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Review

3D printing in the manufacture of orthoses to correct children's flatfoot

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Abstract

Objective: To analyze, through an integrative literature review, the available evidence on the technical aspects, clinical impacts, economic viability, and challenges of adopting three-dimensional (3D) technology in the pediatric context.

Methods: The search was conducted on PubMed, Scopus, SciELO, and Web of Science databases, using specific keywords and previously defined inclusion and exclusion criteria. The data were synthesized descriptively and compared with the existing literature.

Results: 3D printing allows the production of customized orthoses with high anatomical precision and shorter manufacturing time, presenting clinical benefits such as improved function, reduced pain, and increased adherence to treatment. The economic analysis suggests potential cost reduction in the medium term, although strategies are needed to expand access to technology.

Conclusion: 3D printing in the manufacture of orthoses to correct children's flatfoot is a promising technological alternative, capable of favoring higher anatomical precision, comfort, and potential cost reduction compared to traditional methods.

Level of Evidence I; Systematic Review.

Keywords: Printing, three-dimensional; Orthotic devices; Flatfoot; Children.

Introduction

Children's flatfoot deformity is a common orthopedic condition characterized by partial or total collapse of the plantar vault, which encompasses the medial, lateral, longitudinal, and transverse arches of the foot. Such alterations can cause postural repercussions, pain, and functional impairment[1-3]. It is estimated that approximately 5% to 15% of children have some degree of flatfoot, which makes their therapeutic approach a frequent concern in pediatric clinical practice[4,5]. Conservative treatment, mainly through plantar orthoses, aims to correct the biomechanics of the foot and promote proper alignment, preventing future complications[6-8].

In recent years, three-dimensional (3D) printing technology has been widely explored in healthcare due to its ability to produce customized devices with greater accuracy, comfort, and cost-effectiveness[9,10]. The application of this technology in the manufacture of orthoses for children's flatfoot emerges as a promising alternative, capable of overcoming the limitations of traditional methods, which typically rely on manual, time-consuming processes that are less well-suited to individual needs[11,12]. However, despite growing interest, there are gaps in knowledge about the efficacy, feasibility, and clinical impact of orthoses produced by 3D printing in this specific context[7,13].

Therefore, it is important to investigate 3D printing in the manufacture of orthoses designed to correct children's flatfoot, to evaluate its therapeutic potential, and contribute to innovation in pediatric orthopedic treatments[14,15]. This study aims to provide technical solutions that enhance comfort, anatomical adequacy, and functionality for affected children, while also promoting the incorporation of advanced technologies into clinical practice[6,16].

The objective of this study is to analyze, through an integrative literature review, the available evidence on the technical aspects, clinical impacts, economic viability, and challenges of adopting 3D technology in the pediatric context.

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Thus, this research aims to contribute to the advancement of technical-scientific knowledge in the application of 3D printing for the manufacture of orthoses for children with flatfoot, providing insights for future innovations and improvements in clinical practice.

Methods

This research is characterized as an integrative literature review. This method enables the synthesis and critical analysis of previous scientific studies, expanding the understanding of 3D printing in the manufacture of orthoses to correct deformities in children's flatfoot. The choice of an integrative review is justified by the need to gather and systematize available evidence, thereby contributing to the theoretical and practical foundation of the subject.

The review followed pre-established steps, starting with the guiding question: "What are the technical criteria described in the literature for 3D printing in the manufacture of orthoses aimed at correcting children's flatfoot, what parameters should be considered, and what clinical results can be achieved?". Subsequently, a search was conducted on PubMed, Scopus, SciELO, and Web of Science databases, including publications from 2010 to 2025. Specific keywords in Portuguese and English, such as "3D printing", "orthoses", "flatfoot", and "children", and their Portuguese counterparts, were combined through the Boolean AND and OR operators.

The inclusion criteria adopted included original studies, systematic reviews, clinical trials, and case reports that addressed 3D printing in the manufacture of orthoses for children with flatfoot. Articles not fully available, publications not peer-reviewed, studies that addressed only adults, and those that did not directly focus on 3D printing technology applied in this context were excluded.

The article selection process was conducted in two independent stages by two researchers, initially by reviewing the titles and abstracts, followed by reading the full texts to confirm eligibility. Disagreements were resolved by consensus. Data extraction followed a standardized protocol, which included the author, year, type of study, sample characteristics, type of orthosis produced, technology used, clinical results, and main conclusions.

The collected data were organized in an Excel spreadsheet and analyzed through descriptive synthesis, emphasizing technical, clinical, and innovative aspects related to 3D printing in the manufacture of orthoses to correct children's flatfoot. This approach enables the identification of gaps, limitations, and potential advances in technology, thereby contributing to the development of knowledge in this field.

Results and discussion

The search identified 327 records, and after applying the inclusion and exclusion criteria, 11 studies were selected for final analysis. The included studies were from 2015 to 2025 and were predominantly observational studies, non-randomized clinical trials, and case reports. No meta-analyses or randomized clinical trials of high methodological quality specifically focused on 3D printing in the manufacture of orthoses for children's flatfoot were identified. Due to the scarcity of high-quality studies, it was decided to include studies of a lower level of evidence to gather the currently available knowledge and demonstrate initial trends in the clinical applicability of 3D technology. It is important to emphasize that these methodological limitations reduce the strength of the conclusions, reinforcing the need for future controlled studies and higher scientific rigor to establish the effectiveness and safety of this approach. Table 1 presents the summary of the main methodological characteristics and findings of the included articles.

Technical characteristics and orthoses production

The production of orthoses to correct the children's flatfoot using 3D printing involves a workflow that begins with anatomical data of the patient's foot. While traditional methods use plaster casts to capture the plantar shape, digital techniques employ 3D scanning, such as laser scanners, photogrammetry, or structured light scanners. Although both methods share the same objective of reproducing anatomy, 3D scanning offers higher dimensional accuracy, the possibility of digital storage of the models, and the convenience of adjusting or reprints without the need to repeat the entire molding process. On the other hand, plaster casts require additional manual steps, are more susceptible to minor distortions, and do not allow for direct reuse in cases of growth or clinical changes. Thus, the main contribution of digital methods is not to replace traditional methods, but to offer greater reproducibility, standardization, and agility in the production flow of orthoses, particularly relevant aspects in monitoring the growing pediatric population[9,11,14].

After capturing the anatomical data, digital modeling of the orthosis is performed in Computer-Aided Design (CAD) software, a step that establishes structural and functional parameters determining the device's performance. Among these parameters, the following stand out:

- Plantar arch height and shape: determined from 3D foot reconstruction to restore physiologic alignment without placing excessive load on adjacent structures.
- Structural stiffness: determined not only by the orthosis geometry, but also by the material properties (e.g., elastic modulus of polymers such as polylactic acid (PLA), thermoplastic polyurethane (TPU), or nylon). Biomechanical studies use finite element analyses and compression tests to determine the strength and strain of materials under static and dynamic loads.
- Pressure relief areas: mapped through baropodometric analyses, which allow identifying regions of plantar overload and guiding cutouts or thickness variations.
- Structural reinforcements: applied at critical points, such as the medial arch region or the lateral edge, to stabilize the foot during gait and reduce compensatory movements.

Table 1. Characteristics of the included studies

Author/Year	Study type	Population and sample	Intervention	Main results
Lee et al., 2020	Clinical trial	Children with flexible flatfoot	Customized plantar pressure-based 3D printing insoles	Improvement of medial arch and plantar pressure distribution
Yulianto et al., 2024	Comparative study	Flexible flatfoot students	3D printed insoles vs. semi-rigid insoles	Improvement in spatiotemporal gait parameters
Hsu et al., 2022	Biomechanical study	Adults with flatfoot	Different models of 3D insoles	Positive biomechanical changes in the lower limb
Chen et al., 2019	Prospective study (1 year)	Preschoolers with symptomatic flatfoot	Orthopedic insoles	Clinical and functional improvement
Choi et al., 2020	Prospective comparative study	Children with flexible flatfoot	Insoles with medial arch support	Positive radiographic structural changes
Hsieh et al., 2018	Randomized clinical trial	Children with flexible flatfoot	Custom insoles with arch support	Pain reduction and functional improvement in the short term
Bok et al., 2014	Clinical trial	Children > 6 years with flatfoot	Tailored rigid orthosis	Foot alignment correction and clinical improvement
Lee et al., 2015	Observational study	Children with flexible flatfoot	Foot posture index and plantar pressure measurements	Correlation between posture and plantar overload
Paecharoen et al., 2023	Diagnostic study	Children	Radiographic and plantar print indexes	High diagnostic accuracy
Fan et al., 2011	Biomechanical study	Individuals with flatfoot and cavus foot	Analysis of natural gait	Pronounced biomechanical differences
Pang et al., 2023	Experimental study	3D printed ceramic structures	Comparison of internal geometries	Relevance to orthopedic materials

Integrating CAD with biomechanical simulation tools enables the virtual evaluation of orthosis behavior before manufacture, identifying potential failures and optimizing the design according to measurable parameters. Thus, modeling is not restricted to aesthetic adjustments but aims to base orthoses preparation on objective biomechanical criteria, bringing the process closer to evidence-based practice[9,11,12].

As for printing technologies, the included articles indicated a predominance of three main methods:

- **Fused deposition modeling (FDM)** – widely used for its accessibility and compatibility with polymers such as PLA and TPU. The PLA confers rigidity and structural stability, making it suitable for more robust corrections, while TPU offers flexibility and greater comfort for prolonged use[9,10,11,14].
- **Stereolithography (SLA)** – employs photopolymerizable resins that provide high resolution and fine surface finish, favoring high-level anatomical adaptation, although the mechanical strength may be lower than other polymers[9,10].
- **Selective laser sintering (SLS)** – allows the use of nylon and other high-strength synthetic materials, being suitable for orthoses subjected to greater loads and repetitive efforts[9,10].

The production time varied between studies, with a mean of four to 12 hours for complete manufacturing, including scanning, modeling, printing, and finishing steps[9,11,14,15]. This agility represents a considerable advantage over traditional methods, which may require days for final delivery to the patient[11,12,15].

Another relevant technical aspect was the ability for quick adjustments and reprints. As the digital file remains stored, any necessary modification—whether due to clinical evolution, orthotic wear, or patient growth—can be performed expeditiously and at a lower cost[9,12,14,15]. This characteristic makes 3D printing particularly suitable for children, as their physical development requires frequent adaptations[6-8].

In summary, the studies analyzed suggest that 3D printing offers similar or superior performance to traditional methods of producing orthoses, particularly in terms of anatomical precision and customization options. Compared to traditional plaster casts, digital models exhibited less dimensional variability and greater reproducibility, in addition to the advantage of allowing adjustments and reprints without the need to repeat the entire molding process. Some studies also report greater comfort and adherence among patients to the use of 3D-printed orthoses, although these findings are still based on small samples and short-term studies. Thus, despite showing potential for clinical innovations, the available evidence should be interpreted with caution, considering the absence of robust clinical trials that confirm the superiority of the technology over traditional methods[7,9,11-15].

Observed clinical impacts

The included studies demonstrated that 3D printing orthoses for treating children's flatfoot present positive clinical results, both in biomechanical correction and in the functional and symptomatic improvement of patients[6,7,14-16].

Regarding plantar arch correction, studies that used baropodometric analyses reported a measurable improvement in the distribution of plantar pressure after the use of 3D-printed orthoses. Lee et al.[14] observed a reduction of approximately 15% in overload in the medial foot region and a proportional increase in support in the lateral area after 12 weeks of continuous use. Similarly, Yulianto et al.[15] identified a mean increase of 2 to 3 mm in the functional plantar arch height in children with flexible flatfoot, accompanied by more homogeneous redistribution of plantar pressures. These findings suggest that the anatomical precision obtained by 3D scanning and digital modeling not only reproduces foot morphology but also enables more targeted interventions, reflected in objective parameters of postural alignment during gait.

Regarding the reduction of symptoms, some clinical studies have reported quantitative evidence of improvement after the use of 3D-printed orthoses. Hsieh et al.[17] reported a mean reduction of 40% in pain complaints, as measured by the visual analog scale, after eight weeks of continuous use. Bok et al.[18] observed a significant decrease in muscle fatigue reported by parents and caregivers, in addition to an increase in the distance walked without pain in functional tests. Cho et al.[16] demonstrated an increase of approximately 18% in physical endurance for moderate-impact activities, such as light running, in children followed for six months. These findings suggest that symptomatic improvement is associated with the structural support provided by the orthosis, which redistributes loads and reduces mechanical stress on the muscles and ligaments of the foot and ankle.

Another relevant finding was adherence to use. Compared to traditional orthoses, devices produced by 3D printing have higher rates of adhesion, which is related to better comfort, lightness, and anatomical adaptation[6,7,14,15]. The custom design reduced excessive pressure points, minimized friction with the skin, and allowed for adequate ventilation, contributing to continuous use without significant discomfort[6,7,15].

From a functional perspective, studies that applied kinematic analyses reported quantifiable improvements in gait patterns after using 3D-printed orthoses. Hsu et al.[11] identified a mean reduction of 6° in excessive foot pronation during the support phase, as measured by gait 3D analysis. Similarly, Lee et al.[14] reported an increase of approximately 12% in dynamic stability, as evaluated by spatiotemporal parameters of stride variability. Yulianto et al.[15] observed a significant increase in gait symmetry, with an 18% reduction in the difference between the right and left foot stance times. These results suggest that customized 3D-printed orthoses can provide objective improvements in stability and postural alignment, although the evidence is still limited by small sample sizes and short follow-up periods.

In addition, indirect benefits were identified, such as satisfaction of parents and caregivers regarding the positive impact on posture, school performance in physical activities, and reduction of medical visits for complaints associated with flatfoot[6,7]. The possibility of rapid orthosis adjustments and reprinting was also considered a relevant factor in continuing the treatment, especially in children in the accelerated growth phase[6,9,12,15].

On the other hand, some limitations have been reported, including the need for frequent monitoring to make adjustments, especially in cases of rapid growth or body weight variation, and the lack of longitudinal studies evaluating the long-term effects of these orthoses in preventing secondary complications[2,6,7].

In summary, the evidence suggests that 3D printing in the manufacture of orthoses for children's flatfoot offers significant clinical benefits, including biomechanical improvement, symptom reduction, greater adherence to treatment, and user satisfaction, configuring a promising alternative to traditional methods[6,7,14-16,19].

Feasibility, costs, and clinical adoption

The feasibility of using 3D printing in the manufacture of orthoses to correct children's flatfoot has been analyzed from different perspectives: economic, logistical, and operational[9,10,12]. The included studies indicate that, despite the initial investment required to purchase medical-grade 3D printers and modeling software, the cost per unit is lower than that of orthoses manufactured by traditional methods, especially when considering large-scale production[9,12].

From an economic perspective, the average cost reported for manufacturing a 3D printing children's orthosis ranged from US$10 to US$40, depending on the material and technology used[10,12]. This value is significantly lower than the average cost of a traditional custom orthosis, which can exceed $100[12]. This reduction is achieved by eliminating intermediate steps, such as plaster casting and manual finishing processes, in addition to minimizing material waste through additive manufacturing, which uses only the exact amount of input required[9,10].

In logistical terms, the possibility of digitizing the entire workflow—from anatomical capture to modeling and printing—allows clinics and laboratories to produce orthoses on demand, thereby reducing inventory and delivery times[9,12]. The mean production time identified in the studies was four to 12 hours, allowing, in some cases, the orthosis to be delivered to the patient on the same day as the initial examination[9,12]. This agility has a direct, positive impact on treatment adherence and caregivers' satisfaction[6,7,12].

In the operational aspect, the main barrier to wide adoption is the need for technical training of health professionals to use CAD software and operate 3D printers[9,12]. Although some studies have reported simplified processes with semi-automated flows, it is still common to depend on specialized technicians for modeling and adjustments[9]. In addition, factors such as standardization of protocols, health regulations, and broad clinical validation require consolidation to ensure the safety and efficacy of treatment[10,12].

Another highlight is the feasibility in developing countries. The progressive decline in the cost of equipment and inputs has made 3D printing more accessible, opening up opportunities to implement this technology in public clinics and social projects[10,12]. It is noteworthy that the ability to reuse digital files for reprinting reduces the financial impact of frequent adjustments, especially in growing pediatric patients[6,12,15].

Regarding clinical adoption, it was observed that specialized centers and university hospitals are among the first to incorporate the technology, functioning as reference and training centers[9,12]. Adoption in smaller clinics still faces obstacles, but market forecasts indicate that wider uptake will occur as equipment becomes more intuitive, more affordable, and better integrated with orthotic-prescription software[9,10,12].

In summary, 3D printing is technically feasible, economically advantageous, and logistically efficient for the manufacture of customized orthoses for children's flatfoot. However, large-scale clinical adoption still depends on investments in professional training, standardization of protocols, and broader dissemination of long-term clinical studies that demonstrate their efficacy and safety[9,10,12].

Comparison with the literature and identified gaps

The results obtained in this integrative review align with the recent international literature on the application of 3D printing in the manufacture of orthoses, confirming previously described trends regarding customization, cost reduction, and agility in the production process[6,9,10,12-15]. Lee et al.[14], Yulianto et al.[15], and Hsu et al.[11] had already reported that the technology enables precise anatomical adaptations and improvement in patient comfort, observations that were also confirmed in this study.

Regarding clinical performance, the evidence collected corroborates the findings of Cho et al.[16], Molina-Garcia et al.[6], and Oerlemans et al.[7], who report significant improvements in plantar arch alignment and a reduction in painful symptoms in children with flatfoot after using orthoses produced by additive manufacturing. These data are consistent with the biomechanical benefits described by Chen et al.[13] and Yulianto et al.[15], who emphasize the role of 3D printing in plantar load redistribution and posture improvement.

However, some relevant aspects still remain unexplored and even controversial in the literature. First, there is a shortage of randomized clinical trials that directly compare the efficacy of 3D printing orthoses with traditional devices[2,6,7]. In addition, most available studies present small samples, short follow-up periods, and heterogeneous methodologies, which limit the possibility of drawing robust conclusions about their durability and long-term impact[2,7].

Another critical point refers to the lack of consensus regarding the real clinical benefit of using orthoses to treat children's flatfoot. Several studies question its effectiveness, showing that many children naturally correct the deformity without specific intervention, which reinforces the need for caution in interpreting the results and prevents 3D printing from being presented as a definitive solution[2,4,7,9,11,14].

In addition, important gaps remain in the standardization of manufacturing protocols, in the biomechanical criteria to be adopted, and in the definition of objective correction parameters. In the economic aspect, although there is evidence of unit cost reduction, a lack of structured cost-effectiveness analyses exists that consider indirect variables, such as adherence to treatment and quality of life. Added to this is the scarcity of studies on acceptance by health professionals, as well as the lack of consistent assessments of the environmental impacts of the production process[2,6,7,9,10].

Thus, although the results of this review indicate that 3D printing may represent an innovative tool in the manufacture of orthoses for children's flatfoot, such findings should be interpreted with caution. There is still no consensus on its actual therapeutic utility, and the magnitude of its clinical impact remains uncertain. Future studies, with greater methodological rigor and a focus on relevant clinical outcomes, are essential for determining whether technology can indeed assume a consolidated role in managing this condition[6,7,9,12].

Final considerations

Based on the included studies, 3D printing for the manufacture of orthoses for children's flatfoot shows potential for customization and technical feasibility, but the available evidence is still limited, of low methodological quality, and with a short follow-up period. There is no consensus on the clinical impact of orthoses in this context, and their real therapeutic utility remains uncertain. Future studies, with larger samples and more robust methodologies, are needed to clarify the effectiveness, durability, and cost-effectiveness of this technology.

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