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# Review On Advances In Additive Manufacturing Technology For Bio-Medical Applications

[1]Dr.Rohit P. Jadhav, [2]Dr.Shrikant B. Thorat, [3]Dr.Abhijit A. Patil
[1,2,3]Assistant Professor
[1,2]Department of Robotics & Automation, D.Y. Patil College of Engineering, Akurdi, Pune, Maharashtra, India
[3]Department of Mechanical Engineering, Sanjay Ghodawat University, Kolhapur, Maharashtra, India

***Abstract:*** Additive Manufacturing (AM) technologies permit to build up products with high level of geometrical complex shape and personalized as unique product by implying low cost and quick time production compared with other manufacturing processes. There is an increasing need for custom-made products in the medical sector. 3D printing plays a crucial role in personalization of medical products, evolving from “mass production” to “mass individualization”. Additive manufacturing has a wide range of medical applications, and is extremely important to reconstructive surgery. 3D printing is widely used for the development of products ranging from dental implants to heart valves and joint replacements. AM creates accurate three dimensional models, which will help the surgeons for understanding the anatomy of individual patients. It also help for training purpose for the medical institutions, cardio training. The role of 4D printing is also emerging for precisely manufacturing the heart model. 4D printing technology has the potential to manufacture a specific part or customized model of artificial hearts. This innovation can solve this long term problem and opens a new path for heart patients. Heart model printed by 4D technology can also grow with the passage of time and change of temperature.in future 4D printing technology will be also used in printing livers, kidney by using smart materials with perfect fitting and genetically matching

*Keywords* - Additive Manufacturing, 3DP, 4DP, Customization, Cardiology, Smart Materials

## 1. Introduction

Cardiovascular diseases now days are tremendously increasing, millions of peoples are suffering from heart diseases in early stages of life. Millions of people need help every year to overcome these cardiovascular related diseases [1]. Additive manufacturing is providing better solution to such patients for having quick recovery. It is an emerging and crucial adjunctive tool which can help cardiologists and cardiac surgeons for intervention and surgical planning, monitoring and analysis. AM technologies can produce custom parts, replacement parts and short series production runs to be used as a final Product by the user starting as a three-dimensional (3D) images or CAD file which is converted to STL format. AM technologies have increased its use and presence in the market of final parts because their advantages. Some examples can be summarized as, other manufacturing processes do not allow producing parts with some complex geometry and personalized part due to high inversion cost while AM can produce unique parts with difficult geometries [2-3].

## 2. LITERATURE REVIEW

Matt Zarek (2016), Presented the convergence of additive manufacturing and shape-morphing materials is promising for the advancement of personalized medical devices. The capability to transform 3D objects from one shape to another, right off the print bed, is known as 4D printing. Shape memory thermosets can be tailored to have a range of thermo mechanical properties favorable to medical devices, but processing them is a challenge because they are insoluble and do not flow at any temperature. Marija Vukicevic (2017) discussed the basic principles of clinical image segmentation, including coregistration of multiple imaging datasets to create an anatomic model of interest. With applications in congenital heart disease, coronary artery disease, and surgical and catheter-based structural disease, 3D printing is a new tool that is challenging how we image, plan, and carries out cardiovascular interventions Abid Haleem (2018), Additive manufacturing (AM) has emerged as a serious planning, strategy, and education tool in cardiovascular medicine. This review describes and illustrates the application, development and associated limitation of additive manufacturing in the field of cardiology by studying research papers on AM in medicine/cardiology. AM creates an accurate three-dimensional anatomical model to explain, understand and prepare for complex medical procedures. A prior study of patient's 3D heart model can help doctors understand the anatomy of the individual patient, which may also be used create training modules for institutions and surgeons for medical training. Abid Haleem (2018), in the modern era, 4D printing could take the challenges of smart heart model. It will tackle the number of the issue faced in the cardiology. 4D printing has a great ability to control the arrangement of cells concerning time. In the future, it will create a good collaboration among scientists, physicians, biomedical engineers and surgeon to optimize high requirement of cardiology.Elena Milano (2018), Three-dimensional (3D) printing technology in congenital cardiology and cardiac surgery has experienced a rapid development over the last decade. In presence of complex cardiac and extra-cardiac anatomies, the creation of a physical, patient-specific model is attractive to most clinicians. However, at the present time, there is still a lack of strong scientific evidence of the benefit of 3D models in clinical practice and only qualitative evaluation of the models has been used to investigate their clinical use. Siddharth Joshi (2019), Presented highlights the various smart materials, activation mechanisms and the shape-changing techniques employed in the 4D printing process. The potential of the shape-changing structures and their current applications in various biomedical and engineering fields is also explored. The article aims to emphasize the potential and viability of 4D printing and focused on providing an in-depth insight into the 4D printing process. Abid Haleem (2019), Presented the potential of Additive manufacturing to improve the design and development of medical parts and products. This technology is applied for the manufacturing of customized and sophisticated products with different materials, thereby performing it with lesser wastage of time and material. There is a scope to achieve various flexibilities by using different software and technological platforms. AM helps improve the accuracy and reliability of the design, as well as ease of design. This technology is now available for improving the performance of medical part by providing unique and innovative design through the use of different materials with improved quality of the product. This emerging technology provides an extensive capability for future development Ankita J.S (2020), review presents the Bio-medical applications of AM. This review concisely highlights the healthcare sectors that are revolutionized by AM, such as bio-printing, Tissue Engineering, Dentistry, printing patient-specific customized implants, Medical devices/ surgical tools, orthopedics and prosthesis, Drug delivery and also virtual surgical planning. Also, the different bio-inks and Biomaterials utilized for printing cell-seeded tissues, 3DP implants, replacement organ printing and scaffolds, are presented. Thus AM ensures safety, innovation and ease in healthcare sector. Despite these, AM still has tremendous promise and scope for further improvement in pharmaceutical, drug delivery and bio-medicinal sectors Celi Simona (2020), Presented a systematic review to illustrate the 3D printing technology and to describe the workflow to obtain 3D printed models from patient-specific images. 3D printing technique is reliable when applied to high-quality 3D image data (CTA, CMR, 3D echography), but it still needs the involvement of expert operators for image segmentation and mesh refinement. 3D printed models could be useful in interventional planning, although prospective studies with comprehensive and clinically meaningful endpoints are required to demonstrate the clinical utility. Wenxion Zhou (2020), Most of the biomedical materials printed using 3D bio printing are static and are unable to alter/transform with dynamic changes in the internal environment of the body. The emergence of four-dimensional (4D) printing addresses this problem. By preprogramming dynamic polymer materials and their Nano composites, 4D printing is able to produce the desired shapes or Transform functions under specific conditions or stimuli to better adapt to the surrounding environment.

## 2.1 LITERATURE SUMMARY

| Researcher | Title | Findings | 3DP | 4DP |
|---|---|---|---|---|
| Matt Zarek (2016), | 4D Printing of Shape Memory-Based Personalized Endoluminal Medical Devices | Paper in sighted challenges in Shape Memory Thermoset processing | | ✓ |
| Marija Vukicevic (2017) | Cardiac 3DPrinting and its Future Directions | Presented the basic principles of clinical image segmentation, including coregistration of multiple imaging datasets to create an anatomic model of interest. With applications in congenital heart disease, coronary artery disease, and surgical and catheter-based structural disease. | ✓ | |
| Abid Haleem (2018) | Additive manufacturing applications in cardiology: A review | Reviewed about AM potential which will help to the cardiologists and cardiac surgeons for intervention and surgical planning, monitoring and analysis | ✓ | |
| Abid Haleem (2018) | 4D printing applications in cardiology (Letter to Editor) | Scope of 4D printing, solution to solve long term cardiovascular issues which | | ✓ |

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|---|---|---|---|---|
| | | will be a new path for heart patients. | | |
| Elena Milano (2018) | Current and future applications of 3D printing in congenital cardiology and cardiac surgery | Reviewed about basic principles of 3DP technology and present its current and future applications | ✓ | |
| M Bodaghi (2018) | Triple shape memory polymers by 4D printing. | Introduced triple shape memory polymers (SMPs) by four-dimensional (4D) printing technology and shaping adaptive structures for mechanical/bio-medical devices. | | ✓ |
| Siddharth Joshi (2019) | 4D printing of materials for the future: Opportunities and challenges | Reviewed about potential and viability of 4D printing and focused on providing an in-depth insight into the 4D printing process. | | ✓ |
| Ankita J.S (2020) | Bio Medical Applications of Additive Manufacturing: A Review | Reviewed about healthcare sectors that are revolutionized by AM, such as bio-printing, Tissue Engineering, Dentistry, printing patient-specific customized implants, Medical devices/ Surgical tools, orthopedics and prosthesis, Drug delivery and also virtual surgical planning. | ✓ | |
| Celi Simona (2020) | 3D Printing in Modern Cardiology | Describe the workflow to obtain 3D printed models from patient-specific images. Also 3DP still needs the involvement of expert operators for image segmentation and mesh refinement. | ✓ | |
| Wenxion Zhou (2020) | 4D-Printed Dynamic Materials in Biomedical Applications: Chemistry, Challenges, and Their Future Perspectives in the Clinical Sector | Reviewed about the current and potential applications of 4D-printed materials are introduced in different aspects of the biomedical field, e.g., tissue engineering, drug delivery, and sensors. In addition, discussed the existing limitations and possible solutions. | | ✓ |

## 3. SIGNIFICANCE OF STUDY

Today's globalized world, every industry needs customization and innovation in products and services. In this study, we analyse and describe how the surgeon and patient can benefit by implementing this technology in the management of cardiovascular diseases. It has opened a new path to improve the golden hands of a heart surgeon. AM gives an idea about stabilizing heart muscle during operation, short development time and care for the patient. It provides a good co-operation between surgeon and suture. This technology provides a possibility of physical manipulation of the cardiac model in vitro which improves safety and may reduce operating time for complex cardiac surgeries. It provides knowledge of customized cardiac valves and helps its printing using biological/ adaptable materials [4]. Doctors can check the status of an outer and inner layer of the heart wall and quickly determines the health of the heart. The study provides awareness to cardiology surgeon about preoperative evaluation, hemodynamic simulation and development of tools/devices.

### 3.1 ADDITIVE MANUFACTURING IN CARDIOLOGY

Tangible heart model and its components are easily printed by AM technologies that are useful for the patient to review the heart and vessel anatomy. For a complicated case, the benefit of 3D printed model is to see the anatomy of the heart from different angles and understand the anatomical positions of the vessels. For explaining the planned procedure to patients, the anatomical 3D model is also beneficial to understand much better during invention that what will happen. In teaching, the 3D printed model becomes more accessible to explain. They can touch and turn it around. It is a most important educational tool because it gives more information as compared to 2D or 3D images on a screen [5-6].3D printed model is also beneficial for pre-surgical training which saves lives, improving outcomes and offering new treatments.

## 4. ADVANCES IN ADDITIVE MANUFACTURING

Although the 3D structures of biomaterials successfully mimic the structure of physiological geometry, most of the biomedical materials printed using 3D bio-printing technology are static and are unable to change with alterations in the surrounding dynamic environment. Biomaterials should adapt to the dynamic physiological environment over time to solve this problem. Hence, four-dimensional printing has emerged to overcome this issue. 4D printing is an emerging field in additive manufacturing of time responsive programmable materials. The combination of 3D printing technologies with materials that can transform and possess shape memory and self-healing capabilities means the potential to manufacture dynamic structures readily for a myriad of applications. The printing technologies used in 4D printing are the same as 3D printing as the fourth dimension refers to the nature of the materials printed rather than the technology. The emergence of smart materials that can transform through external stimuli offers an exciting new opportunity for 3D printing technologies. This combination has led to the new field known as 4D printing, the fourth dimension referring to time [8]. This technology was first introduced by Skylar Tibbit in collaboration with Stratasys ™ as a printed material that is programmed to change over time in response to an external stimulus. 4D printing imparts new dimensions of transformation on time in response to external stimuli. These materials can be programmed to react within parameters of their surrounding environment and, consequently, change their forms.

## 4.1 4D PRINTING SCOPE IN CARDIOLOGY

4D printing is an emerging technique, where time is integrated additionally with 3D printing. Data of defective heart is taken quickly through Computed Tomography (CT), or Magnetic Resonance Imaging (MRI) and the cardiologist can design a precise heart model or even a small part of the same as per the patient's requirements. Product designing software can be used to design part as per the requirements. After the designing step, 4D printing technology can print a 3D heart model by using suitable smart materials which should have the capability of changing their shape and functionalities as per the requirements. 4D printing can be used to manufacture the outer and inner heart valve, and the operation becomes safer and faster. 4D printing could easily develop stents used in the heart valve that can further be expanded as per the required shape with the help of heat in the patient body. This technology could be quite beneficial to save lives of children which are suffering from medical problems. Because the body has to grow with time, so there is an essential requirement of a smart implant which can grow as children body grow. 4D printing has also wide scope in manufacturing of smart medical implants and tissue engineering applications due to use of smart materials [9]. It manufactures smart cardiac tube which will be beneficial in cardiology and could be useful for making a variety of objects or structures that can adapt to their environment. 4DP is capable of manufacturing smart heart valve that can automatically control the blood flow rate by increasing and decreasing the diameter of the valve.

## 4.2 CHALLENGES IN 4D PRINTING

In the past few decades, with the remarkable development of 3D printing technology and materials science, stimuli-responsive biomaterials have begun to attract attention, and numerous studies have been conducted to provide a new era of 4D printing. Since 4D printing is an emerging field, many limitations and challenges remain to be overcome. First, 4D printing technology is in its infancy, and its printing materials are still in the exploration stage. Indeed, a printer specifically designed for 4D printing is currently unavailable. The corresponding technology must be further improved to develop additional highly precise medical devices. However, the current printing precision and material performance are unable to meet this criterion. Second, the biological environment is complex, dynamic, and different for each person [10-11]. The printed products should be adapted to the microenvironment of the organism, for instance, using microfluidic systems to apply 4D printing to biomedicine. In terms of the starting materials, although many advanced polymers and Nano composites are able to change their shape or function in response to stimulation, the materials used in biomedicine must possess some specific features, such as biocompatibility, noncytotoxic, a certain mechanical strength, and the response stimulus strength does not impair the tissues. Hence, a few dynamic materials meet the mentioned requirements. In addition, most of the materials only respond to a single stimulus, and most of these stimuli are limited to temperature, which restricts their biological applications. AM provides less tangible benefits in specific areas. It does not provide information about blood loss, blood clot; chest wound infection, and metabolic abnormalities [12].

## 5. CONCLUSION

- AM has the potential to be of immense help to the cardiologists and cardiac surgeons for intervention and surgical planning, monitoring and analysis.
- In future, 4D printing can print heart, liver and kidney by using the smart material with a perfect fit and genetically match.
- In the modern era, 4D printing could take the challenges of smart heart model. It will tackle the number of the issue faced in the cardiology.
- 4D printing is providing new opportunities for biomedical treatment, and thus organic and inorganic materials are becoming more suitable for use in organisms.

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