REVIEW ARTICLE

CONTENTS

Current perspectives on 3D-printed casts

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ABSTRACT

Aim: Fractures of the distal radius and ulna are among the most common skeletal injuries and are traditionally treated with cast immobilization. However, conventional casting techniques have significant limitations. In recent years, three-dimensional (3D) printing technology has emerged as a promising alternative in the production of personalized post-traumatic stabilization devices. The aim of this review was to present current information and perspectives on the development of 3D-printed casts, with particular emphasis on the diversity of designs, material properties, and clinical applications.

Materials and Methods: A literature review was conducted using the PubMed and Google Scholar databases. The results of the analyzed studies indicate that additive technologies enable the production of lightweight, ventilated, individually tailored orthoses with high mechanical strength and improved moisture resistance compared to traditional casts and glass fiber casts.

Conclusions: Materials such as polylactide (PLA) and PLA composites produced by Fused Filament Fabrication (FFF) demonstrate superior properties in static and dynamic tests. Furthermore, 3D-printed casts offer improved hygiene, greater comfort, a reduced risk of skin complications, such as wound healing, and high aesthetic acceptability. Clinical applications also include planning corrective osteotomies and the production of personalized surgical instruments. Although further research is needed on long-term durability and broad clinical outcomes, current reports indicate that 3D printing is a promising and increasingly viable alternative to traditional cast immobilization.

KEY WORDS: 3D printing, distal radius fracture, durability

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INTRODUCTION

Closed fractures of the distal radius and ulna are among the most common skeletal injuries and can occur in all age groups. Routine treatment involves temporary immobilization of the limb with a plaster cast. However, traditional plaster application techniques can be labor-intensive, largely dependent on the experience of the operator, and do not always provide optimal results [1]. Commonly used plaster materials have limitations, such as low mechanical strength and moisture resistance, difficulties in maintaining hygiene, and unpleasant odors [2]. From a clinical perspective, plaster casts are often perceived as uncomfortable; they can cause skin irritation and sometimes temporary numbness of the superficial branch of the radial nerve [1,3]. A significant problem with conservative treatment with plaster remains the high rate of secondary displacement of bone fragments [3]. Individually designed orthoses manufactured using 3D printing are increasingly becoming an alternative to traditional casts [3]. 3D printing is a rapidly developing technology that may, in the future, provide an alternative to traditional plaster casts [2]. It is gaining increasing importance in orthopedics, primarily due to the ability to individually tailor products to the patient and their efficient manufacturing process. Conservative fracture treatment has begun to utilize the concept of creating personalized 3D-printed immobilization devices, which are characterized by

precise fit to the patient's anatomy and an openwork, ventilated structure [4]. Three-dimensional (3D) printing, classified as additive manufacturing (AM) and rapid prototyping, involves building a three-dimensional object by applying successive layers of material. Unlike classical subtractive machining methods, where material is gradually removed from a solid block to achieve the desired shape, 3D printing creates a component by gradually adding it. This method is characterized by high versatility, enabling the production of complex structures from a variety of materials, such as polymers, ceramics, metals, and composites. This technology allows the design and production of structures with various geometries, both high density and macro- or microporous structures [5].

AIM

The review aimed at briefly presenting up-dated information on advances in 3D printed casts for perspective focusing on its diversity and need for complex approach.

MATERIALS AND METHODS

The research material was a review of the current literature advances in 3D printed casts for rehabilitation. For this purpose, the available data base was searched using Pub Med website, Google Scholar.

REVIEW

CAST AND 3D-PRINTING

Thanks to advances in medical imaging technologies and computer software, it is now possible to convert two-dimensional axial images into other planes (sagittal and coronal) as well as into three-dimensional (3D) virtual models that accurately replicate the individual anatomy of a patient. These digital data can then be thoroughly analyzed by orthopedic specialists to plan procedures tailored to the specific patient. The use of 3D printing in medicine is growing and becoming increasingly popular, as surgeons and researchers more frequently take advantage of the flexibility of this technology in producing a variety of objects. 3D printing is a manufacturing process in which materials such as plastics or metals are deposited layer by layer to create a three-dimensional object based on a digital model [6]. Advances in computer-aided design (CAD) software and 3D printing technology for personalized orthoses have opened new possibilities for improving conservative treatment. While these modern solutions allow for individualized design and production of orthoses, they also present challenges for researchers regarding the selection of appropriate designs, materials, and additive manufacturing methods. Different materials have specific properties that can influence the quality of the final print, and the chosen printing techniques determine the production time. Ideally, a 3D-printed orthosis should be precisely tailored to the patient's anatomy, providing optimal stabilization and immobilization of the fracture while offering greater comfort compared to a traditional plaster cast [3]. 3D digital models can be generated from CT scans using freely available software. These models can then be used to create physical models, plan procedures, or design surgical guides that assist the orthopedic surgeon during complex operations [7]. The development of 3D printing technology has enabled the introduction of new, standardized procedures for immobilization: additive manufacturing (AM) involves creating highly personalized cast models based on 3D anatomical data using digitally controlled material deposition tools. Compared to traditional plaster casts, AM-produced casts can potentially reduce the risk of skin complications while meeting mechanical and clinical requirements for functionality, comfort, and aesthetics [1].

Additive manufacturing represents a promising technology that can be used to produce personalized, more comfortable, and lightweight forearm orthoses and casts, although it requires careful selection of materials and process parameters [2]. The end result is a personalized 3D-printed cast with a highly ventilated structure, low weight while maintaining high strength, and hygienic benefits, reducing the risk of skin complications, potentially improving treatment efficacy, and increasing patient satisfaction [1].A malunion of the distal radius is a common complication following conservatively treated fractures in this region. When the malunion is clinically significant, treatment involves performing a corrective osteotomy (CO). The aim of corrective osteotomy is to restore the original bone alignment as accurately as possible by cutting the bone at the site of the previous fracture (osteotomy), followed by repositioning and stabilizing the bone fragments in a near-anatomical alignment.

Modern CO techniques combine three-dimensional (3D) preoperative virtual planning with the use of 3D-printed, patient-specific surgical instruments (PSI). In virtual planning, 3D models of both the affected and contralateral healthy radius are created based on bilateral computed tomography (CT) scans of the patient's forearm [8,9]. Additive manufacturing provides an advantage in producing objects with complex, freeform geometries, which is difficult or impossible to achieve using traditional subtractive methods [6].

TECHNOLOGIES

The cast model is first created based on patient images to achieve an individualized fit. A specialized method for creating geometric references has been developed to allow precise modeling of the cast. Its funnel-shaped design helps smooth edges and reduces the risk of bruising caused by minor limb movements. Ventilation patterns and holes are incorporated into the surface to improve hygiene and wearing comfort. Additionally, the cast can be adjusted to accommodate limb swelling during treatment [10]. To produce a 3D-printed cast, technicians use imaging data containing three-dimensional spatial information of the limb, obtained via a 3D scanner or medical imaging devices. Computer-aided design is then used to generate a stereolithography (STL) file ready for 3D printing [4]. A comparison was conducted between traditional materials standard plaster and fiberglass plaster and Polylactic Acid (PLA) materials as well as PLA–$CaCO_3$ composites produced using Fused Filament Fabrication (FFF), and functional casts were made from each of these materials. The materials were tested for tensile and bending strength. The results showed that tensile and bending strength decreased as the $CaCO_3$ content in the composite increased. In fatigue tests, traditional plaster and fiberglass plaster did not exhibit typical fatigue curves, whereas 3D-printed materials did. Cyclic loading tests further revealed that traditional casts cannot maintain the same load at the same deflection after previously being subjected to higher loads. These results clearly indicate that 3D-printed materials demonstrate superior properties in both static and dynamic mechanical tests. Therefore, 3D printing technology could soon provide an attractive alternative for personalized splints and casts. Materials produced using the FFF method, such as PLA and PLA–$CaCO_3$, exhibit better mechanical properties and higher water resistance compared to traditional plaster or fiberglass casts. Cyclic loading tests showed that 3D-printed casts do not require replacement after impact or loading, as PLA and $CaCO_3$ materials recover their original shape. These characteristics are beneficial for both patients and the healthcare system, improving treatment efficiency, enhancing patient compliance, and reducing the risk of complications such as infections or re-injury [2].

DISCUSSION

CAD software enables the development of designs tailored to the individual patient's anatomy, providing an alternative to conventional plaster casts. An orthosis designed in this manner can subsequently be manufactured using 3D printing technology and further refined through additive manufacturing techniques. The materials used in the analyzed designs are lighter than traditional plaster, water-resistant, and characterized by high mechanical strength. However, further studies are still required to evaluate their resistance to typical functional loads and accidental impacts. Some of the materials employed, such as polycarbonate, additionally exhibit flexibility, impermeability, UV resistance, and do not interfere with radiological imaging quality. The most commonly applied manufacturing method is FDM, valued for its low cost and its ability to produce complex, precise, and durable structures. The openwork design of 3D-printed orthoses enhances ventilation, facilitates skin inspection, improves hygiene, and increases aesthetic acceptance [3]. Prototypes produced using 3D printing technology are exceptionally lightweight, with a mass of approximately 10% of that of traditional solutions. Importantly, even a technician with limited experience can design such a cast within a short time, approximately 20 minutes using the proposed method [10]. A personalized 3D-printed cast ensures accurate adaptation to the limb, effectively immobilizing the injury site and maintaining proper alignment of bone fragments [11]. Studies have shown that this type of orthosis can generate appropriately directed corrective forces, supporting the maintenance of proper forearm alignment and resulting in satisfactory clinical outcomes and high patient comfort [4]. An individualized design reduces the risk of complications associated with localized excessive pressure, while the lightweight and ventilated structure minimizes skin-related issues and facilitates daily functioning. Improvements in the visual appearance of the cast, enhanced anatomical fit, and a beneficial effect on hand function during immobilization have also been reported. In numerous publications, patients express a clear preference for 3D-printed casts compared to traditional plaster casts [11-15]. The ability to precisely control the internal scaffold structure and to incorporate various materials, including bioactive components, enables the creation of an environment conducive to the healing process [1,10,16-19]. No serious complications have been reported with 3D-printed casts, whereas moderate adverse events have been observed more frequently with traditional plaster casts [17]. Personalized casts produced using dedicated software have been shown to be safe in the treatment of distal radius buckle fractures in children, which encourages the extension of this technology to more complex injuries [20]. Furthermore, screw fixation supported by a 3D-printed cast demonstrated superiority over minimally invasive plate osteosynthe-

sis in terms of operative time, fluoroscopic radiation exposure, restoration of calcaneal morphology, and functional outcomes in the treatment of displaced intra-articular calcaneal fractures (DIACFs) [21]. The rapid advancement of 3D printing technology highlights its growing importance in the production of personalized orthopedic and rehabilitation devices [10].

CONCLUSIONS

3D printing presents a promising future for casts development, offering personalized, cost-effective, and efficient solutions for patients. While challenges persist, ongoing research and technological advancements are likely to address existing limitations, paving the way for broader clinical adoption and improved patient care.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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