Podiatry (Buenos Aires). 2025; 4:153
doi: 10.56294/pod2025153

ORIGINAL

Advances in the Prescription of Plantar Orthoses: Clinical Effectiveness and Biomechanical Perspectives

Avances en la Prescripción de Ortesis Plantares: eficacia clínica y perspectivas biomecánicas

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Cite as: Romero-Carazas R, Román-Mireles A, Bracho Mosquera AS, Villacorta Guzmán JR. Advances in the Prescription of Plantar Orthoses: Clinical Effectiveness and Biomechanical Perspectives. Podiatry (Buenos Aires). 2025; 4:153. https://doi.org/10.56294/pod2025153

Submitted: 07-06-2024 **Revised:** 14-09-2024 **Accepted:** 03-01-2025 **Published:** 04-01-2025

Editor: PhD. Márcio Flávio Moura De Araújo

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ABSTRACT

This article presents a systematic review of recent developments in the prescription of plantar orthoses, emphasizing their clinical, biomechanical, and technological impact. Various orthotic interventions applied to musculoskeletal conditions are analyzed, assessing their effects on gait parameters, load redistribution, and shock absorption. The study highlights emerging trends such as the integration of sensors, additive manufacturing through 3D printing, and the application of artificial intelligence—technologies that have redefined the design, functionality, and degree of personalization of modern orthotic devices. Based on a structured search across scientific databases, the evidence suggests that properly prescribed customized orthoses represent an effective, adaptable, and patient-centered therapeutic strategy. The review also identifies persistent challenges in clinical settings, including ethical barriers and issues of accessibility that hinder broader implementation.

Keywords: Podiatry; Plantar Orthoses; Biomechanics; 3D Printing; Personalized Therapy; Clinical Innovation.

RESUMEN

Este artículo examina los avances recientes en la prescripción de ortesis plantares, a partir de una revisión sistemática centrada en su impacto clínico, biomecánico y tecnológico. Se analizan distintas intervenciones ortésicas aplicadas a afecciones musculoesqueléticas, evaluando su influencia en parámetros de marcha, redistribución de cargas y absorción de impactos. La investigación identifica tendencias emergentes como la incorporación de sensores, la fabricación mediante impresión 3D y el uso de inteligencia artificial, tecnologías que han redefinido el diseño, la funcionalidad y el grado de personalización de las ortesis modernas. A través de una búsqueda estructurada en bases de datos científicas, se constata que las ortesis personalizadas prescriptas adecuadamente constituyen una estrategia terapéutica eficaz, adaptable y centrada en el paciente. El estudio también advierte sobre desafíos persistentes en el ámbito clínico, incluyendo barreras éticas y de accesibilidad que limitan su implementación en contextos diversos.

Palabras clave: Podología; Ortesis Plantares; Biomecánica; Impresión 3D; Terapia Personalizada; Innovación Clínica.

INTRODUCTION

Foot orthoses are one of the most important therapeutic tools in podiatry. They act as biomechanical mediators capable of modifying the distribution of ground reaction forces on the foot in order to realign structures, correct deformities, and improve functional performance during walking and standing. These external structures, designed to interact directly with the body's support and propulsion mechanisms, respond to a logic of both corrective and compensatory intervention, whose clinical impact translates into substantial improvements in postural parameters, dynamic stability, and reduction of pain associated with multiple dysfunctions of the musculoskeletal system.[1,2,3]

From a morphological and functional point of view, orthoses are classified according to their manufacturing characteristics, their response to movement, and their degree of customization. Prefabricated orthoses, which are produced in a standardized manner, offer accessible solutions that can be implemented immediately. Customized orthoses are designed using individual molds or scans, allowing for a more precise fit to the anatomy of the foot. Dynamic orthoses incorporate materials or elements that can adapt during the gait cycle, facilitating active modulation of loads according to the kinetic variations of the foot. This diverse typology not only expands therapeutic possibilities and orthotics, but also requires deeper reflection on the selection, indication, and prescription criteria for each model.[4,5]

In structural terms, the foot represents a fundamental interface in the kinetic chain of the human body, whose participation in shock absorption, postural axis stabilization, and impulse generation is decisive in the dynamics of movement. Alterations such as hyperpronation, whose systemic impact is often underestimated, can trigger upward imbalances that affect the knees, hips, and spine. Tools such as the Foot Posture Index (FPI) allow for the objective assessment of morphofunctional deviations in the plantar plane and the accurate evaluation of the effectiveness of orthotic interventions. Thus, it has been observed that even prefabricated models can induce improvements in the postural orientation of the rearfoot, shifting the foot configuration towards more neutral and functional patterns, with possible protective implications in dynamic contexts.[6]

The relevance of addressing this issue from an integrative approach is justified by the growing body of clinical evidence supporting the effectiveness of foot orthoses in prevalent conditions such as plantar fasciitis, flat feet, and metatarsalgia, all of which are associated with biomechanical balance disorders that negatively impact the patient's quality of life. In particular, recent studies have documented significant reductions in plantar pain, accompanied by improvements in postural alignment and walking function, following the application of custom-made rigid orthoses. Likewise, a decrease in fascial thickness has been observed in patients with plantar fasciopathy, suggesting a positive adaptive response of the tissue to the redistribution of loads imposed by the device. These findings provide empirical support for the need to continue refining both the intervention protocols and the biomechanical principles underlying orthotic design.[4,6]

In recent years, significant advances have been made in terms of types, materials, and manufacturing technologies, allowing for greater precision in fitting and improved functional response. This study aims to describe recent advances in the prescription of foot orthoses and analyze their contribution to clinical improvement, biomechanical efficiency, and treatment customization.

METHOD

This research was based on a systematic literature review aimed at examining recent developments, applied biomechanical principles, and emerging technological solutions in the field of foot orthoses. The search strategy was developed using the scientific databases Scopus, PubMed, MDPI, ScienceDirect, and the academic search engine Google Scholar as the main sources, due to their extensive coverage and access to peer-reviewed literature.

The searches were carried out using combinations of key terms in English such as: plantar orthoses, foot biomechanics, custom insoles, gait analysis, orthopedic devices, smart orthotics, and 3D printed insoles. Filters were applied by type of publication (peer-reviewed articles that included experimental results, systematic reviews, or clinical evaluations) and by publication period (2021-2025). A total of 34 scientific articles were selected, which were organized by topic and analyzed based on their contribution to the understanding of the therapeutic efficacy, functional customization, and clinical feasibility of foot orthoses. This process allowed us to identify predominant approaches, evaluate clinical and technological trends, and define the current challenges in customized orthotic prescription.

DEVELOPMENT

Biomechanical foundations for the use of foot orthoses

The implementation of foot orthoses in adults with flat feet has shown significant influences on the joint mechanics of the lower extremities during gait. A systematic reduction in excessive pronation in the subtalar joint has been observed, accompanied by modifications in ankle dorsiflexion and knee adduction moments. These biomechanical changes, far from being mere isolated adaptations, respond to a comprehensive corrective process that seeks to optimize structural alignment and improve load distribution during locomotion. Such kinetic reorganization may play an essential role in alleviating discomfort and preventing secondary musculoskeletal complications.(7,8) Despite the diversity observed in the orthotic designs analyzed in the studies, the biomechanical effects were consistent, reinforcing the clinical relevance of customized foot orthoses as a conservative tool for correcting abnormal gait patterns. Their ability to modulate joint kinematics and kinetics, particularly in subjects with flat feet, positions these interventions within a comprehensive approach to functional rehabilitation and joint overload prevention.(7)

In symptomatic runners, foot orthoses have been widely used to modify key biomechanical parameters such as rearfoot movement, impact attenuation, and redistribution of plantar pressures. Clinical evidence suggests that these mechanical adaptations may have a favorable effect on symptom relief and injury prevention. However, the degree of effectiveness appears to be modulated by variables such as orthotic design, individual morphology, and specific running mechanics.(9,10) Mechanistic findings show that orthotics have the potential to reduce excessive pronation and modify load patterns in the lower limb joints, a factor that could translate into a lower incidence of overuse injuries. Even so, the variability observed in therapeutic responses highlights the need for individualized assessment and prescription tailored to each patient's particularities in order to enhance the desired clinical outcomes.(9,11)

Design, materials, and technological customization

In a clinical context increasingly influenced by technology, the design and manufacture of foot orthoses have evolved towards highly customized approaches. An experimental study focusing on different footwear and orthotic conditions revealed that those made using 3D scanning and specialized printing offered a superior fit, accompanied by viscoelastic materials capable of absorbing impacts more efficiently. When integrated, these elements resulted in a more harmonious cadence and a substantial improvement in running mechanics.(12,13) As pointed out by Lescure Y et al.(12), the incorporation of sensors in orthotics, capable of providing real-time feedback on the distribution of plantar pressures, has expanded the possibilities for intervention and adjustment during use. This type of technology allows direct relationships to be established between the user's physiological variables and the structural parameters of the device, promoting not only comfort but also therapeutic adherence and functional efficacy.(14)

Another study looked at the impact of orthotics with arch support and heel cups in patients with flat feet, observing an improvement in calcaneal alignment and a noticeable decrease in eversion angles. Such mechanical realignment significantly indicates that orthotic design can transform altered postural patterns from the structural base of the foot. Thus, the use of rigid supports combined with cushioning layers demonstrates a dual strategy between biomechanical correction and perceptual comfort.(15,16)

Consequently, the customization process is not limited to a morphological reproduction of the foot, but involves a functional analysis that considers movements, pressures, and gait patterns. As Park D et al.(15) point out, this level of technological intervention enables a clinical approach that is more tailored to the specific needs of the patient, resulting in more effective and sustainable interventions.

Specific clinical indications

The targeted application of foot orthoses has been shown to positively modify the angular velocity of the foot segments during gait in individuals diagnosed with plantar fasciitis. A decrease in excessive rearfoot movement velocity has been demonstrated, a parameter closely linked to pain and increased tension on soft tissues. These biomechanical alterations justify their clinical use in cases characterized by abnormal foot kinematics.(5) Likewise, the importance of prescribing orthotics after a precise biomechanical evaluation is emphasized, with the aim of identifying and addressing specific pathological movements. This clearly individualized approach increases the likelihood of achieving satisfactory functional results and mitigating symptoms with targeted intervention.(17)

In cases of plantar pain located in the heel, the use of customized foot orthoses has led to significant reductions in pain levels, as well as tangible improvements in patients' functional capacity after twelve weeks of intervention. Biomechanical analysis showed optimized shock absorption and more efficient redistribution of plantar pressures, which is a major factor in symptom remission.(18,19) The individualized adaptation of these orthotics, taking into account both the morphology and pathology of the foot, has proven essential for achieving superior therapeutic results. Unlike generic orthotics, custom-designed orthotics respond to the specific clinical needs of each patient, offering a more precise, effective, and sustainable solution for the treatment of plantar pain.(20)

Clinical efficacy assessment and therapeutic outcomes

The efficacy of foot orthoses has been demonstrated in the context of running-related injuries, particularly in terms of reducing pain in the heel region and in structures such as the plantar fascia and Achilles tendon. These improvements are largely explained by the ability of orthoses to modulate load mechanics, absorb impact, and enhance proprioception during repetitive running movements.[21] However, it is recognized that the diversity of orthosis types and the duration of the interventions evaluated introduce variability that requires consideration of standardized clinical protocols. In addition, factors such as patient adherence and the suitability of the device to their specific needs are key determinants in achieving tangible and sustained benefits.[22]

On the other hand, analysis of the influence of foot orthotics on economy and running performance has revealed modest but clinically relevant improvements in runners with biomechanical abnormalities or a history of injury. Optimization of mechanical efficiency in locomotion and reduction of energy expenditure are effects attributable to load redirection and functional stabilization of the joints.[23] This preventive approach not only contributes to better athletic performance, but also minimizes the downtime associated with injuries, generating a positive impact on the continuity of training and the athletic career of users.[24]

Recent technological advances: sensors, smart orthoses, and AI

The incorporation of artificial intelligence and sensor technologies in ankle-foot orthoses has marked a turning point in the field of personalized rehabilitation. Through deep learning algorithms integrated into the system, these devices are capable of monitoring gait in real time and automatically adjusting assistance levels according to the user's needs, promoting functional symmetry and prolonged stability during movement.[25] Experimental results show that users of these smart orthoses experience notable improvements in variables such as stride length, walking speed, and joint position. This level of dynamic adaptation represents a break with traditional passive orthosis models, opening the door to a much more interactive and patient-centered therapeutic paradigm.[26] Smart foot orthoses that integrate sensor arrays and pressure mapping systems have demonstrated the ability to modify the resting position of the calcaneal in real time, especially in patients with flat feet. This continuous monitoring allows for precise adjustments based on the user's biomechanical responses, improving both comfort and treatment efficacy.[6,15,27,28]

By establishing constant feedback between the technology and the behavior of the foot, a more precise intervention is achieved that favors the progressive correction of the deformity. This convergence between bioengineering and health sciences redefines the role of orthotics within contemporary rehabilitation schemes.[15,29]

Functional innovation in personalized clinical settings

The development of smart insoles using 3D printing has enabled the integration of pressure sensors and pneumatic cameras into structures capable of supporting loads greater than body weight, allowing ground reaction forces (GRF) and centers of pressure (COP) to be recorded with high accuracy. This type of orthosis, in addition to being highly durable, is able to capture gait dynamics in multiple planes, with margins of error of less than 9 %. These characteristics make these insoles a clinically viable tool for biomechanical analysis in non-laboratory settings, allowing for constant and personalized monitoring of the functional behavior of the foot.[30,31,32]

In turn, 3D printing and digital foot scanning have facilitated the creation of fully customized orthotics that accurately replicate the patient's morphology. This structural precision improves load redistribution, especially in subjects with cavus feet, in whom customized insoles have been shown to be more effective than generic ones in significantly reducing plantar pressure peaks. These findings reinforce the importance of geometric customization based on specific clinical parameters to achieve adaptive, effective orthotic intervention focused on the individual physiology of the user.

Ethical and clinical limitations: cost, professional training, accessibility, patient adherence

Despite technological and clinical advances in the design of foot orthoses, their implementation faces significant ethical and operational barriers. Among the most notable challenges are the high production cost and limited coverage of these devices by health systems, which restricts access for many patients, especially in low-resource settings. In addition, variability in professional training in clinical biomechanics and orthotic prescription compromises the quality and effectiveness of treatment, leading to inequalities in its application.[5,35,36]

Another relevant aspect is patient adherence, which can be affected by factors such as perceived discomfort, lack of knowledge about the correct use of the device, or lack of clinical follow-up. These limitations highlight the need for educational strategies aimed at both professionals and users, as well as interdisciplinary care models that take into account the economic and social reality of the patient. Overcoming these obstacles is crucial to consolidating the use of foot orthotics as an accessible and equitable therapeutic tool.[5,37]

CONCLUSIONS

This paper describes recent advances in the prescription of foot orthoses, highlighting their impact on clinical improvement, therapeutic customization, and biomechanical efficiency. Current orthoses, integrated with advanced technology, allow for more precise, functional, and patient-specific interventions. Their application is becoming established as a key strategy in the treatment of various foot conditions in modern clinical practice.

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FUNDING
The authors did not receive funding for the development of this research.

CONFLICT OF INTEREST
The authors declare that there is no conflict of interest.

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