------------------|---------------------------------|
| **Myelomeningocele (n=12)**    | **Arthrogryposis (n=4)**        | **Neuropathy (n=1)**            |
| Age y:m, mean (range)          | 11.6 (6.9–17.4)                 | 10.4 (4–16)                     |
| Weight kg, mean (SD)           | 41.4 (18.4)                     | 34.6 (11.94)                    |
| Height cm, mean (SD)           | 141 (18)                        | 140 (25)                        |
| Orthosis                       | 8 AFOs, 4 KAFOs                 | 2 AFOs, 2 KAFOs                 |
| **Muscle strength**            |                                 |                                 |
| 0–5 scale                      | n=24 limbs                      | n=8 limbs (Right/Left)          |
| Plantarflexion                 | Grade 0–1: 18, Grade 3: 6       | Grade 0–1: 6, Grade 3: 6        |
| Dorsiflexion                   | Grade 0–1: 11, Grade 4: 15      | Grade 0: 4, Grade 4: 4          |
| Knee flexion                   | Grade 2–3: 5, Grade 4: 19       | Grade 4: 6, 2 limbs^a            |
| Hip extension                  | Grade 0–3: 4, Grade 4: 20       | Grade 2–3: 2, Grade 4: 6        |
| Hip abduction                  | Grade 0–2: 8, Grade 3–4: 16     | Grade 3: 1, Grade 4: 7          |
| **Spasticity**                 | Peroneus 4 limbs, Plantarflexors 1 limb |
| **Joint range of motion**      | n=24 limbs                      | n=8 limbs (Right/Left)          |
| Dorsiflexion                   | –10˚: 2                         | +5˚/+5˚                         |
| Plantarflexion                 | –10˚: 2                         |                                  |

^aTwo limbs not measurable due to knee flexion restriction at 90˚. ^b+ indicates knee hyperextension. AFO, ankle–foot orthosis; KAFO, knee–ankle–foot orthosis.
AFOs with thermoplastic foot sections and composite material in the shank segments. Six children used KAFOs made from the same material, with unrestricted sagittal knee motion, and shank and thigh sections connected via a metal joint. The ankle joint was designed at a neutral position to restrict ankle motion in participants with excessive tibial advancement. The sole extends to the end of the toes and foot section border is tapered to the fifth metatarsal head (Fig. 1).

GAIT ANALYSIS
All children underwent 3D gait analysis with a six-camera motion analysis system (Vicon, Oxford, UK) along a 10m walkway with two force plates (Kistler, Winterthur, Switzerland). Participants were equipped with 34 reflective markers aligned with anatomical landmarks on the lower body modelled according to the Newington model and those on the upper body modelled according to the Plug In Gait model (Vicon). Markers were placed on the orthoses as near as possible to the correct anatomical position.

DATA ANALYSIS AND STATISTICAL ANALYSIS
An ensembled, or point-to-point, average gait cycle was generated from three gait cycles for each side, from which 43 distinct values of joint/segment angles, joint moments, powers and work (where positive/negative work done is the cumulative sum of joint power generation and absorption respectively, throughout the gait cycle), and temporo–spatial parameters were obtained. These gait parameters were statistically compared for CFSO versus RO using a two-way repeated measures analysis with within-participant factors of orthosis type and side, and 95% confidence intervals (CI) for mean differences were calculated. Statistical significance was set at $p \leq 0.05$. If the 95% CI for a mean difference did not contain zero, a systematic difference was statistically demonstrated. Analysis according to the entire group and to diagnosis subgroups was performed.

QUESTIONNAIRE
A questionnaire was sent out to the parents after the child had used the CFSO for longer than 2 months. The questions concerned frequency of use, gait, and standing function changes, walking velocity, acceptance, and ease of putting on and removing the orthoses.

Results
Results are presented as 95% CI for mean differences, and $p$ values. Angles are shown in degrees, moments in N·cm/kg. joint power in weight/kg, and joint work in J/kg. Table II shows joint angles, moments, and power at all joints, as well as temporo–spatial parameters, with RO and CFSO in the entire group and MMC and AMC subgroups.

SAGITTAL PLANE KINEMATICS
With CFSO, trunks were slightly more posterior in the entire group when compared with ROs (–2.0 to –0.1; $p = 0.034$). There was no difference observed in pelvis movements. With CFSO, hips were more extended in terminal stance (3.0–3.5; $p = 0.002$); knees were more extended at initial contact (1.0–5.3; $p = 0.007$), and more flexed during swing (–7.2 to –1.5; $p = 0.005$). No difference was observed in ankle movements (Fig. 2). In the MMC subgroup using CFSOs, hips were more extended (0.4–4.4; $p = 0.021$); knees were more extended at initial contact (approx. 5˚; 2.4–6.4; $p = 0.001$), and more flexed during swing (approx. 5˚; –1.2 to –0.4; $p = 0.03$).

SAGITTAL PLANE KINETICS
In the entire group, hip flexion (2.4–13.1; $p = 0.007$), dorsiflexion (4.0–19.5; $p = 0.005$), and plantarflexion (–37.7 to

Figure 1: (a) Carbon fibre spring ankle–foot orthosis. (b) Carbon fibre spring knee–ankle–foot orthosis. (c) Regular ankle–foot orthosis. (d) Regular knee–ankle–foot orthosis.
CFSOs (0.02–0.26; \( p \leq 0.001 \)), moments as well as power generation at the ankle (–0.67 to –0.12; \( p = 0.007 \)), were increased when CFSOs were used (Fig. 2). All of the above differences were observed in the MMC subgroup (3.4–16.5, \( p = 0.007; 2.3–24.2, p = 0.022; -45.0 \) to –18.9, \( p < 0.001; -0.86 \) to –0.11, \( p = 0.015 \) respectively), in addition to decreased mean knee extension moment in stance (1.2–13.9; \( p = 0.024 \)). In the AMC subgroup ankle absorption was increased with use of CFSOs (0.02–0.26; \( p = 0.035 \)).

**JOINT WORK**

With CFSOs, negative work done at the ankle increased (0.019, 0.076; \( p = 0.005 \)) with CFSO by a mean of 0.05 J/kg (64%) in the entire group and 0.07 J/kg (93%) in the MMC subgroup (–0.067 to –0.038; \( p = 0.001 \)). Positive work done at the ankle increased with CFSOs by a mean of 0.04 J/kg (86%) in the entire group and 0.07 J/kg (93%) in the MMC subgroup (–0.056 to –0.028; \( p = 0.001 \)), and 0.05 J/kg (106%) in the AMC subgroup (–0.067 to –0.038; \( p = 0.011 \)).

**TEMPORO–SPATIAL PARAMETERS**

With CFSOs, stride length increased in the entire group by a mean of 11cm (–0.17 to –0.06; \( p = 0.051 \)), and in the MMC subgroup (3.4–16.5, \( p = 0.007 \)). Positive work done at the ankle increased with CFSOs by a mean of 0.04 J/kg (86%) in the entire group and 0.07 J/kg (93%) in the MMC subgroup (–0.067 to –0.038; \( p = 0.001 \)). With CFSOs walking speed increased in the entire group by a mean of 11cm (–0.17 to –0.06; \( p = 0.001 \)). Positive work done at the ankle increased with CFSOs by a mean of 0.04 J/kg (86%) in the entire group and 0.07 J/kg (93%) in the MMC subgroup (–0.067 to –0.038; \( p = 0.001 \)).

**QUESTIONNAIRE RESPONSE**

Parents of 16/17 children answered the questionnaire. Fourteen of 16 reported that the children used CFSO regularly; of these, 2/16 used CFSOs more than the RO was used previously, and 12/16 used CFSOs equally as often as ROs were used previously. Two of 16 parents reported that the CFSO was not used regularly; these patients continued to use the RO. With use of CFSO (when compared with RO), the parents of:

- 16/16 children found that their child’s gait improved;
- 13/16 children reported that the walking velocity was faster and 3/16 perceived no difference;
- 6/16 children perceived the child’s acceptance as better, 0/16 as worse, 8/16 as equal, and 1/16 did not answer this question;
- 7/16 children perceived that the difficulty in putting on and taking off the CFSO was greater, and 9/16 perceived no difference.

**Discussion**

Participants with plantarflexion weakness have improved ankle kinetics using CFSOs compared with their former orthoses. Wolf et al. studied five patients and found that the carbon fibre spring contributes to approximately 60% of entire ankle power when the heel lifts from the ground. The present study did not measure directly whether the spring element stores power and returns energy during pre-swing. However, results confirm previously reported findings by the same authors that the carbon fibre spring improves temporo–spatial parameters as well as kinematic and kinetic parameters, although affecting the kinematic and kinetic parameters in different ways.

**Table II: Joint angles (˚), moments (N·cm/kg), joint power (W/kg), joint work done (×10² J/kg), and cadence, stride length, and walking speed with regular orthosis (RO) and carbon fibre spring orthosis (CFSO) in entire group, and in myelomeningocele (MMC) and arthrogryposis multiplex congenita (AMC) subgroups. Data are shown as means (SD). Statistically significant differences, i.e. when \( p < 0.05 \) and 95% confidence interval for mean difference did not contain zero, are indicated in bold text.**

<table>
<thead>
<tr>
<th>Angles (˚)</th>
<th>All (n=17)</th>
<th>RO</th>
<th>CFSO</th>
<th>MMC (n=12)</th>
<th>RO</th>
<th>CFSO</th>
<th>AMC (n=4)</th>
<th>RO</th>
<th>CFSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk</td>
<td>(Mean*)</td>
<td>0.7 (5.1)</td>
<td>1.8 (4.8)</td>
<td>-0.1 (5.4)</td>
<td>1.1 (4.9)</td>
<td>2.3 (4.2)</td>
<td>2.5 (4.5)</td>
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<tr>
<td>Hip</td>
<td>Extension</td>
<td>-3.0 (10.3)</td>
<td>-4.9 (9.7)</td>
<td>-1.8 (10.9)</td>
<td>-4.2 (9.9)</td>
<td>-7.8 (8.5)</td>
<td>-8.8 (9.2)</td>
<td></td>
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<tr>
<td>Knee</td>
<td>Flexion</td>
<td>8.1 (9.3)</td>
<td>5.2 (8.0)</td>
<td>10.6 (8.2)</td>
<td>6.4 (7.9)</td>
<td>3.7 (10.4)</td>
<td>2.5 (8.9)</td>
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<tr>
<td>Ankle</td>
<td>Dorsiflexion</td>
<td>55.8 (11.8)</td>
<td>60.4 (9.3)</td>
<td>57.4 (10.1)</td>
<td>61.6 (8.2)</td>
<td>52.5 (15.9)</td>
<td>56.2 (12.4)</td>
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<td></td>
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<tr>
<td>Moments, N·cm/kg</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hip</td>
<td>Flexion</td>
<td>-68.6 (25.1)</td>
<td>-76.4 (27.3)</td>
<td>-68.8 (25.6)</td>
<td>-78.7 (26.5)</td>
<td>-63.1 (25.6)</td>
<td>-58.8 (31.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee</td>
<td>Flexion</td>
<td>68.1 (31.5)</td>
<td>65.3 (29.2)</td>
<td>78.1 (25.7)</td>
<td>68.5 (27.8)</td>
<td>38.3 (30.5)</td>
<td>49.2 (25.5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ankle</td>
<td>Dorsiflexion</td>
<td>11.7 (15.6)</td>
<td>8.5 (14.8)</td>
<td>15.6 (14.4)</td>
<td>18.1 (14.6)</td>
<td>1.8 (15.7)</td>
<td>5.4 (13.9)</td>
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</tbody>
</table>

**Power, W/kg; and Work, ×10² J/kg**

| Hip       | Absorption (Max) | -1.77 (2.46) | -1.39 (0.78) | -1.95 (2.88) | -1.36 (0.55) | -1.12 (0.76) | -1.11 (0.85) |
| Generation | (Max)            | 1.76 (1.79) | 1.22 (0.65) | 1.97 (3.00) | 1.22 (0.62) | 1.09 (0.60) | 0.97 (0.60) |
| Knee      | Absorption (Max) | -1.76 (1.79) | -1.41 (0.80) | -2.06 (2.01) | -1.49 (0.74) | -0.96 (0.91) | -0.89 (0.65) |
| Generation | (Max)            | 1.50 (1.60) | 1.19 (0.61) | 1.78 (1.82) | 1.25 (0.62) | 0.85 (0.55) | 0.97 (0.54) |
| Ankle     | Absorption (Max) | -0.94 (1.45) | -1.00 (0.41) | -1.11 (1.70) | -1.12 (0.41) | -0.50 (0.23) | -0.64 (0.20) |
| Generation | (Max)            | 0.88 (0.59) | 1.28 (0.59) | 0.99 (0.64) | 1.48 (0.52) | 0.61 (0.37) | 0.66 (0.45) |
| Positive joint work | | 6.5 (3.6) | 10.6 (4.7) | 7.4 (3.7) | 12.6 (3.6) | 4.2 (2.2) | 5.2 (3.2) |
| Negative joint work | | 9.7 (3.8) | 14.5 (6.2) | 9.9 (3.6) | 16.9 (5.4) | -9.3 (4.7) | -8.8 (4.2) |
| Cadence, steps/min | 123 (13) | 119 (16) | 120 (13) | 118 (18) | 123 (12) | 123 (15) |
| Stride length, m | 1.13 (0.15) | 1.23 (0.13) | 1.15 (0.13) | 1.26 (0.08) | 1.05 (0.17) | 1.08 (0.13) |
| Walking speed, m/s | 1.14 (0.17) | 1.22 (0.18) | 1.14 (0.15) | 1.25 (0.17) | 1.06 (0.20) | 1.10 (0.13) |

*Mean throughout gait cycle. \(^{1}\)IC. = initial contact. \(^{2}\)Mean during stance.
among the participants. Positive work done at the ankle increased with use of CFSOs in all participants, but it was still lower than the value from the reference database of control children (0.25 J/kg) as reported by Gutierrez et al.\textsuperscript{17} from the same gait laboratory.

Subgrouping participants according to diagnostic group was performed to test whether CFSOs had a different influence on different patient populations. The main group of patients in this study consisted of children with MMC. One characteristic of this group is plantarflexor weakness which occurs with even a low lesion level, and is often associated with need of orthoses. The observed kinematic gait patterns in the trunk and hips were very similar to those reported in a previous study\textsuperscript{5} which described characteristic gait strategies in children with lumbo-sacral MMC. Using video observation, Michael\textsuperscript{18} found that the participants walking with CFSOs showed decreased lateral trunk sway compared with those using conventional orthoses. This could not be confirmed in the present study. Future studies may demonstrate whether excessive lateral trunk sway can be attenuated by increased push-off in the long term. It has been argued that, in individuals with MMC the presence of spasticity affects walking ability and should be taken into consideration when setting ambulatory goals.\textsuperscript{21} Three participants with MMC in the present study had spasticity in muscles spanning the ankle, but the spasticity was not considered to influence initial heel contact negatively, especially as the participants wore orthoses.

The current research group has not found any gait study of participants with AMC. Orthotic management with corrective splinting during growth is recommended to enable independence.\textsuperscript{19} As the child first starts to walk, KAFOs are often needed. Later, AFOs may be adequate, and with time the child may not need to use bracing.\textsuperscript{20} According to the clinical experiences of the researchers, and as suggested by the results of the current study, persons with AMC, if indicated, benefit from continuously wearing orthoses throughout adolescence and even possibly in adulthood.

The CFSO manufacturer has indicated that a standard carbon fibre spring can only be used when there are no contractures more than 10 to 15˚ from a neutral joint position in the ankle, knee, or hip. No plantarflexor contractures more than 10˚ from neutral were seen among the participants studied. Because the CFSO is constructed with a slightly plantarflexed position to achieve a tension on the spring during stance, there should generally not be a dorsiflexion contracture. One participant, however, with very strong dorsiflexors and paretic

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**Figure 2:** Sagittal plane kinematics (°), joint moments (N·m/kg), and joint powers (W/kg) in the hip, knee, and ankle with the regular orthosis (RO) and the carbon fibre spring orthosis (CFSO) in the entire group. Mean trace of all participants' right limbs is shown in this figure with arrows which illustrate differences found in entire group. Flex, flexion; Extens, extension; Plant, plantarflexion; Dors, dorsiflexion; Gen, generation; Abs, absorption.
plantarflexors showed bilateral 10° dorsiflexion contractures. This led to a careful application by the orthotist to avoid pressure on the ankle. Among the participants there was no knee flexion contracture more than 10° except the one 30° knee contracture which was unilateral and, therefore, made the use of the CFSO possible in this case. One participant with AMC had a knee flexion maximum of approximately 90° that did not interfere with use of the CFSO.

Orthesis design often has a limitation with respect to second and third ankle rockers. This might have been the case in the study by Õunpuu et al.9 who found more power generation in a barefoot condition than with a posterior-leaf spring AFO. This was supported by Thomson et al.9 who found that the only improvement in the MMC S1–2 group with AFOs was a reduction in excessive dorsiflexion, but that there was a reduction in power generation at the ankle. Six months after the present study’s data collection, a third child with muscle function grade 3 in the plantarflexors returned to wearing the RO, which was a hinged AFO with 15° plantarflexion range that enabled more power generation and faster walking speed than the CFSO.

Fourteen of the 16 participants who answered the questionnaire continued to wear the CFSO, whereas two participants, both with MMC, did not. One child chose the RO for cosmetic reasons and the other child who had had asymmetric muscle function began to experience pain in his subluxated hip and lower back which the researchers attributed to the longer steps he took with the CFSO. This confirms that criteria such as asymmetry in muscle strength and joint limitations to prescribe the CFSO are essential.

Conclusion

The CFSO was designed to integrate the plantarflexors’ moment-producing function and to control tibial advancement. In this tested population with plantarflexor weakness, gait analysis indicates that the CFSO was able to control tibial advancement, produce plantarflexor moment, supplement ankle power and work, and enable longer strides in almost all participants.

Acknowledgments

We would like to thank the children and their parents for participating in the study. This study was supported from Norrbacka-Eugenia Foundation, and Frimurare Barnhuset i Stockholm, Sweden.

References


List of abbreviations

AFO Ankle–foot orthosis
AMC Arthrogryposis multiplex congenita
CFSO Carbon fibre spring orthosis
KAFO Knee–ankle–foot orthosis
MMC Myelomeningocele
RO Regular orthosis