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Biomechanical Mechanisms and Clinical Efficacy of Ankle-Foot Orthoses in the Treatment of Flat Feet

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Abstract: Flatfoot, featuring medial longitudinal arch collapse, causes biomechanical alterations and functional impairment. Ankle-foot orthoses (AFOs) serve as a key conservative treatment, correcting deformities through multiple biomechanical pathways. This review summarizes recent advances in AFO mechanisms, efficacy, and design optimization. Evidence supports tailored AFO selection based on individual needs, while future research should prioritize 3D-printed customization and long-term studies to confirm their role in delaying disease progression.
Keywords: Ankle-foot orthosis; Flat feet; Biomechanical mechanisms; Clinical efficacy

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1. Introduction

Flatfoot, characterized by arch collapse, frequently causes pain and functional impairment. Ankle-foot orthoses (AFOs) are increasingly used as a conservative treatment, yet a systematic understanding of their mechanisms and selection criteria remains limited. This review adopts a biomechanical perspective to analyze how AFOs correct deformity and restore musculoskeletal balance. It compares customized AFO designs, such as hinged, lateral extension, and UCBL types, for specific populations, including pediatric and PTTD patients, and proposes an individualized framework to support evidence-based application and potentially delay surgery.

2. Overview of flatfoot disorders

2.1. Definition and epidemiology of flat feet

Flatfoot is a common deformity defined by the collapse of the medial longitudinal arch, leading to abnormal biomechanics and impairment [1]. It is classified as congenital or acquired. Prevalence is approximately 20% in adults, with about half experiencing symptoms like pain and walking difficulty.

2.2. Clinical manifestations and pathological mechanisms of flat feet

Primary clinical manifestations include foot pain, fatigue, arch collapse, and hindfoot valgus. These can impair function and lead to joint degeneration. Pathological mechanisms involve bony abnormalities, ligament laxity, and muscle imbalance, with PTTD being a leading cause of acquired flatfoot in adults, leading to progressive deformity [2].

2.3. Overview of treatment methods

Treatment includes conservative and surgical options. Conservative management, such as physical therapy and orthotic use, is first-line. The ankle-foot orthosis (AFO) is a key intervention for correcting alignment, alleviating pain, and improving function. Various AFO types are used, though their efficacy and selection require evaluation [3].

3. Biomechanical mechanism of action of AFO

AFO improves flatfoot deformity through multiple biomechanical mechanisms, primarily encompassing the following three aspects.

3.1. Increased hindfoot pronation

Patients with flat feet often experience hindfoot valgus deformity, which leads to abnormal foot biomechanics and increases stress on the foot and ankle joints. AFOs help restore normal foot alignment by restricting rearfoot eversion. Research indicates that custom hinged AFOs can increase rearfoot inversion angles by 2.6–4.1° while reducing calcaneal eversion [4]. This design maintains arch support while allowing controlled range of motion for natural foot movement, thereby alleviating pain and functional impairment caused by rearfoot eversion.

3.2. Correction of forefoot abduction

Some individuals with flat feet experience forefoot abduction, which further exacerbates biomechanical abnormalities in the foot. AFOs with lateral extensions effectively correct forefoot abduction deformities by providing additional lateral support. Research confirms that compared to standard AFOs, AFOs with lateral extensions significantly increase forefoot adduction by 2.6° ($p = 0.02$) and achieve a 4.1° improvement over barefoot conditions ($p < 0.01$), whereas standard AFOs show no such effect [4]. This design is significant for comprehensively improving the biomechanical abnormalities associated with flatfoot.

3.3. Dorsiflexion of the forefoot

Patients with flat feet often experience excessive dorsiflexion in the forefoot due to collapsed arches, leading to uneven pressure distribution across the foot and increased strain on the forefoot. AFOs help restore arch height and reduce forefoot pressure by increasing the angle of forefoot plantar flexion. Studies have found that all AFO types increase forefoot plantar flexion angle (2.7–6.1°), thereby elevating the medial longitudinal arch [5]. This mechanism not only alleviates forefoot pain but also improves patients' walking gait.

3.4. Redistribution of ankle joint contact pressure

AFO can also reduce stress on the ankle joint by redistributing pressure across the joint. The UCBL orthosis is a common type of AFO designed to shift the ankle joint's pressure center from the posterolateral position to its normal location, thereby reducing peak pressure [6]. This adjustment in pressure distribution helps alleviate stress on the ankle joint and delay joint degeneration.

4. Comparison of efficacy of different types of AFO

4.1. Customized hinge AFO

Customized hinge-type AFOs represent a common type of foot orthosis designed to allow limited foot mobility while providing adequate support. Studies have shown that in patients with TTD II (third-degree plantar fasciitis), these custom-hinged AFOs demonstrate optimal corrective outcomes, showing significantly better arch support than off-the-shelf orthoses and rigid customized models. Additionally, patients report higher satisfaction levels [1]. By offering controlled mobility, this design maintains arch support while permitting natural foot movement, a crucial balance for long-term use and patient acceptance.

4.2. An AFO extending outward on the outside

The AFO with lateral extension offers unique advantages by simultaneously improving forefoot eversion and hindfoot inversion, making it suitable for flat feet with associated forefoot eversion. By providing additional lateral support, this AFO effectively corrects forefoot eversion deformity [4]. Studies have shown that patients using AFO with lateral extension exhibit significantly reduced forefoot eversion angles and increased hindfoot inversion angles, thereby comprehensively addressing biomechanical abnormalities in flat feet [5].

4.3. UCBL orthosis

The UCBL orthosis, a specialized ankle-foot-ankle (AFO) device, is engineered to redistribute contact pressure across the ankle joint. In cadaver model studies, UCBL orthosis has demonstrated superior effectiveness in restoring ankle contact characteristics compared to calcaneal osteotomy, suggesting its potential to delay progression of post-traumatic ankle dislocation (PTTD) to stage III. Through its innovative design, this orthosis reduces joint strain and may play a crucial preventive and therapeutic role for early-stage PTTD patients [6].

4.4. Double arched foot orthosis (DFO)

The Double-Arch Orthosis (DFO) is an innovative Ankle-Foot Orthosis (AFO) design that simultaneously supports both the anterior and posterior portions of the foot, delivering comprehensive support and corrective effects. Compared to Single-Arch Orthosis (SFO), DFO significantly increases navicular height ($p < 0.001$) while reducing metatarsophalangeal joint mobility [7]. This design is particularly suitable for female patients with flexible flat feet, effectively improving arch morphology, alleviating pain, and enhancing walking ability.

5. Effects of AFO on lower limb compensation mechanisms

In pediatric flexible flatfoot, AFOs modify activation of key tendons (tibialis anterior/posterior, peroneus longus) and counteract compensatory mechanisms [8]. Children exhibit reduced GRF, ankle torque, and propulsion during push-off (30–45% below normal) due to arch collapse [9]. Full-contact orthoses improve GRF via increased medial arch torque ($p = 0.035$) [10]. AFO use raises hip thrust by 20% ($p < 0.05$) through restricted plantar flexion [11], shifts center of pressure laterally ($p < 0.05$), and redistributes load to reduce joint stress.

5.1. Changes in muscle activation

Posterior tibialis (PT) weakness causes compensatory muscle patterns that stress the ankle. Orthoses, particularly rigid designs (RFOs), work by sharing this load. Research shows that over 12 months, this leads to beneficial muscle adaptation, specifically, strengthening of the peroneus longus (PL) [12]. This PL growth was directly linked to pain reduction (explaining 28% of improvement), confirming that redistributing muscle load is a key therapeutic mechanism for flexible flatfoot.

5.2. Changes in joint stress

Children with flatfeet exhibit reduced GRF, ankle torque, and propulsion during push-off (30–45% lower than normal) due to MLA collapse [9]. Full-contact orthoses improve GRF transmission by increasing MLA torque ($p = 0.035$) [10]. AFO use elevates hip thrust by 20% ($p < 0.05$) through restricted plantar flexion and shifts the center of pressure laterally ($p < 0.05$), redistributing load to reduce joint stress and improve long-term outcomes.

6. Applicable evidence for special populations

6.1. Childhood flat feet

In pediatric symptomatic flatfoot, medial arch support orthoses significantly improve foot alignment and AOFAS scores [13]. Correction efficacy inversely correlates with age, highlighting the importance of early intervention. For refractory cases, subtalar arthroereisis with Achilles lengthening effectively restores alignment [14]. Orthotic design should avoid overcorrection to prevent functional impairment or discomfort.

6.2. PTTD II phase patients

Stage II PTTD requires individualized orthotic management. Lateral extension AFOs target forefoot eversion, while custom articulated designs effectively address arch collapse. Quantitative gait analysis demonstrates that articulated AFOs significantly improve hindfoot varus and forefoot plantar flexion while slowing deformity progression [15]. These designs provide superior ankle stabilization and enhance corrective efficacy compared to off-the-shelf or fixed alternatives, emphasizing the necessity of customizing AFO selection to specific anatomical requirements.

7. Conclusion

This review demonstrates that AFOs effectively correct flatfoot deformity through distinct biomechanical mechanisms, controlling hindfoot pronation, forefoot abduction, and redistributing joint pressure. Customized designs (hinged, lateral extension, UCBL, dual-arch) show specific advantages for different patient profiles. Evidence supports AFOs' role in improving gait parameters, reducing compensatory mechanisms, and delaying disease progression in pediatric and PTTD populations. Future development should focus on personalized designs using advanced manufacturing technologies to optimize clinical outcomes.

Disclosure statement

The authors declare no conflict of interest.

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