MONITORING ORTHOTIC INTERVENTION ON THE FLAT FOOT

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Abstract. *Introduction: The flat foot favours the appearance of generalised lower limb disorders due to overload. Objectives: The aim of the study is to monitor changes in the biomechanical parameters of the flat foot during a complex intervention. Methodology: The study included an experimental group of 20 participants (average age: 12, average weight: 48.18 kg) diagnosed with bilateral flat feet. Biomechanical parameters of the flat foot were evaluated with the RSscan pressure plate that was used to measure the active contact area and maximum force (Fmax) for 10 areas of the foot. Participants were assessed at two moments (T1 and T2), at a 6-month interval. Treatment involved an orthotic intervention and a physical therapy programme performed throughout this period. Results: There are higher average values at the moment T1 for the right foot in the following contact areas: Midfoot - 33.6 cm^2, Medial heel - 15.42 cm^2, Metatarsal 2 - 10.67 cm^2, Metatarsal 1 - 11.14 cm^2; at T2, a decrease of 2% is noticed for all contact areas. At the moment T1, higher average values are recorded for the left foot in the following contact areas: Midfoot - 36.42 cm^2, Medial heel - 14.55 cm^2, Metatarsal 2 - 9.15 cm^2, Metatarsal 1 - 8.62 cm^2; at T2, a decrease of 6% is noticed for all contact areas. Results indicate a favourable bilateral development. Conclusion: There are significant differences between the two moments. The analysis of biomechanical parameters helps to monitor changes in the flat foot under the specific treatment intervention.*

Keywords: *kinetics, biomechanical parameters, flat foot, orthosis*

Introduction

The human foot has developed over time, specialising in fulfilling two divergent functions: static balance and propulsion. These objectives are met by a complex osteoarticular structure that forms different arches. The foot is a complex anatomical structure that acts to transmit force between the lower limbs and the ground, allowing stable gait and stance.

Foot arches have an important function in dispersing the forces applied to the foot depending on the type of activity performed at a given time. Variation in height of the arch is achieved by the contraction or relaxation of tibial muscles. The medial longitudinal arch has an important role in the propulsion phase of walking, the transverse plantar arch is important during rest (without loading), and the anterior metatarsal plantar arch disappears in walking conditions during the loading phase (prior to propulsion).

The medial longitudinal arch consists of the calcaneus, talus and navicular bones, the three cuneiform bones and the first three metatarsals. The talus is located at the top of the arch and provides stability by acting as a wedge (lever) between the calcaneus and the navicular.

Dawe and Davis (2011) state that "during gait the foot functions as a flexible shock-absorber, deforming to uneven surfaces before undergoing a series of biomechanical changes which allow it to act as a rigid lever to exert force" (p. 279).

According to Leardini et al. (2014), any injury or neuromuscular disorder of the foot leads to dysfunction, causing degradation, instability and affecting normal gait.

The flat foot, also known as pes planus, can be defined as a static foot disorder characterised by the collapse of the medial longitudinal arch, eversion of the hindfoot and abduction of the loaded forefoot.

There are two types of flat feet, namely rigid and flexible. The rigid form is a congenital flat foot that is often associated with a spastic deformity. The flexible form is described as a lax joint complex that leads to the development of the valgus flat foot. The incidence of rigid flat foot is 1% and decreases quality of life, often requiring surgery and orthotics. Flexible pes planus affects between 2% and 23% of the adult population, with prognoses and pathways remaining predominantly unclear, vague and controversial.

Vittore et al. (2009) found that the incidence of flexible flat foot was between 21% and 57% in children aged 2 to 6 years but decreased to 13.4% to 27.6% in primary school students. In general, babies are born with flexible flat feet (El et al., 2006); their foot arch quickly develops between 2 and 6 years of age (Volpon, 1994) and becomes structurally mature by the age of 12-13 years (Garcia-Rodriguez et al., 1999).

Plantar morphology allows identifying two types of flat feet according to their grading: Grade 1 - Supporting the midfoot more than one third of the length of the foot, with a decrease in external support. Grade 2 - Contact on the outer and inner edges of the foot but no contact on the medial longitudinal arch. Grade 3 - The medial longitudinal arch completely disappears; the width of the longitudinal plantar arch is equal to the width of the transverse (metatarsal) plantar arch. Grade 4 - The footprint shows the presence of an additional contact area in medial part of the midfoot. (Moreno de la Fuente, 2009)

Factors that contribute to the appearance of the flat foot:

1. Low ankle flexibility;
2. Weakness of the foot muscles;
3. Weakness of the ankle muscles;
4. Mechanics of posture and gait;
5. Weakness of the hip muscles;
6. Supination of the foot.

The therapeutic approach to the flat foot is extremely complex and involves a double intervention: physical therapy and orthotics.

According to Periyasamy and Anand (2013), a better result can be obtained by combining leg exercises and orthoses than using a single intervention. The above authors state that this combination of specific exercises and orthoses improves the foot posture and corrects the collapsed medial longitudinal arch of the foot during gait.

Corrective orthosis is performed with static orthoses that are widely used and promoted in sport as well as in the treatment of congenital and neuropathic diseases of the foot. They are used in many sports but particularly in athletics not only for static foot corrections but especially for one of their most important properties, that of absorbing shocks and reducing the force transmission to the foot and the lower limb chain. Several authors have noted that, in the current clinical climate, the science of orthosis design and function appears to be somewhat overshadowed by the widespread prescription of static orthoses, mainly in sport (Brodsky et al., 2007).

Rigid foot orthoses are prescribed in the conservative treatment of the flat foot (Landorf & Keenan, 2000). There is no general classification of the types of static foot correction orthoses, and the tendency is to recommend them without too much differentiation between prefabricated and customised orthoses (adapted to static foot pathology) (Landorf et al., 2001).

Through the variety of materials and manufacturing processes, static foot correction orthoses are mainly aimed at restoring the alignment of the foot joints, changing the lower-limb movement patterns during gait and, most importantly, reducing the pathology associated with the lower limbs (Collins et al., 2007; McMillan & Payne, 2008).

One hypothesis regarding the mechanism by which foot orthoses have a clinical effect is the influence of muscle activity, and a lot of studies demonstrate this intervention. For example, Abbas and Kahtan (2018) used the force plate to make a comparison between rigid and flexible foot orthoses, noticing that flat foot orthoses made of soft (flexible) material were better than rigid material orthoses due to pressure reduction. The two authors state that the durability of a material is usually assessed by fatigue tests. In orthotic therapy, durability is more appropriately determined by the number of cycles until the loss of performance, a condition that may occur before the complete deterioration of the material.

In this paper, we did not aim to investigate through durability tests which of the two types of orthoses would be more efficient but to monitor the effectiveness of corrective orthoses by means of the RSscan pressure plate, taking the contact area as a main indicator.

In flat foot research, lots of questions arise about the complexity of this disorder, its symptoms and how the types of flat feet influence disability. If there are many types of flat feet, do all of them result in a collapsed longitudinal medial arch? These questions can generate multiple research topics.

Methodology

Participants

The study included a group of 20 participants diagnosed with bilateral flat feet (average age: 12, average weight: 48.18 kg). The monitoring period was between September 2020 and February 2021.

Biomechanical and morpho-functional evaluation

Biomechanical parameters of the flat foot were evaluated with the RSscan pressure plate (Figure 1) that was used to measure the active contact area and maximum force (Fmax) for 10 areas of the foot: Medial heel, Lateral heel, Midfoot (toes, hallux) and Metatarsal. Participants were assessed at two moments (T1 and T2), at a 6-month interval. During this period, they wore customised flexible static foot correction orthoses and performed a flat-foot kinetic programme.

Moment T1: without orthotic intervention and kinetic programme; moment T2: after wearing customised static foot correction orthoses and performing the flat-foot kinetic programme/

Figure 1. RSscan pressure plate

Visual evaluation of the footprint is performed with a pedograph, which indicates plantar pressures by the size and density of an inked area. The resulting footprint reflects the magnitude of the longitudinal medial arch (Figure 2).

Figure 2. Flat foot evaluation – Pedograph

Morpho-functional evaluation allowed the identification of differences between flexible and rigid flat feet as follows:

Flexible flat foot:

- disappearance of the medial longitudinal arch during gait and stance tasks;
- reappearance of the medial longitudinal arch at rest without loading;
- Jack's Test (hallux hyperextension): involves the hallux dorsiflexion performed by the examiner while the patient stands in a relaxed double-leg position; in a normal test, the hallux dorsiflexion is performed freely with minimal resistance, while the hallux movement is associated with a tightening and raising of the medial longitudinal arch;
- Standing Heel-Rise Test: the patient lifts the heel off the ground and returns to the starting position repeatedly; in the case of a flexible flat foot, the patient's heel will move into the varus position.

Rigid flat foot:

- Jack's Test (hallux hyperextension): non-appearance of the medial longitudinal arch when the examiner hyperextends the patient's hallux;
- Standing Heel-Rise Test: in the case of a rigid flat foot, the patient's heel does not move into the varus position.

Therapeutic approach

Orthotics

In this study, we used two types of orthoses for flat feet, namely made of soft (flexible) and rigid materials (Figure 3a2, Figure 4, Figure 4a, Figure 5), which were manufactured for patients with bilateral flat feet (Figure 3a1, Figure 3a3).

Figure 3a1. Flat feet

Figure 3a2. Flat feet – Rigid orthoses

Figure 3a3. Flat foot radiography

Rigid flat foot orthoses are made of thermoformable materials, have a low degree of elasticity and are especially indicated for patients with above-average height and weight, in whose case the compression force and the degree of wear are high (Figure 4, Figure 4a).

Figure 4. Rigid orthoses – Flat foot

Figure 4a. Rigid orthosis – Flat foot

Flexible orthoses are made of materials of higher density and elasticity; they are indicated for people with grade 1 and grade 2 flat feet, active people and especially athletes (Figure 5).

Figure 5. Flexible orthosis

The instructions specified that the orthoses should be used throughout the day, especially when performing sports activities to prevent muscle fatigue and thus reduce the risk of injury.

Physical therapy had the following goals:

1. Toning, in conditions of shortened plantar muscles;
2. Restoring foot flexibility;
3. Fighting foot muscle contractions.

All participants in the study performed two weekly physical therapy sessions that included specific correction exercises for the flat foot. The duration of a session was 45 minutes.

Kinetic programmes for flat foot correction (Cotoman, 2005):

- Exercises to increase flexibility

Passive exercises: global movement of the ankle and all joints of the foot. Stretching exercises for the gastrocnemius-soleus complex and peroneus brevis muscle (to induce varus and foot adduction)

- Exercises for foot muscles

The tibialis posterior muscle is often suspected of weakness in people with flat feet. One of the best exercises for toning both the tibialis posterior muscle (Figure 7) and the entire leg extensors is “lifting on the toes” (or “rising on the heels”) (Figure 6).

Figure 6. “Lifting on the toes” exercise

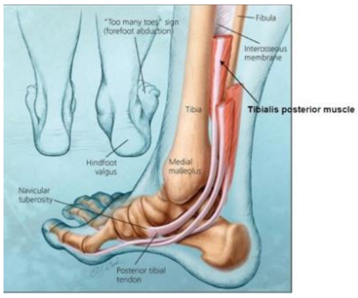

Figure 7. Tibialis posterior muscle

These exercises aimed to increase muscle tone especially in the tibialis anterior and posterior, flexor hallucis longus (to neutralise the valgus), plantar interosseous and intrinsic abductor hallucis muscles (to prevent flattening of the anterior arch).

Global activation and movement of the muscles involved in maintaining the medial longitudinal arch and the varus (with and without load) were achieved through one-leg swinging exercises and toe-grip and walking exercises.

Proprioception exercises used walking on tiptoes (Figure 6) and heels (Figure 8) in 3 sets of 15-20 repetitions; balance exercises involved single-leg support (Figure 9, Figure 10) (to cause the foot to hollow after the dynamic forefoot pronation) in 3 sets of 10 repetitions (for 10-15 seconds) (Figure 10); tilted-plane and ramp-climbing exercises were performed in 3 sets of 10 repetitions (Figure 11).

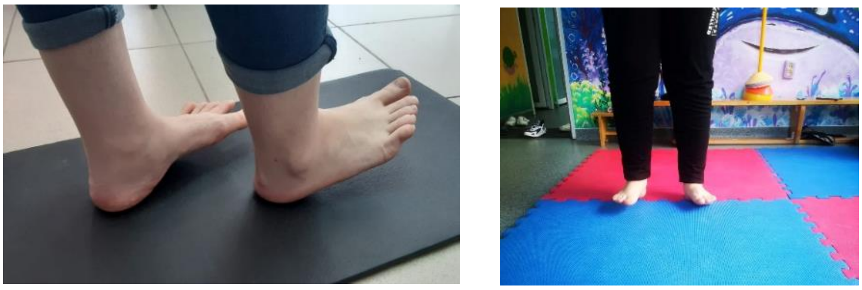

Figure 8. “Walking on the heels” exercises

Figure 9. Single-leg support exercises

Figure 10. Balance exercises

Figure 11. Ramp-climbing exercises

Results

There are higher average values at the moment T1 for the right foot in the following contact areas: Midfoot - 33.6 cm^2, Medial heel - 15.42 cm^2, Metatarsal 2 - 10.67 cm^2, Metatarsal 1 - 11.14 cm^2. At T2, also for the right foot, a decrease of 2% is noticed for all contact areas, with the largest share in the following areas: Midfoot - 5%, Medial heel - 2%, Lateral heel - 3%, Metatarsal 5 - 2%. (Table 1, Figure 12, Figure 13)

At the moment T1, higher average values are recorded for the left foot in the following contact areas: Midfoot - 36.42 cm^2, Medial heel - 14.55 cm^2, Metatarsal 2 - 9.15 cm^2, Metatarsal 1 - 8.62 cm^2. At T2, also for the left foot, a decrease of 6% is noticed for all contact areas, with the largest share in the following areas: Midfoot - 6%, Medial heel - 3%, Lateral heel - 3%, Metatarsals 1 and 2 - 8%, Fingers 2-5 - 17%. (Table 1, Figure 12, Figure 13)

Results indicate a favourable bilateral development that is more pronounced for the left foot.

Table 1. *Average values for the right and left foot contact areas*

Foot areas	Average values right foot T1	Average values right foot T2	Average values left foot T1	Average values left foot T2
Weight [kg]	47.5	49	47.4	49
Age	11.8	12.3	11.8	12.3
Height [cm]	155.6	157.5	155.6	157.5
Toe 1 [cm^2]	11.5	11.5	13.6	13.1
Toes 2-5 [cm^2]	13	12.9	11.1	9.5
Meta 1 [cm^2]	11.1	11.1	8.6	8
Meta 2 [cm^2]	10.7	10.9	9.2	8.5
Meta 3 [cm^2]	8.6	9	7.7	7.6
Meta 4 [cm^2]	9.3	9.3	8.5	8
Meta 5 [cm^2]	7.9	7.7	10.4	9.9
Midfoot [cm^2]	33.6	31.9	36.4	34.5
Medial heel [cm^2]	15.4	15.1	14.6	14.1
Lateral heel [cm^2]	13.7	13.4	12.8	12.4

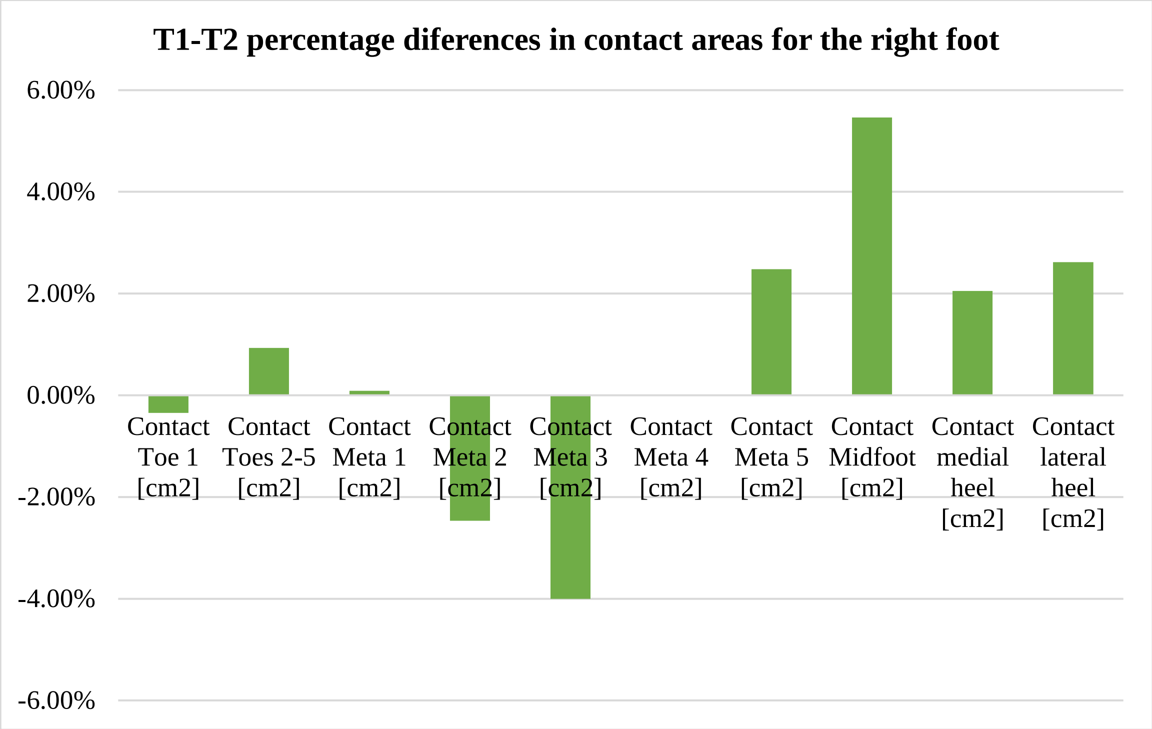

Figure 12. T1-T2 percentage differences in contact areas for the right foot

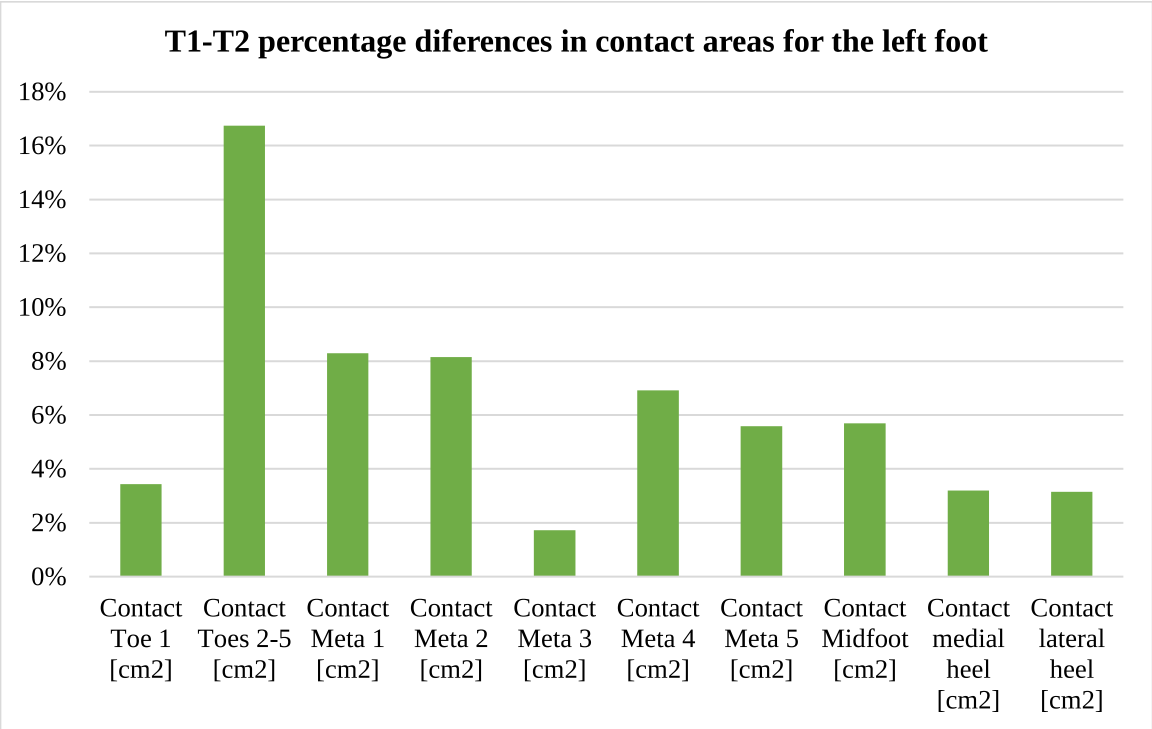

Figure 13. T1-T2 percentage differences in contact areas for the left foot

Discussion

The results of our study are consistent with other research, showing that there are kinetic and kinematic changes in the pes planus compared to the normal foot. These pathological mechanical alterations include greater eversion of the hindfoot, greater plantar flexion of the forefoot, greater abduction of the forefoot, less adduction of the forefoot, greater tibial internal rotation and greater subtalar eversion. All these altered movement patterns affect normal gait and balance, thus increasing the risk of injury.

In addition, during the single-leg support phase, there is a decrease in the activity of the abductor hallucis, medial gastrocnemius, tibialis anterior and vastus medialis muscles. Given that the abductor hallucis acts as a dynamic stabiliser of the lateral medial arch, a lower activity of this muscle can lead to decreased biomechanical capacity, poor absorption of external forces and postural instability, which eventually leads to injury (Jung, Koh, & Kwon, 2011; Kim, 2015).

Much more abnormal foot alignment involves weakness of the intrinsic muscles (abductor hallucis, flexor hallucis, flexor digitorum brevis and interosseous ones), causing musculoskeletal dysfunction and overload injuries (Jung et al., 2011).

Our research is in line with that conducted by Kim et al. (2015) as regards the areas of the second and third metatarsals, where concentrated pressures are reported for patients with flat feet compared to the control group with normal arch of the foot during dynamic activities such as walking.

Besides, the altered plantar pressure observed during standing causes poor postural stability, which subsequently leads to a higher incidence of lower extremity injuries.

Although some people do not need intervention, this disorder should be carefully approached when associated with pain and functional problems. There are several predefined methods of flat foot management, which have their advantages and disadvantages; some methods can be used anywhere, while others require extensive measurements and technology to evaluate them for therapeutic interventions.

Therapeutic management is chosen depending on each patient’s disease severity, situation, needs and accessibility to technology and facilities.

According to Jane MacKenzie et al. (2012), there is limited evidence on the effectiveness of non-surgical interventions for paediatric flexible flat foot, the authors concluding that complex future research is needed to properly assess the type of flat foot, use effective measurements with validated indicators, use control groups to monitor separately the effectiveness of orthopaedic footwear, make comparisons between age groups, provide clearer evidence and prospective follow-up over a longer period of time.

Expectations about the effects of foot orthoses on lower limb biomechanics are found in the systematic review conducted by Murley et al. (2009), who investigated the effect of foot posture, foot orthoses and footwear on lower limb muscle activity during walking and running and concluded that “foot orthoses increase activation of tibialis anterior and peroneus longus” (p. 172); they also stated that “statistically significant changes in electromyographic activation” (p. 172) were reported in most studies (Tomaro & Burdett, 1993; Tome et al., 2006; Mündermann et al., 2006).

In their study, Jafarnezhadgero et al. (2020) examined the effects of four-month wearing of correction orthoses on children with flat feet, demonstrating that the coordination function could be useful to improve the exercise programme for flat foot correction. Kirby (2017) presents the evolution of foot orthoses in sports, making an analysis of experimental evidence on their effectiveness and concluding that they could improve the individual's postural stability. Hertel et al. (2001) stated that postural stability was more reduced when orthopaedic patients performed inversion/eversion rather than medial/lateral movements on the plate, observing unwanted movements of the foot and ankle joint or even restricted movements and/ or limited ability of the mechanoreceptors to detect movement disturbances, which were apparently masked by corrective orthoses. Also related to the fact that static foot orthoses can improve postural stability, Kirby (2017) observes that individuals performing the single-leg balance test also show a significant decrease in forward trunk deviation. In the study by Rome and Brown (2004) involving patients with grade 3 and grade 4 flat feet, static foot orthoses reduced the medial-lateral foot deviation during standing, thus indicating improved postural balance.

Conclusion

The results of our study are consistent with those obtained by other authors and highlight the need for a complex approach to the flat foot not only regarding physical therapy but especially the complex evaluation of this disorder, the prescription of orthoses and the use of scientific evidence-based kinetics.

It is noted that the analysis of contact areas in terms of plantar pressure distribution is an element that allows better knowledge of the behaviour of each plantar area by its own weight.

Our study reveals that the main improvement is the expansion of the overall contact area.

Customised static foot correction orthoses can change interarticular coordination and its variability during gait and can improve the stability of the ankle-foot system.

Foot orthoses improve postural control skills.

The kinetic programme and the use of customised corrective orthoses prove their usefulness in the flat foot management.

We believe that the monitoring of the complex orthotic and kinetic intervention using the biomechanical analysis of the foot at a maximum interval of 6 months allows the modulation of the intervention.

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