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Review Study

A Review: 3D Printing in Medical Technology

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ABSTRACT

This article looks at how 3D printing is being used in medicine today. It starts by explaining how and why 3D printing is changing the way doctors work, teach, and do research. Then, it gives some recent examples to show what is currently possible with this technology. Finally, it talks about the limits of 3D printing in medicine and where we might see improvements in the future in recent years, 3D printing has become a powerful tool in healthcare, offering personalized solutions for patients. It allows for the creation of custom implants, prosthetics, and even models of organs that help surgeons plan complex procedures more accurately. Medical students and professionals use 3D-printed models for better hands-on learning and training. Researchers are also exploring how 3D printing can be used to produce tissues and organs using biocompatible materials. Despite these advancements, challenges like high costs, limited material options, and regulatory issues remain. However, ongoing innovation and research suggest that 3D printing will continue to play a major role in the future of personalized and precision medicine.[1].

INTRODUCTION

This paper talks about how 3D printing is being used in many areas, especially in medicine. One important use is bio printing, which means using 3D printers to make things like body parts, models, or even living tissue. We will look at some new ideas and how they might help in the future before surgery, doctors need to plan carefully. They usually use medical images like X-rays or CT scans. But now, they can also use 3D-printed models of the body part they are going to operate on. These models help doctors see and feel what they will be working on, which helps them make better choices and work faster during surgery. This can lead to better results for the patient doctors can also use 3D printing to make custom-made artificial body parts, like arms, legs, or joints. These can be made faster and more cheaply than older methods. This means patients can get the help they need sooner.3D-printed models are also great for training future doctors. Instead of using

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real human bodies, students can practice on models that look like real body parts. This helps them learn safely and give better care in the future. in science and research, 3D bio printing is helping to study diseases, like cancer. Scientists like Zhao and his team have shown how it can be used to build more realistic disease models. Another exciting idea is mixing 3D bio printing with tiny fluid systems, called micro fluidics. This helps build more complex tissues. Snyder and his team are working on this. This kind of work might help us build real human organs someday but right now, printing full organs is still not possible. Scientists like Lode are working on it, but it's hard to make something strong and complex enough to work like a real organ. For example, printing a working heart valve is still very difficult [1]

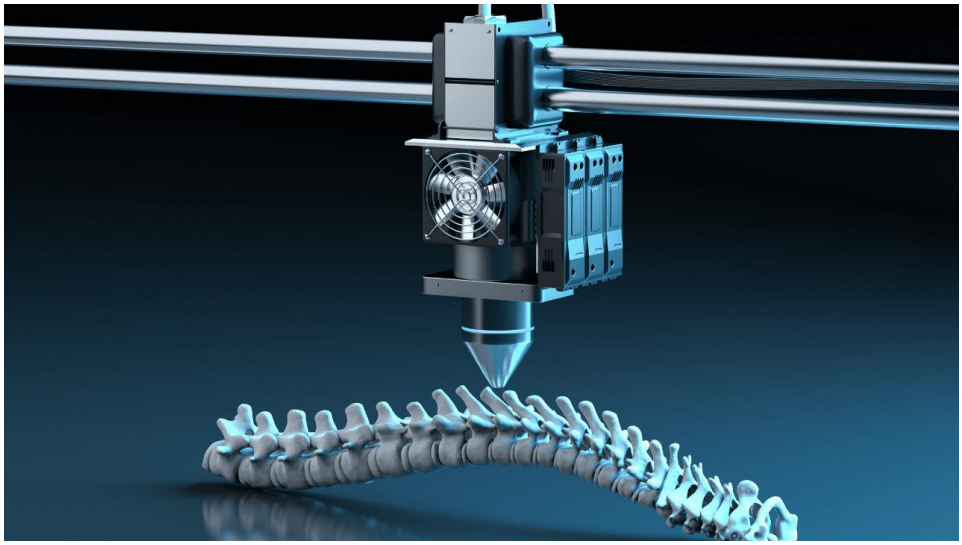

Figure 1: 3d Printing Medical Device

Types of 3D printing technology: 1. Thermal Ink-Jet Printing [2,3] Thermal inkjet printing works by heating the ink with a tiny resistor. This heat turns the liquid ink into gas, creating pressure that pushes a drop of ink out of a nozzle. **2. Inkjet printing [4]** This is a type of 3D printing that uses powder as the main material. A mixture of ink and active ingredients is sprayed layer by layer on the powder. The tiny ink droplets dry and form a solid shape, like a pill or tablet for medicine-making, the ink is replaced with a liquid that has drugs in it. Instead of normal paper, edible sheets (which can be safely eaten) are used as the base. **3. Selective Laser Sintering (SLS) [5]** Selective Laser Sintering (SLS) is a fast way to make 3D objects. It uses metal powder as the main material. This method is often used to quickly make and test new designs (called prototyping) SLS works by using a laser beam to heat and join the powder. The laser moves over the surface of the powder and draws a pattern. This pattern hardens the powder and forms the shape of the object, one layer at a time. Slowly, the layers build up to create the full 3D structure. **4. Fused Deposition Modeling [6]** Fused Deposition Modeling (FDM) printers are more common and cheaper than Selective Laser Sintering (SLS) printers instead of ink, FDM printers use heated plastic, which comes out in small drops from the printer head. These drops are placed in thin layers, one on top of another, to build the object. **5. Stereo Lithography [7]** Stereo lithography was invented by Charles Hull in 1988. It works by using a laser controlled by a computer to harden a liquid plastic (polymer) into solid layers this process builds the object layer by layer, creating a full 3D shape it is used to make parts

that are very accurate and have fine details. **6. Hot melt extrusion [8]** In this type of 3D printing, plastic (polymer) and medicine (drug) are heated under high temperature and pressure to mix them together the process involves several steps like feeding, heating, mixing, and shaping the material this method is called Hot Melt Extrusion. It is often used to help improve the solubility and absorption (bioavailability) of drugs that don't dissolve well in the body. **7. Extrusion 3D Printing [9]** In this 3D printing method, plastic and medicine are heated and mixed together using high heat and pressure the process includes steps like adding materials, heating them, mixing them well, and shaping them this method is called Hot Melt Extrusion. It helps make medicines that don't dissolve easily in the body work better. **8. Zip dose [10]** Zip Dose 3D printing is the first and only 3D printing method for making medicines that is approved by the FDA for large-scale use this method is used to make tablets with high doses of medicine that are also easily absorbed by the body. It uses precise digital layering without pressing the tablet hard (no compression) because of this, the tablets are easy to swallow, which helps people who have trouble swallowing pills.

Applications of 3D Printing in Medical Technology:

Patient-Specific Implants [11]: 3D printing gives the creation of implants which precisely match a patient's unique structure such as cranial plates, hip joints, and prosthetic limbs**.** Patient-Specific Implants are custom-made medical implants designed to match the unique anatomy of an individual. These are especially useful when off-the-shelf implants don't offer the precision or fit needed for complex cases.

Figure 2: 3D printed dental implants

Surgical Guides and Tools [12]: 3D-printed models can be used to guide surgeons during complex procedures, ensuring accurate placement of implants or instruments**.** Surgical Guides are custom-made devices that help surgeons precisely position and align instrument**s** or implants during an operation. Surgical Tools like clamps, retractors, and forceps can also be 3D printed, customized for specific surgeries or patient anatomy.

Figure 3: 3d Printed Surgical Instruments

Drug Delivery Systems [13]: 3D printing technique give opportunity to create personalized drug delivery devices, including 3D-printed pills with multiple drug compartments and customized release profiles these are drug-containing devices or forms (like pills, patches, or implants) that are custom-manufactured using 3D printing to control the release, dosage, and delivery location of medications inside the body

Benefits of 3D Printing in Medical Technology:

Personalized Treatments [14]:

- 3D printing allows tailor-made medical devices, implants, and prosthetics that perfectly match a patient's body.
- Improves comfort, fit, and functionality compared to mass-produced options
- 3D printing can rapidly produce complex items.
- This means faster treatment, especially critical for surgeries, bone injuries, and emergencies.

Improved Surgical Planning [15]:

 Patient-Specific Models: Surgeon's 3D prints exact replicas of a patient's organs, bones, or tumors based on CT or MRI scans.

 Practice Before Surgery: Doctors can physically hold, study, and practice on a life-like model before the real operation.

 Better Visualization: Complex structures (like heart defects, brain tumors, or twisted fractures) become much easier to understand in 3D than on flat images.

 Customized Surgical Tools: 3D printing can create surgical guides or instruments specific to the patient's anatomy, improving precision.

Streamlined Drug Administration [16]:

- Custom Dosages: Medications can be printed with personalized doses based on a patient's age, weight, genetics, or condition.
- Controlled Release: 3D printing can design pills that release drugs at specific times or different rates — like slow release over 24 hours.
- Combination Pills: Multiple medications can be printed into one single pill, making treatment simpler (especially for people with chronic illnesses).
- Unique Shapes and Textures: Pills can be printed in special shapes that dissolve faster, taste better, or are easier to swallow.

Reduced Costs and Waste [17]:

- Exact Production: 3D printing uses only the material needed, minimizing leftover waste compared to traditional manufacturing.
- Fewer Prototypes: Custom models, implants, and tools can be printed perfectly the first time, avoiding the cost of multiple prototypes.
- On-Demand Manufacturing: Items can be printed only when needed, eliminating the cost of large inventories and storage.
- Cheaper Customization: Personalizing an implant or device with 3D printing is much cheaper than traditional custom manufacturing, which often requires expensive molds or special tools.

Faster Development and Iteration [18]:

- Rapid Prototyping: 3D printers can quickly create new models, implants, prosthetics, or devices for testing — sometimes within hours.

- Easy Adjustments: If a design isn't perfect, it can be modified digitally and reprinted quickly, skipping the long traditional manufacturing process.

- Parallel Testing: Multiple versions of a design can be printed and tested at the same time to find the best fit or function.

Shorter Design Cycles: Doctors and engineers can collaborate faster, going from idea to finished product in days instead of months. **Jong Woo et al [19]2015** Conducted systematic review that underscores the clinical applications of 3D printing in craniofacial plastic surgery. Their findings indicate that 3D printing is not only utilized for creating patient-specific models but has also extended to bio-cell printing, which facilitates the development of tissues and organs. This versatility positions 3D printing as a critical tool in personalized medicine, allowing for tailored solutions that enhance surgical outcomes. **Min Kwan Kim *et al* [20] 2016** In the realm of ortho pedis emphasizes the importance of 3D printing in producing patient-specific applications. The process begins with clinical imaging, which is then translated into 3D printed models that assist surgeons in preoperative planning and intraoperative guidance. This application of 3D printing enhances precision in surgical procedures, potentially leading to improved patient recovery times and outcomes. **Kwok Chuen Wonget al [21] 2018** The production of titanium bone implants is another significant application of 3D printing, as detailed by Their review outlines the comprehensive process from initial imaging to the final production of implants, highlighting the technological advancements that enable the creation of customized implants tailored to individual patient anatomy. This capability not only improves the fit and function of implants but also reduces the risk of complications associated with traditional implant methods. **Vladimir V Popov et al [22]2019** Provide a broader overview of additive manufacturing in healthcare, noting that while the technology is still evolving, it has already begun to address the pressing demands for optimal performance and cost reduction in medical settings. The authors argue that 3D printing can significantly enhance the efficiency of healthcare delivery by enabling rapid prototyping and production of medical devices. **Mohd Javaid *et al* [23] 2019** In the context of surgery discuss the potential of 3D printing to revolutionize surgical training and patient care. Their analysis suggests that the technology could lead to the establishment of new hospital facilities designed to leverage 3D printed models for enhanced surgical education and practice. **Md Shoaib Alam *et al* [24] 2019** Provide insights into the evolution of pharmaceutical product development through 3D printing technology they summarize various strategies that leverage in-depth knowledge of drug properties and manufacturing processes to innovate drug delivery systems, bridging the gap between conventional method and novel approaches. **A. Uziel *et al* [25] 2019** Conduct a state-of-the-art survey on 3D printing for drug delivery devices, highlighting the advantages of this technology, such as the ability to design complex shapes and tailor dosages to individual patient needs. They also address the limitations of current methods, providing a balanced perspective on the potential and challenges of 3D printing in drug delivery. **Pattaraporn Panraksa *et al* *[26]* 2021** Research by focuses on the use of hydrophilic polymers in the 3D printing of or dispersible films, showcasing the feasibility of using various polymeric materials in pharmaceutical applications. Their findings contribute to the understanding of material selection in the design of 3D printed drug delivery system. **Mengsuo Cui*et al* [27] 2022** Explore the fabrication of customized implantable drug delivery systems for orthopedic therapy using 3D

printing technologies. Their study highlights the application of semisolid extrusion and FDM techniques, demonstrating the potential for personalized medicine through tailored drug delivery solutions. **Qiqi Gaod *et al* [28] 2022** Discuss the advancements in 3D printing techniques, particularly in the context of smart constructs that utilize stimuli-responsive biomaterials. This review emphasizes the role of 3D printing in the development of precision medicine, where drug delivery systems can be designed to respond dynamically to physiological conditions. **Rabinarayan Parhi *et al [29]* 2024** Finally examine the evolution of 3D printing into 4D printing, which incorporates smart materials that can change shape or properties in response to external stimuli. This advancement represents a significant leap in drug delivery systems, offering new possibilities for responsive and adaptive therapies. **Javaid Haleem *et al* [30] 2018** The future of 3D printing in healthcare is promising. Experts predict advancements in 3D bioprinting of functional organs, patient-specific drug printing, and on-site medical manufacturing at hospitals. Technologies like 4D printing, where materials adapt and transform over time, may further revolutionize personalized medicine. **Rengier *et al* [31] 2010** Surgeons use 3D printed models to simulate complex surgeries, improving surgical precision and reducing operation times Patient-specific models derived from CT and MRI scans allow better visualization of tumors, vascular systems, and bone structures. **Tack *et al* [32] 2016** Custom implants, such as cranial plates, spinal cages, and dental prosthetics, are now frequently 3D printed. These implants offer a better anatomical fit and improved recovery outcome. **Murphy A *et al* [33,34] 2014** 3D bioprinting uses bio-inks made of living cells to fabricate tissues and, in the future, whole organs. demonstrated early success with printing simple tissues like cartilage and skin, although full organ printing remains under research.

DISCUSSION

This paper talks about many ways 3D printing is being used, especially in medicine and bio printing. It looks at what we've learned from recent progress and how we might use these ideas in the future. for many surgeries, careful planning is needed to get good results. Besides regular scans and images, doctors can now use 3D-printed models of organs. These models help surgeons see different options before the surgery. They are made from high-quality CT scans and help doctors understand the surgery better, finish faster, and get better results. 3D printing also helps make custom-made body parts, like prosthetics, that fit the patient perfectly. This process is faster and cheaper than other methods. These printed models are also great for training doctors. They can be used instead of real human bodies and help doctors practice for real-life surgeries. Bio printing (printing with living cells) is also improving. It's helping researchers study diseases like cancer more accurately.

CONCLUSION

3D printing has revolutionized the field of medical technology, offering innovative solutions that were once thought impossible. From custom prosthetics and implants to bioprinter tissues and patient-specific surgical models, this technology has significantly improved patient outcomes, reduced healthcare costs, and enhanced the precision of medical treatments. The adaptability and personalization that 3D printing brings to healthcare have transformed traditional practices and opened new avenues for research and clinical application.Despite its remarkable advancements, challenges such as regulatory hurdles, material limitations, and ethical considerations remain.

Addressing these issues through interdisciplinary collaboration, rigorous testing, and continuous technological development will be crucial to fully realizing the potential of 3D printing in medicine. Looking forward, as materials science evolves and bio printing techniques advance, the future holds promise for printing fully functional organs and complex tissues, potentially alleviating the global shortage of organ donors. Ultimately, 3D printing stands as a transformative force in medical technology, reshaping how we approach healthcare and offering new hope for patients worldwide.

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