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# 3D impression as an additive technology in upper limb orthotics and prosthetics: advancements, applications, and perspectives

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**Abstract:** 3D additive technology is revolutionizing the field of upper limb orthotic and prosthetic manufacturing, offering customized, efficient and cost-effective solutions. This article examines the evolution of the use of 3D printing in the design and manufacture of orthotics and prosthetic for the upper limb, highlighting its advantages over traditional methods. We explore the various applications of this technology, such as the creation of custom orthotics and prosthetic for patients with orthopedic, neurological or musculoskeletal disorders. In addition, we discuss current challenges and future opportunities in this field, particularly with regard to the accuracy, durability and accessibility of orthotics and prosthetic made by 3D printing. In conclusion, this article highlights the potential of 3D additive technology to improve the quality of life of patients requiring upper limb orthotics and prosthetic, while paving the way for new advances in rehabilitation and personalized treatment.

***Keywords:*** 3D printing, additive technology, upper limb orthoses, upper limb prostheses, personalization, rehabilitation, cost-effectiveness, durability, accessibility.

## 1. **Introduction**

People with upper limb deficiencies, whether congenital, accidental or due to degenerative diseases, face considerable challenges in their daily lives. These deficiencies affect not only functional mobility, but also patients' quality of life. Traditional solutions to treat these deficiencies rely mainly on orthoses and prostheses, which are essential for restoring upper limb function, supporting the joint or replacing a missing limb. However, to be effective, these devices must be perfectly adapted to each patient's specific anatomy and the particular needs associated with their pathology or condition. Customization is therefore a key aspect in the design of these devices, to ensure their long-term effectiveness and comfort of use (Gadhave et al., 2024).

Traditional methods used to manufacture these devices include molding, milling and laminating. Although these methods have been widely used for decades, they have several major limitations. Casting, for example, involves manual impression taking, which can be an invasive and uncomfortable procedure for the patient. Secondly, producing the prosthesis or orthosis from these impressions can be time-consuming and costly, with margins of error likely to affect the fit of the device. What's more, these methods do not allow adjustments to be made easily after initial manufacture, which can make it difficult to achieve the best solution for the patient, particularly in cases requiring frequent modifications (Farhan et al., 2021).

The emergence of 3D additive manufacturing technology, or 3D printing, has transformed the field of orthotics and prosthetics. This technology makes it possible to create medical devices with a high degree of customization, directly from digital models of the patient. Unlike traditional techniques, 3D printing offers unprecedented flexibility, enabling the production of customized prostheses in a matter of hours rather than weeks, while reducing the associated costs. Devices can be designed with extreme precision, taking into account the anatomical specifications of each patient, thanks to 3D scans obtained by computed tomography (CT) or magnetic resonance imaging (MRI). This approach overcomes the challenges associated with manual manufacturing, while guaranteeing devices that are more comfortable and better adapted to each patient's unique anatomy (Aimar et al., 2019).

What's more, the use of polymer and composite materials in 3D printing makes it possible to obtain devices that are not only lightweight, but also resistant and functional. The new materials used in this technology offer mechanical characteristics comparable to those of materials used in traditional methods, but with reduced production costs and considerably shorter lead times. What's more, 3D printing allows flexibility in the choice of materials, offering solutions that can be optimized according to the patient's specific needs, particularly in terms of strength, comfort and durability (Pal et al., 2021).

One of the main advantages of 3D printing lies in its ability to offer truly customized solutions for each individual patient. By combining high-precision scanning technologies with computer-aided design (CAD) software, it is possible to create detailed 3D models of the affected area, and then tailor the design to the patient's functional, aesthetic and biomechanical needs. This contrasts with traditional methods, which can impose compromises in customization due to the rigidity of manufacturing processes (Dave et al., 2024). In addition, 3D printing enables rapid adjustments to be made to the prosthesis or orthosis model, without having to restart the entire manufacturing process. This minimizes waiting times and enables faster, more efficient patient care (Iftekar et al., 2024).Therefore, this technology has the ability to change the way prostheses and orthoses are made, as well as how they are to be perceived by patients and used by patients in accordance with such products. Improved fit and comfort of device are also received with almost absolute personalization in terms of satisfaction by patients, which can then move toward positive outcomes in the functional unchanging future. Further, 3D printing reduces the cost of production for orthoses and prostheses, thus providing many patients with better access to such medical devices, even in those areas where conventional modes of medical practice are limited (Roh et al., 2013)

The purpose of this article is to investigate the evolution of 3D printing in the design and manufacture of upper limb orthoses and prostheses and to demonstrate its advantages to previous traditional manufacturing methods. This article will also discuss challenges in the mass adoption of this technology, which include but are not limited to issues of accuracy, material durability and access in various clinical settings. Finally, we will see in future what might happen with this upcoming technology of 3D printing, including how it will change their rehabilitation and personalized treatments into increasingly affordable, speedier and better tailored solutions for specific patient needs.

2. **3D printing evolution in the manufacture of upper limb orthoses and prostheses**
    - Early applications of 3D printing in the medical field

3D printing was first introduced to the medical device field in the 1990s, but its adoption in the orthotics and prosthetics sector has intensified over the past decade. Initially used for the manufacture of surgical models and tools, it quickly found applications in the manufacture of prostheses, thanks to its ability to create custom parts from digital scans (Whitaker et al., 2014).

- Recent technological advances

Advances in 3D printing technologies have led to significant improvements in precision, speed and cost. The introduction of materials such as thermoplastics and carbon-fiber composites has enabled the creation of stronger, lighter and more durable devices (Pérez et al., 2020). In addition, the use of digital modeling enables devices to be customized with great precision, guaranteeing greater adaptability to patient needs.

- Clinical adoption of 3D printing

The integration of 3D printing into clinical practice has led to shorter manufacturing times for prosthetics and orthotics, improved fit quality and more suitable and accessible solutions for patients (Huang et al., 2013).

3. **Process of Creating Customized 3D-Printed Upper Limb Orthotics and Prosthetics**

Architectural, tailoring, and utility are among the most paramount keynotes, which are essentially specific in the processes of designing 3D printed orthotics and prosthetics for upper limbs (Xu et al., 2017; Oud et al., 2021):

1. Patient evaluation and imaging: This comprises a physical examination of the patient as well as the acquisition of highly detailed anatomical information via 3D scanning or another modality such as MRI or CT. This captures the unique body structures, resulting in a precise fit for the finished product.
2. A beautiful and useful design resulted from careful consideration of details such as joints and grips. Prototype 3D designs that precisely match a patient's anatomy are created from scanned data using modern CAD software.
3. Materials Selection: The appropriate materials that meet the specific needs of the patient with respect to how the device needs to be formed should be defined. The most used materials in the production of upper limb prosthetics and orthoses include thermoplastic, thermoplastic elastomer and very light composites, each of which offers strength, flexibility and comfort to some degree.
4. After selecting the design and materials, the 3D printing process can start. Techniques such as Fused Deposition Modeling (FDM) or Selective Laser Sintering (SLS) replace solid components in conventional manufacturing with layer-by-layer construction from a digital model, allowing for high precision and complex forms not achievable through conventional processes.
5. Post Processing and Finishing: Following printing, the device goes through post-processing, which may involve cleaning, smoothing surface finishes, and joining numerous components (if necessary). To improve comfort and functionality, additional features like as padding or straps may be incorporated.
6. Fitting and Adjustment: The printed prosthesis or orthosis is fitted to the patient and adjusted as needed to achieve maximum comfort and function. Iterations are simply controlled with 3D printing.
7. Follow-up and Iteration: Regular follow-up sessions are suggested to monitor the patient's improvement and the device's functionality. Based on these evaluations, more adjustments can be made to ensure that the device continues to fulfill the patient's demands.

This is how 3D printed orthotics and prosthetics gain what is very arguably the highest level of functionality while, at the same time, offering customized tailoring to individual patients' unique anatomical requirements, adding value over traditional methods regarding comfort, cost, and efficiency.

**Figure 1.** Production process of the 3-dimensional (3D)-printed orthosis. (A)

Scanning the hand and forearm, (B) designing the orthosis based on the digital model of the hand, and (C) the 3Dprinted orthosis (Oud et al., 2021).

**Figure 2.** Manufacturing workflow of the 3D-printed upper limb prosthesis. The entire process including: (1) measurement and scanning of the limb stump, (2) customization, (3) printing, and (4) assembling of the components (Górski et al., 2021).

4. **Benefits of 3D printing for upper limb orthotics and prosthetics**
    - Personalization and added comfort: Perhaps the most significant advantage of 3D printing is the ability to produce devices entirely customized for each patient, which significantly increases comfort and improves function. Prostheses and orthoses can be tailored to the anatomical peculiarities of each user, thus maximizing rehabilitation (Pathak et al., 2023).
    - Aestheticism and Lightness: Devices produced from 3D printing may be made aesthetically more pleasing and lighter than what performing them by traditional means has to offer. This increases the acceptance of the devices as well as comfort on an everyday basis (Mian et al., 2023).
    - Reduced lead times for production: Additive Manufacturing can drastically shorten lead times for devices from several weeks to just days. This is a great step forward in patient care, especially in cases of emergency or where the equipment must change in keeping with evolving pathologies (Chen et al., 2020)
    - Cost reduction: In place of saving, significant savings are to be gained from the application of 3D printing. This includes savings in labor, materials, and manufacturing steps; plus, increased responsiveness by on-demand manufacture of prosthetics and orthotics decreases the costs associated with inventory (Cheo et al., 2024).
5. **Challenges and limitations of 3D printing in upper limb orthotics and prosthetics:**

3D technology for printing saw a welcome development, but there still remains innumerable challenges when it comes to their application with regards to medical devices: Accuracy and fit continue to be the most significant limitations since the functionality and safety of devices can be critically affected by any modeling or manufacturing mistakes (Iftekar et al., 2023). A further limitation is the strength and durability of 3D printed materials, which have improved but fail to achieve the stringent requirements of medical devices, especially prostheses, subjected to daily wear and tear (Ko, 2018)). Material constraints of 3D printing remain because available materials are still much more limited compared to traditional prosthetics and orthotics manufacturing. Therefore, further research and development of biocompatible, flexible, and stronger materials are needed (Behm et al., 2018). Also, though the cost of such technologies was expected to lessen the financial burden, the dual barriers of accessibility and cost were still there, especially in developing countries where the requisite infrastructure for the widespread adoption of this technology is lacking.

## 6. Future opportunities and prospects:

The present status of research in 3D printing for orthotics and prosthetics is highly promising thanks to future technological advances in bioactive polymers and artificial intelligence for personalizing products even more (Gutierrez et al., 2023). These would provide even better and much more individualized solutions for patients. Accessibility improvements could transform healthcare by reducing the cost of orthotic and prosthetic devices for many patients, especially in low-resource settings (Hassan and Wong, 2023). Besides, mass customization where a large number of products can be produced, individually tailored devices that meet the needs of each patient may be produced without raising costs or extending the time for production (Shaikh, 2024). This combination of new technological innovations and better accessibility is capable of changing the face of the future of prosthetic and orthotic care all around the world.

## 7. Conclusion:

Revolutionized upper-limb 3D printing technologies-based manufacturing orthoses and prostheses, which brings personalized approaches to each patient’s unique needs in terms of anatomy. This makes it possible to improve the comfort and functional performance of devices; thus, improving patient satisfaction and effectiveness devices. Cost-effective and shorter lead times mean that orthotic and prosthetic devices would become less expensive and made available quickly, promoting even more treating options in countries with lower healthcare capacity. However, works still have to be done concerning the perfecting of the fit of the devices, their lifespan, and easy access within resource-limited countries. There is a lot of room for improvement as far as new materials and technical improvements, along with investing in infrastructure are concerned. Therefore, 3D printing can revolutionize rehabilitation and personalized treatment approaches, making them cost-effective, efficient, and effective for patients.

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