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Review Article

Transforming Medicine Through 3D Printing: Evaluating Its Impact on Devices, Drugs and Organ Bioprinting

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ABSTRACT

This paper examines the transformative potential of 3D printing in the medical field, focusing on its applications in medical devices, pharmaceuticals and organ bioprinting. It evaluates how additive manufacturing enables the creation of cost-effective, patient-specific devices such as prosthetics, implants and hearing aids, which are already in mainstream use. In pharmaceuticals, 3D printing has facilitated the production of personalised drugs, exemplified by the FDA-approved Spritam, though scalability and regulatory challenges hinder wider adoption. The paper also explores advancements in organ bioprinting, where printed tissues and miniature organs indicate future solutions to organ shortages. While 3D printing is reshaping aspects of healthcare, its adoption remains uneven due to ethical, technical and financial barriers. Ultimately, overcoming these challenges could allow 3D printing to revolutionise medicine by delivering safer, more personalised and accessible healthcare solutions worldwide.

Keywords: 3D printing, medical devices, personalised medicine, organ bioprinting, healthcare innovation

INTRODUCTION

3D printing, also known as additive manufacturing, is a process that creates a three-dimensional object layer by layer from a digital 3D model on a computer. Initially, it was invented to address the need for faster and more cost-effective ways to create prototypes for manufacturing and product development. Charles Hull's development of this technology enabled him to create physical models from thin layers of material using computer-aided design (CAD) (Cup, 2024). 3D printing has evolved over the years, becoming more precise and efficient. It has also expanded its applications beyond manufacturing, finding opportunities in the medical field.

The healthcare sector faces several challenges. For instance, there is a significant global shortage of organ donors, leaving patients vulnerable. Medical devices, such as implants or prosthetics, are expensive and often time-consuming to produce. Moreover, traditional methods of producing drugs and treatments offer limited personalisation and require years of testing and development, making it difficult to prescribe them to individual patients. 3D printing shows great potential to address these challenges. It can be used to create customised implants, surgical tools, prosthetics, and even models of organs that help doctors visualise complex surgeries (Sybridge Technologies, 2020). The healthcare 3D printing market size was valued at USD 8.52 billion in 2023 and it is projected to reach over USD 27.29 billion by 2030 (Grand View Research, 2024), demonstrating how notable this technology is becoming in medicine. In line with the aforementioned, this paper aims to answer the following research question: To what extent can 3D printing transform the medical field in terms of devices, drugs, and organ printing?

This paper argues that while 3D printing has already proven to be effective in producing customised medical devices and shows great promise in areas such as drug development and organ bioprinting, its full-scale integration into healthcare is not to be considered without its challenges. Regulatory approval, ethical considerations, and technological limitations continue to be significant barriers. Therefore, while 3D printing is set to play a transformative role in the future of medicine, its utilisation will depend on overcoming these challenges to ensure safety, accessibility and long-term quality.

Background and Problem Statement

3D printing has become remarkable over the past few years. The concept was initiated in the 1970s, but the first experiment started in 1981 (Sculpteo, 2019). In 1984, Charles Hull filed the first patent for stereolithography (SLA), a machine that uses ultraviolet light to fabricate complex parts with photopolymer resin layer by layer, in half the time it usually takes (Turney, 2021). This invention laid the foundation for the rapidly expanding industry today. In the early years, 3D printing was primarily used for industrial prototyping, which meant creating prototypes for product development. This provided engineers with a faster and cost-effective way to test designs before mass production (Castaneda, 2019).

3D printing, also known as additive manufacturing, differs from subtractive manufacturing. Additive manufacturing creates objects by adding materials layer by layer from a digital model, while subtractive manufacturing removes materials to create parts. Additive manufacturing enables the creation of complex geometries with reduced time and costs. Different types of technological categories have emerged over the years. Stereolithography (SLA) 3D printing, mentioned previously, exposes a light source to cure liquid resin into a three-dimensional object. SLA 3D printing offers the highest speed, resolution, and accuracy among 3D printing technologies as well as producing sharp details and smooth surface finishes (FormLabs, 2015). Fused Deposition Modelling (FDM), also known as Fused Filament Fabrication (FFF), builds parts layer by layer using melted thermoplastic filaments. FDM is the most widely used in many industries (Protolabs Network, 2024). Selective Laser Sintering (SLS) uses a high-power laser to fuse small particles of powdered material into a solid structure based on a 3D model. It has become a popular choice for manufacturers and engineers over the years due to its high productivity (FormLabs, 2025). These processes share the same principles as additive manufacturing, although they vary in materials, applications and precision.

Modern medicine, although advancing rapidly, still faces challenges that require leveraging new technological advancements, such as 3D printing. The first major issue is the organ shortage crisis. In the United States alone, more than 100,000 people remain on the national transplant list, and approximately 13 patients die every day while waiting for a suitable donor (HRSA, 2025). This significant gap in donor supply highlights the limitations of the transplant system and underscores the importance of finding an alternative approach to organ replacement. It is unacceptable that a patient remains vulnerable, not from the lack of medical expertise or treatment, simply because of the unavailability of donor organs.

The second challenge is the cost and accessibility gap in medical devices. Life-changing technologies, such as prosthetics and implants, are expensive due to the complexity of design, the high cost of materials and the extensive manufacturing measures required for customisations. For example, a simple prosthetic leg can cost between $3,000 to more than $120,000, depending on its sophistication and materials (Zepeda, 2024). The World Health Organisation (WHO) estimates that only one in ten people in need have access to assistive products, due to their high cost and a lack of awareness, availability, and trained professionals (World Health Organisation, 2017). In developed countries, patients may be fortunate to have medical insurance, which can help offset some of these expenses; however, in some developing nations, patients are left without any access to these life-changing technologies. This unequal access widens global health disparities; individuals in wealthier regions can gain mobility more quickly than those in poorer regions with limited accessibility.

The third issue lies in the inefficiency of the drug development process. In 2019, the pharmaceutical industry invested approximately $83 billion in research and development (R&D) (Austin & Hayford, 2021). The drug discovery and development process can take around 10 to 15 years (Dobie, 2024). Even after extensive development, it still fails to account for patient differences. Most drugs are developed to be "one-size-fits-all". Genetics plays a vital role in how patients respond to medication, and because everyone has a unique genetic makeup, standardised drug dosages often fail to achieve the intended result. As the field expands, it emphasises personalised healthcare; however, manufacturing and pharmaceutical processes still struggle to be equipped to deliver customised solutions, highlighting a critical gap.

Such problems in healthcare, including organ scarcity, high costs, limited accessibility, inefficiencies in drug development, and the lack of personalised treatments, require an urgent need for innovative solutions. Among all the emerging technologies, 3D printing appears promising with its ability to provide solutions ranging from customised medical devices to potentially producing working organs. The pharmaceutical industry has begun to slowly embrace 3D printing, with FDA approvals in the US (Mesko, 2024). This tool can play a significant role in the future of medicine.

3D Printing in Medical Devices

Additive manufacturing has revolutionised the prosthetics field by opening opportunities for customisation, allowing patients to have access to devices that are personalised just for them. 3D printing has enabled the manufacturing of lighter designs, offering unique aesthetics and durability. It can also print more complex geometries compared to other production technologies. One of the leading examples of 3D printing's impact on prosthetics is the community known as e-NABLE. They have developed an open-source design that allows volunteers worldwide to 3D print a prosthetic hand for children, as shown in Image 1, for as low as $50 (e-Nable, 2023), compared to traditional prosthetics, which can range from $3,000 to over $120,000 (Zepeda, 2024). This drastic decrease in prices has empowered access, especially for children who can still outgrow devices, making replacements more feasible for families. However, significant challenges remain: 3D printed prosthetics are often less durable than conventional ones, are made of non-medical materials, and may lack clinical oversight from approved professionals for safety and functionality. 3D printing has opened up many opportunities for customisable and affordable prosthetics; however, further improvements are needed to achieve widespread, reliable adoption.

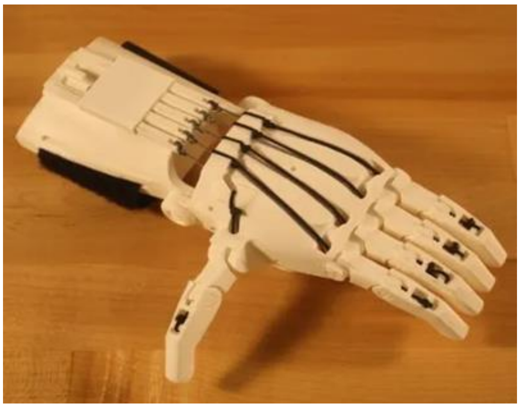

Image 1: The Raptor Reloaded hand by e-NABLE

3D printing has also made a significant impact in developing implants by matching patients' unique physiology and anatomy, providing the best fit. Real-life cases demonstrate its clinical potential. For example, the FDA cleared Oxford Performance Materials' OsteoFab Patient-Specific Cranial Device (seen in Image 2) in 2013, marking the first polymer 3D-printed cranial implant (OsteoFab, 2024), and in 2016, Stryker's Trident II Tritanium Acetabular Shells became the first fully additively manufactured hip replacement that received FDA 510(k) approval (Stryker, 2024). Such approvals demonstrate a motivation to facilitate the growth of 3D printing in the medical field. These technologies offer several advantages, including complex lattice structures that improve bone integration, faster turnaround times for patient-specific implants, and customised designs that lower surgical complication rates. However, some barriers remain. Long-term safety data are still limited, production is expensive, and regulatory pathways are still adapting (the FDA's 2017 guidance outlines concerns about consistency and sterilisation). Failing to address these challenges restricts 3D printing from reaching its full potential in implants.

Image 2: The Osteo Fab 3D-printed cranial implant

Hearing aids and dental devices are prime examples of how 3D printing enables mass customisation in healthcare. In 2013, the hearing aid industry underwent a significant shift when a major company, such as Sonova, adopted a production process that relied entirely on additive manufacturing (Sonova, 2025). This change allowed manufacturers to design custom shells that matched each patient's ear with greater precision than the traditional methods. Now, the industry produces millions of personalised hearing aids annually, making 3D printing one of the widely adopted technologies in the industry. Dentistry has had similar developments with their production of crowns, bridges and orthodontic aligners (Jeong et al., 2023). Previously, the manufacturing of such devices required labour-intensive work and lengthy laboratory development hours, resulting in patients waiting weeks for treatment. With 3D printing, digital scans can be taken almost immediately, ensuring patients receive perfectly fitting devices in just a few days (Alqutaibi et al., 2024). Apart from speed and reliability, these devices demonstrate how additive manufacturing can deliver large-scale personalisation while still maintaining efficiency.

The evaluation of 3D printing in medical devices raises a question about whether it is a niche invention or a larger-scale industry solution. So far, its most substantial impact has been the ability to produce high-quality customisable products, like low-cost prosthetics, patient-specific implants and mass-customised devices like hearing aids and dental aligners. These cases demonstrate that 3D printing has progressed beyond experimental developments and has now become mainstream in certain areas of the medical field. Yet, universal adoption still seems to be out of reach due to production costs, limited long-term safety data, and regulatory challenges with FDA approvals. Access remains uneven, with wealthier areas able to adopt this technology while developing regions remain excluded. Thus, 3D printing, for now, is best distinguished as a transformative but niche technology, one that has demonstrated its potential; however, it still needs to undergo significant changes before being scaled to the entire healthcare industry.

3D Printing Drugs & Organs

The most common application of 3D printing in the pharmaceutical industry is the production of tablets and capsules. A significant moment of 3D printing in pharmaceuticals came in 2015, when the FDA officially approved Spritam (levetiracetam), introduced by Aprecia Pharmaceuticals as the world's first 3D-printed pill. It is designed as a therapy for the treatment of seizures. Spritam is a revolutionary drug that is quick to dissolve, making it easier for patients who have swallowing difficulties (Epilepsy Foundation, 2015). This case illustrates how 3D printing can enhance drug delivery in ways that traditional pill manufacturing cannot.

Furthermore, the importance of personalised drugs is increasing, given that each person's genetic makeup is different and influences how they respond to certain medications. These differences affect pharmacokinetics (how a person responds to a drug) and pharmacodynamics (how the drug affects the body). The standard 'one-size-fits-all' concept may be ineffective and harmful for many with certain drug-taking restrictions. Tailoring medicines to individual needs ensures safer and more effective treatment. 3D printing further opens opportunities for personalised dosing, in which medication can be precisely tailored for children, the elderly or even patients with certain conditions. It also supports the production of polypills, which combine multiple drugs into a single tablet, simplifying treatment for patients with complex prescriptions (Mayo Clinic, 2024). Researchers can precisely control the placement and layering of active ingredients, allowing timed or sequential drug release. This flexibility supports the creation of personalised regimens where drugs act at different intervals within one pill. Additionally, the medical field is often criticised for being unsustainable due to the production of drugs and medical devices, which can generate significant amounts of material waste. The US annually produced over 6 million tonnes of medical waste in 2024 and this is projected to continue to increase (Markntel Advisors, 2024). Once again, while traditional manufacturing methods are designed for mass production rather than efficiency, 3D printing utilises additive processes, which reduce waste and support more sustainable, on-demand manufacturing in healthcare (Markforged, 2024).

Despite all these advantages, widespread adoption still seems to be limited. Specialised pharmaceutical printers are expensive, and scaling production to industrial levels is not viable. Regulatory organisations also pose barriers, such as the FDA's requirement for strict reproducibility, but even minor changes in the manufacturing process can severely affect drug quality. Pharmaceutical companies are hesitant to shift away from conventional drug development methods, which are already well-established, to 3D printing, which appears to be financially and operationally disruptive and difficult to manage.

Regarding the 3D printing of organs, the global organ shortage has reached a critical point. In the European Union, about 26,000 organ transplants took place in 2021 (including 15,684 kidney, 6,483 liver, 2,026 heart, and 1,711 lung transplants). Yet, more than 52,000 patients remained on transplant waiting lists - double the number of actual transplants. Traditional transplant systems are not able to meet the high demand, causing several lives to be lost. Even when transplant

organs have been available, compatibility issues, long waiting times, and unequal access across different regions worldwide further intensify the crisis, making transplantation an uncertain and often inaccessible solution for many patients (Bauer-Babef, 2023). This has prompted researchers to explore alternative solutions, one of the most promising being bioprinting.
A specialised branch of 3D printing, known as bioprinting, has recently emerged. It is a technology that utilises bio-inks containing living cells to create tissue-like structures, thereby opening the possibility of fabricating biological components for research and therapeutic applications. It continues to follow the same process as additive manufacturing (Cellink, 2019). Although it is a relatively new technological development, it has already demonstrated its great ability in 3D printing, extending beyond industrial applications.
For example, Organovo has successfully bioprinted small sections of liver and kidney tissues, which are used for drug testing and disease modelling, although not yet for transplantation. This achievement is significant as it enables pharmaceutical companies to test new drugs on human-like tissues, rather than relying on animal models that inaccurately represent human responses. By creating reproducible tissue samples, bioprinting has the potential to reduce costs, speed up drug discovery and improve patient safety (Neff, 2017).
Furthermore, at the Wake Forest Institute for Regenerative Medicine, researchers were able to produce scaffolds of ears and bladders (Fox, 2016), thus proving that relatively simple organ structures can be engineered. This demonstrates how 3D printing can not only be used to recreate flat tissue but can also print three-dimensional, anatomically complex shapes. These scaffolds provide a foundation for how living cells can be involved in the engineering of implants that can replace damaged body parts in patients.
A major breakthrough that accurately demonstrated the potential of 3D printing occurred in 2019, when researchers at Tel Aviv University successfully printed a small heart, as seen in Image 3. They did this by using the patient's cells and biological material. Although the size of the heart was relatively small, almost the same size as a rabbit's (Tel Aviv University, 2019), this breakthrough was historic because vascularisation – the ability to print blood vessels – has been one of the biggest challenges in organ engineering. By demonstrating the feasibility of printing a heart with blood vessels and immune-compatible cells, the Tel-Aviv team highlighted a crucial step toward further developing fully functional, transplantable organs in the future.


Image 3: First-ever 3D printed heart

The benefits of these breakthroughs are profound. If fully functioning organs can be bioprinted, the transplant list would drop dramatically, saving countless lives. Furthermore, rejection is one of the risks of traditional transplantation. Five out of 52 recipients who experienced rejection had died (Akhil et al., 2024). Because bioprinting can use the patient's own cells, the risk of immune rejection will also decrease, allowing the organs to be the 'perfect fit'. Beyond transplantation, bioprinting can also be utilised in regenerative medicine, where damaged tissues are repaired or replaced in situ, thereby transforming the treatment of chronic diseases and injuries (Ma et al., 2024).
One of the technical hurdles is printing organs in full, functional vascular networks at the human scale; without a proper blood supply, tissues cannot survive. Additionally, the costs of bioprinting are incredibly high,

and access to it is limited. Furthermore, ethical issues arise: who should own a bioprinted organ, and should human tissues be commercialised? These issues must be addressed when adopting large-scale technologies, such as 3D printing, for these matters.

CONCLUSION

3D printing can transform the medical field, particularly in the areas of device, drug, and organ printing. 3D printing has demonstrated effectiveness in creating customised medical devices and holds potential in pharmaceuticals and bioprinting; however, its widespread adoption remains limited due to regulatory, ethical, financial, and technical barriers.

The discussion of medical devices demonstrates how prosthetics, implants, hearing aids and dental tools already benefit from 3D printing as they are able to deliver cost-effective, patient-specific and efficient solutions. In pharmaceuticals, the technology has enabled the production of personalised medicines, including the world's first FDA-approved 3D-printed pill, Spritam. However, pharmaceutical adoption remains slow due to cost, scalability and regulatory challenges. Finally, organ bioprinting, although still in its early stages, has achieved breakthroughs, including the bioprinting of tissues and even a miniature heart, illustrating how the organ shortage can be significantly reduced in the future.

The significance of these findings shows that 3D printing is no longer just a niche experiment; it is already reshaping certain aspects of medicine. However, the pace and scope of this development are causing adoption to be uneven. Medical devices have transitioned into mainstream use in certain areas, but 3D-printed drugs remain underadopted despite having technical proof, and organ bioprinting continues to remain experimental. This unevenness limits its further development in medicine, reflecting that medicine is cautious in adopting disruptive technology that directly impacts patient safety.

Overall, 3D printing holds enormous transformative potential in healthcare, but its future depends on overcoming these barriers. The key takeaway is that while 3D printing has made remarkable changes, it still requires development in some areas to be widely adopted. If these challenges are addressed, the technology could ultimately redefine boundaries of modern medicine, making treatment safer, more personalised and accessible worldwide.

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