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Orthotic management in cerebral palsy

Beyin felcinde ortez uygulamaları

Demet OFLUOĞLU

Department of Physical Medicine and Rehabilitation, Çamlıca Alman Hospital, İstanbul

Children with cerebral palsy (CP) may have many musculoskeletal deformities depending on the type of CP. These deformities may result from *(i)* lack of motor control, *(ii)* abnormal biomechanical alignment, *(iii)* impairment in timing of muscle activation, *(iv)* impairment in normal agonist/antagonist muscle balance, *(v)* lack of power generation, and *(vi)* balance disorder. Rehabilitation, orthopedic surgical intervention, and additional orthotic management can prevent and correct these deformities. In this review, mainly lower extremity orthoses are described, with brief explanation on upper and spinal orthotic applications.

Key words: Ankle; cerebral palsy/rehabilitation; foot; gait; orthotic devices.

Beyin felçli (BF) çocuklarda, BF tipine göre değişen kas-iskelet sistemi deformiteleri ve sorunları bulunur. Bu deformiteler, *(i)* motor kontrol hasarı, *(ii)* anormal biyomekanik dizilim, *(iii)* kas aktivasyonu zamanlamasında bozukluk, *(iv)* normal agonist/antagonist kas dengesinde bozukluk, *(v)* güç üretme yetersizliği ve *(vi)* denge bozukluğu gibi sorunlardan kaynaklanabilir. Deformitelerin önlenmesinde ve düzeltilmesinde rehabilitasyon ve ortopedik cerrahi girişimler yanı sıra ilgili deformite için uygun ortez(ler) kullanılmaktadır. Bu yazıda temel olarak BF'de kullanılan alt ekstremite ortezleri ve kısaca üst ve spinal ortez uygulamaları anlatılmaktadır.

Anahtar sözcükler: Ayak bileği; beyin felci/rehabilitasyon; ayak; yürüme; ortotik cihaz.

Cerebral palsy (CP) is the dysfunction in the control of movement and posture that develops from non-progressive damage to the developing brain.[1] A child with CP often presents musculoskeletal system deformities. These deformities may arise from *(i)* lack of motor control, *(ii)* abnormal biomechanical alignment, *(iii)* compromised timing of muscle activation, *(iv)* compromised normal agonist/antagonist muscle balance, *(v)* lack of power generation, and *(vi)* balance disorder. In addition to rehabilitation and orthopedic surgical intervention, orthotic management can prevent and correct these deformities.

Orthoses are plastic or metal devices applied to support any segment of the body or inhibit/increase its movement. The aims of orthotic applications can be summarized as follows:

- Increase function;
- Prevent contracture and deformity development;
- Keep the extremities in a functional position;
- Stabilize the extremity and the body;
- Support the weak muscle functions;
- Increase selective motor control;
- Reduce spasticity;
- Protect the extremity in the postoperative period.

The key points of designing an efficient orthosis are understanding the development of musculoskeletal system and the internal and external forces affecting the underdeveloped musculoskeletal system, knowledge of ways of altering these forces, and recognition of the useful/harmful effects of ortho-

Correspondence / *Yazışma adresi*: Dr. Demet Ofluoğlu. Emniyet Mah., Yunus Emre Sok., No:6. Kısıklı, 34634 Üsküdar, İstanbul, Turkey.
Tel: +90 216 - 422 78 50 e-mail: dofluoglu@hotmail.com

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Table 1. Classification of orthoses

Lower extremity orthoses
- Foot orthoses (FO)
Inframalleolar foot orthoses
UCBL
Supramalleolar foot orthoses
Supramalleolar orthoses (SMO)
Dynamic AFO (DAFO)
- Ankle-foot orthoses (AFO)
Solid AFO
Hinged AFO
Ground force AFO (GRAFO)
Reflex AFO (Posterior leaf spring-PLSO)
- Knee-ankle-foot orthoses (KAFO)
- Hip-knee-ankle-foot orthoses (HKAFO)
Upper extremity orthoses
- Dynamic
- Static
Spinal orthoses

UCBL: University of California Biomechanics Laboratory.

sis. Table 1 shows the types of orthoses used for the above-mentioned targets. In CP, the lower extremity orthoses are the most commonly used devices.

In this article, lower extremity orthoses will be described in detail and upper and spinal orthotic applications will be briefly explained in a child with CP. Under the topic of lower extremity orthoses, shoe and orthopedic boot use will be explained, together with certain basic principles of lower extremity kinetics.

Lower extremity orthoses

In children with CP, many orthoses are used to improve walking skills. In order to achieve this goal, thorough knowledge is necessary about phases of walking, the forces affecting the body, and the effects of orthosis on movement, function, and walking. The force applied on the ground by a standing person is equal to the person's weight. According to the Newton's action-reaction law, the ground simultaneously exerts a force of the same magnitude in the opposite direction.[2] The force exerted by the ground is called ground reaction force (GRF). The magnitude and location of the GRF vary during the stepping phase of walking (Fig. 1). The conveying of the GRF through the joints generates a turning force –called the external momentum– applied to the joint. The external momentum is counterbalanced by the internal momentum generated by the muscles around the joints.

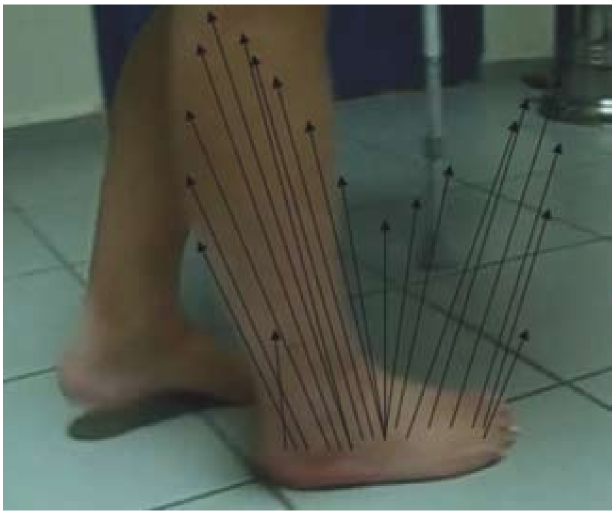

Fig. 1. Variations in the magnitude and place of the ground reaction force during walking.

During normal walk, the GRF exerted is close to the muscular line, which decreases the amount of force needed for stability. In cases of pathological walking or standing, however, the GRF applied on the joints is higher. In other words, the muscles are compelled to generate a higher amount of force to maintain stability.

An efficient lower extremity orthosis maintains GRF control in addition to three-point pressure control. For GRF control, the magnitude and direction of the GRF can be altered via an orthosis. The three-point principle involves three forces: one force is applied via the rotation axis, the second is applied from under the rotation axis, while the third force is applied over the rotation the axis on the opposite direction of the other two forces (Fig. 2). The longer the lever arm, the higher the control. Expanding the pressure spots is crucial to increase the comfort and minimize the pain of the patient.

Foot orthoses (FO)

These orthoses cannot provide efficient plantar and dorsiflexion control in the ankle (Fig. 3). These de-

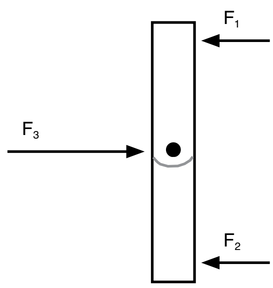

Fig. 2. The three-point principle in orthosis design.

Fig. 3. Foot orthosis (inframalleolar type).

vices are generally used in hypotonic children and in the presence of deformities like planovalgus/varus to maintain and control the alignment of the hindfoot, midfoot, and forefoot. They are classified in two groups according to their heights, as inframalleolar and supramalleolar orthoses.

Inframalleolar orthoses do not affect the sagittal-plane movements of the ankle. They are used in hypotonic or ataxic CP to control the moderate planovalgus deformity (Fig. 4). These orthoses are also known as UCBL, abbreviation of the University of California Biomechanics Laboratory. These orthoses are placed in shoes, after removing the insole of the shoe.[3]

Supramalleolar orthoses (SMO) look like half of ankle-foot orthoses (AFO), terminating at the proximal ankle. Hence, they have partial control on the sagittal plane movements of the ankle. They are used in cases of mediolateral instability of subtalar joints, midfoot instabilities causing varus/valgus deformity of the forefoot, in mild to moderate spasticity, and to reduce the hypertonic foot reflex activity.[4]

Supramalleolar orthoses used to reduce the hypertonic foot reflex activity are called dynamic AFOs (DAFO). Being quite thin and flexible, DAFOs maintain full contact, support and stabilize the dynamic arch of the foot. They allow limited movement on each of the three planes. In addition to reducing spastic reflexes and tonus, DAFOs allow movement via maximum midline stability, maintaining movement control.[5] Romkes and Brunner[6] compared the efficiency of DAFO and hinged AFO in CP children with spastic equinus deformity and showed that, unlike hinged AFO, DAFO did not improve spastic equinus deformity.

Fig. 4. Planovalgus deformity in a child with hypotonic cerebral palsy. It can be controlled by an inframalleolar orthosis with medial arc support.

General indications and contraindications of foot orthoses are shown in Table 2.

Ankle-foot orthoses (AFO)

In general, AFOs are used to prevent deformity, restore and maintain normal joint alignment and support joint mechanics, improve range of motion in appropriate cases, and to facilitate and improve the

Table 2. Indications and contraindications of foot orthoses

Indications		Contraindications	
1	Mediolateral instabilities of the subtalar joints	1	Insufficient voluntary dorsiflexion control
2	Midfoot deformity resulting in varus/valgus deformity of the forefoot	2	Moderate to severe spasticity
		3	Fixed equinus deformity
3	Mild to moderate spasticity	4	Insufficient heel strike
4	Hypertonic reflex foot activity	5	Lack of ambulation

Table 3. Indications of solid AFO use in cerebral palsy

Nonambulatory children	Ambulatory children
Decrease spasticity	Reduce severe spasticity
Prevent deformity and contracture	At the stance phase: increase stability, prepare for the first contact and swing phase
Maintain stability of the limbs for standing	
Maintain postoperative stability	At the swing phase: help foot's elevation

functions. There are various AFO designs to be prescribed for individual needs and purpose.

Solid AFO. They are hinge-free orthoses made of rigid, inflexible material, extending just up to the distal of the fibula head, and to the metatarsus heads or toe tips proximally, with sufficient lateral height to provide varus/valgus control (Fig. 5a). The main indications of solid AFOs in nonambulatory children are to reduce spasticity, prevent deformity and contractures, and maintain stability in the postoperative period. In ambulatory children, on the other hand, solid AFOs are used to reduce severe spasticity, increase stability during the stance phase, prepare for the first contact and help foot's elevation during the swing phase (Table 3). There are numerous studies on the effects of AFO use on the walking pattern of these children. While some studies found no beneficial effect of AFOs on the walking pattern, some studies showed that some of the general parameters of walking improved with the use of an AFO. Considering that AFOs would increase the pace, step length, the single support phase and decrease the cadence, White et al.[7] studied the effects of various types of AFOs on walking in 115 children with CP. Their study included both diplegic and hemiparetic CP cases and two types of solid AFOs and two types of hinged AFOs were used. Gait analyses showed increased walking pace, step length, and single support phase in all children regardless of the AFO type. A decrease in cadence was noted, but this was not statistically significant. Improvements in the walking pace were similar with solid and hinged AFOs. It was concluded that increased step length might be due to increased ankle stability provided by the AFOs or to a pendulum effect with increased weight at the tip of the foot. Similarly, Radtka et al.[8] investigated the effects of solid and hinged AFOs on walking in spastic diplegic children with CP. Gait analyses with both AFO types showed increased step length, decreased plantar flexion of the abnormal ankle during the first contact, and normalization of plantar flexion moments at the end of the stance phase. Moreover, the use of a hinged AFO was associated with increased ankle dorsiflexion at the completion of the stance phase and a greater ankle power generation prior to the swing phase

Hinged AFO. Unlike solid AFOs, these orthoses incorporate a hinge compatible to the anatomic ankle axis (Fig. 5b). They are usually used in ambulatory, active children, who can walk downwards and upwards, and use the stairs. In these children, hinged AFO increases stance stability, normalizes the first contact, controls knee instability, and helps foot elevation during the swing phase. A prerequisite of hinged AFO use is to have at least 5° of passive ankle joint dorsiflexion. Hinged AFOs prevent plantar flexion of the ankle, allow dorsiflexion, and thus, facilitate the second rocker during the stance phase, and increase toe elevation enabling energy absorption during the transition from

Fig. 5. **(a)** Anterior and lateral views of a solid ankle-foot orthosis (AFO). **(b)** Hinged AFO. **(c)** Ground reaction AFO. **(d)** Reflex AFO.

the second to the third rocker. Furthermore, they maintain maximal improvement in the knee and hip by normalizing the plantar flexion-knee extension of the pathological ankle. Increased dorsiflexion angle by the hinged AFO also provides control of the genu recurvatum deformity. A solid AFO has the disadvantage of causing disruption of toe clearance, whereas a dynamic AFO (a hinged AFO) improves toe clearance by allowing ankle dorsiflexion.[9]

In addition to improving angular parameters of the joints during gait (turning the first contact point from the toe tip to heel strike), hinged AFOs improve gait parameters through influence on muscular activities. They decrease activity of various proximal leg muscles including semitendinosus, biceps femoris, vastus medialis, and especially tibialis anterior.[10] Hinged AFOs also correct equinus deformity and provide an energy-efficient gait in children with CP.[11]

Ground reaction AFO (GRAFO). These orthoses look like solid AFOs, but have a closed top surface. They prevent forward translation of the tibia during stance and creates extension momentum on the knee. (Fig. 5c).[12] It decreases the energy required by the quadriceps muscle. It is used in CP children with a bent-knee gait (increased knee flexion and ankle dorsiflexion during the stance phase), but it cannot be used in cases with flexion contractures greater than 10° in the knee and hip. For a well-tolerated use of the device, the ankle must have a dorsiflexion of at least up to the neutral position while the knee is in extension.[13]

Non-hinged AFOs including both solid AFOs and GRAFOs substantially limit the ankle movements. Therefore, their use in ambulatory children may be problematic. There are hinged GRAFO models enabling plantar flexion, but limiting dorsiflexion. These models are generally used after lengthening operations, aiming to increase muscle strength and to prepare the patient for a orthosis-free gait.[13]

Reflex AFO (Posterior leaf spring orthoses- PLSO). These are solid orthoses with lateral ends terminating at the posterior malleolus. Despite its hinge-free appearance, the mechanics of the device enables passive dorsiflexion at the stance phase (Fig. 5d). It prevents drop foot during the swing phase. It can be used in children with dynamic equinus deformity and mild spasticity. These orthoses are not beneficial in moderate-severe spasticity, fixed equinus deformity, and mediolateral instability.

A study on the effects of solid, hinged, and reflex AFOs on the proximal joint dynamics, energy expenditure, and functional skill performance in spastic diplegic children showed that all AFO types normalized ankle movements at the stance phase.[14] Furthermore, all AFO types increased step length, decreased cadence, reduced energy expenditure during gait, with additional improvements in walking, running, jumping, and upper extremity skills. On the other hand, no beneficial effect was observed on the quality of motor skills and ambulation independence.

Knee-ankle-foot orthoses (KAFO)

These orthoses are not used for ambulatory purposes in CP. The aims of using knee orthoses are: *(i)* to protect joint range of motion and support weak muscles after multi-level lower extremity operations, *(ii)* increase knee extension until antigravity control during stance or gait is maintained, or *(iii)* control hyperextension of the knee during gait.[4,13] Their use is often limited, since the knee control is generally maintained by the AFOs based on the closed kinetic chain principle. The most commonly used type in CP is the knee immobilizer used to limit knee movements in the postoperative period (Fig. 6).

Hip-knee-ankle-foot (HKAFO) and hip orthoses. Hip orthoses are generally used in nonambulatory children to protect and improve the range of motion of the hip joint, and to position the hip to eliminate risks for subluxation and dislocation.[13] There are some hip orthoses used to facilitate ambulation, but they are rarely used. These are especially used to decrease hyperadduction of the hip and increase sitting balance in children with scissoring gait. Figure 7 shows how a hip abduction device hinders scissoring during stance and improves sitting balance.

Use of orthopedic boots

In general, orthopedic boots are preferred to orthoses. However, orthopedic boots do not prevent equinus de-

Fig. 6. Knee immobilizer.

Fig. 7. **(a)** A child with diplegic cerebral palsy without support (left) and wearing the device that hinders hyperadduction of the hip (right). **(b)** The same child sitting without support (poor sitting balance) and with hyperabduction device.

formity. Figure 8 shows the extent of wearing on the upper side of the orthopedic boots used for only one week by a diplegic child with CP. Orthopedic boots are used only in spasticity-free children with impaired mediolateral stability (valgus/varus deformity) with addition of lateral or medial wedges. However, these boots are insufficient in severe mediolateral instability.

Use of shoes with orthoses

Shoe wear with or without an orthosis is important for children with CP. Usually parents inquire about the shoe type their children should be using. Shoes affect foot movements of all directions via the GRF. An appropriate shoe must support normal external joint movements and should not lead to excessive muscle activity. The qualities of a proper shoe are: *(i)* a non-skid outsole; *(ii)* a wide toe box and a lace panel wide enough to expose the foot and toes; *(iii)* enfolding the foot (or the orthosis if present) tight enough to prevent back and forth movement of the foot inside the shoe; *(iv)* a removable insole (especially if the shoe is to be used with an orthosis).

Fig. 8. Orthopedic boots. Although new, the upper sides indicated by arrows are worn due to deficiency in preventing equinus deformity.

It should be borne in mind that the insole of the shoe may affect the rockers at the stance phase. For instance, when a solid AFO with 90° plantar flexion stop is worn in a shoe with a hard heel, the leverage effect accelerates knee flexion. This would decrease the child's control during the early stance. Alternately, a soft-heeled outsole decreases the flexion moment by absorbing the GRF during the first rocker; and thus increases the child's control. Likewise, the heel height affects knee movements. When a solid AFO set at 0° dorsiflexion is worn with a medium-height heel, the dorsiflexion increases by a couple of degrees, resulting in increased knee flexion moment. Furthermore, manual modifications on the shoe (rocker outsole) facilitate the third rocker of the foot. Such a modification especially in solid AFO use helps an efficient toe clearance.

Fig. 9. **(a)** Upper extremity problems in cerebral palsy: Flexion deformity of the wrist and thumb-in-palm deformity. **(b)** Resting orthosis that keeps the hand-wrist in the neutral position.

Fig. 10. **(a)** Ring orthosis and **(b)** its effect on functionality in a child with hemiparetic cerebral palsy with finger flexion contracture.

Upper extremity orthoses

Common upper extremity problems in CP are flexion contractures of the fingers and wrist due to spasticity, pronation deformity of the forearm, thumb-in-palm deformity (Fig. 9a), and hand-related disabilities. While upper extremity orthoses are inadequate in overcoming these problems, they can be used especially to prevent the development and progression of deformities, formation of contracture, and to assist rest in the postoperative period.[4,13]

Orthoses may not always boost the functionality of the upper extremity. The use of orthosis is generally limited to night wear. Therefore, resting orthoses are preferred for use at night or during the postoperative period (Fig. 9b). Sometimes even a ring orthosis (Fig. 10a) can revive functionality. Figure 10b demonstrates how a hemiparetic child with CP, having difficulty in using the keyboard due to finger flexion deformity can overcome the problem with the help of a ring orthosis. Another functional orthosis is the thumb opposition splint (Fig. 11).

Use of large-scale orthoses should be avoided in CP, in particular in the upper extremity. Furthermore, the orthoses should not cover the palm and the volar part of the fingers, because orthoses swathing the palmar part hinder tactile and sense-related stimuli, which may result in negligence in the use of the hand.[13]

Fig. 11. Thumb opposition splint.

Spinal orthoses

Spinal orthoses used in CP are thoracolumbosacral devices used to support sitting in cases who cannot sit independently (Fig. 12a). Sometimes, sitting is also supported by using a sitting mold (Fig. 12b). Considering the beneficial use of orthosis in adolescent idiopathic scoliosis, spinal orthoses were used in children with CP, but were found not to improve scoliosis.[13]

Fig. 12. **(a)** A thoracolumbosacral type spinal orthosis used to support sitting in cerebral palsy. **(b)** Sitting mold and its application.

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