



## Letter to the Editor

## Expected applications of five-dimensional (5D) printing in the medical field



**Keywords:**  
5D printing  
Applications  
Implants  
Medical

Dear Editor,

Three-dimensional (3D) printing has provided development in the medical field such as complex surgery, presurgical planning, replacement of defective bone, education, research, training, etc. However, there are requirements for providing stronger curved implants in the patient body. Therefore, five-dimensional (5D) printing is introduced in the medical field to improve the reliability of implants and provide better strength for lifetime support.<sup>1</sup>

The concept of 5D printing was introduced by William Yerazunis to make stronger 3D printed parts. In 3D printing technology,

manufacturing undertaken by adding horizontal layers, which produce parts having weak points at corners, need postprocessing for improving strength. Sometimes, an implant needs different strengths and densities at different places of the part. This new technology makes parts in curved layers, thereby providing them with about five times more strength without postprocessing.<sup>2</sup> Different fields of engineering require high-strength products which can be used for a long time. Therefore, this technology can easily fulfil this requirement.

Five-dimensional printing technology prints a 3D object using a 5-axis technology. It does not refer to five dimensions of printing. It refers to the printing of parts in three dimensions using a 3D printer having five axes to print a stronger part than made by ordinary 3D printing. In this process, the printing plate and printing head also move along the X, Y and Z axis. These five axes easily print a part with curved layers. The input data are obtained through computer-aided design (CAD) data.<sup>3</sup> In this process, there is also the saving of material. During the printing process, 5D printing provides a new dynamic range of motion for complex structures. This new version of printing technology creates innovation in manufacturing, medical and other fields.<sup>4</sup> The concept of four-

**Table 1**  
Expected applications of 5D printing in the medical field.

S. No	Application area	Description
1	Medical tools/equipments	<ul style="list-style-type: none"> <li>5D printing is used to manufacture customised medical tools/equipment with high strength.</li> </ul>
2	Surgical tools/equipments	<ul style="list-style-type: none"> <li>It can create any curved tools/equipment as per patient match with the help of CAD data.</li> <li>Effectively implements the surgery for humanised design tools with better strength, appearance and precision.</li> <li>Manufacture any surgical accessories, kits and patient care device as per requirement.</li> <li>Easily designs surgical tools with different designing software programs and analysis and manufacturing software programs, thereby attaining higher strength using this technology.</li> </ul>
3	Implants	<ul style="list-style-type: none"> <li>Human parts are not in geometric shapes; they are somewhat curved and do not have sharp edges. Thus, to make exact fit implants, we need curved parts.</li> <li>These implants replace the missing biological structure.</li> </ul>
4	Bone traction	<ul style="list-style-type: none"> <li>5D printing manufactures any type of implants with high strength.</li> <li>This set of the mechanism helps straighten the broken bone.</li> </ul>
5	Medical pipes	<ul style="list-style-type: none"> <li>This technology manufactures bone traction as per the amount of weight applied.</li> <li>Easily manufactures medical pipes such as surgical section pipes having higher strength and longer life.</li> </ul>
6	Buttress plates	<ul style="list-style-type: none"> <li>Provides satisfaction to the patient.</li> <li>A buttress plate is helpful to hold the fracture place of the bone such as ankle and knee where there are large distorting and compressive bones.</li> </ul>
7	Medical fasteners	<ul style="list-style-type: none"> <li>Manufactures any plates such as L-shaped, T-shaped and bulbous end-shaped plates with better strength.</li> <li>Medical fasteners have the potential to interact between surgical implants and the human body.</li> </ul>
8	Prosthetics	<ul style="list-style-type: none"> <li>5D printed medical fasteners cover the mechanical requirements.</li> <li>Prosthetics are the artificial devices that replace body parts lost through disease, trauma, accident and condition present at birth.</li> <li>General prosthetics require high strength to sustain the load of the human body; this technology can manufacture high-strength patient-specific prosthetics.</li> </ul>
9	Heart valves	<ul style="list-style-type: none"> <li>Heart valves are used to keep the movement of the blood of the heart in the right direction</li> <li>Heart valves printed by this technology provide a somewhat reliable result</li> </ul>

5D, five-dimensional; CAD, computer-aided design.

<https://doi.org/10.1016/j.cmrp.2019.07.011>

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dimensional (4D) printing technology was different as it prints a 3D object with self-assembling materials/smart material. These materials can change shape with the increase of temperature of the human body with respect to time.

Generally, in the medical field, there is a requirement of an artificial part which should be as strong as the original human parts. Bones have curved ends and different density and strength at some places, and they need better strength at ends and curvature. Manufacturing of this type of requirements using the 3D printing machines is not feasible; therefore, we need technological innovation to fulfil these essential requirements.<sup>1</sup>

Different experiments are taken to check the strength of the part printed by 5D printing. It has been observed that this technology prints parts 3 to 5 times stronger than a part printed using an ordinary 3D printer. Another experiment observed that a cap manufactured by 3D printing technology could only handle a pressure of 0.1 megapascals whereas a cap manufactured by 5D printing technology gave an outstanding result, i.e., able to withstand 3.7 megapascals of pressure.<sup>3</sup> In the medical field, there are outstanding capabilities of this technology. Table 1 discusses different expected applications of 5D printing in the medical field.

Five-dimensional printing saves about 25% of material as compared with traditional 3D printing. It prints a curved part with higher strength. An object larger than the print bed size is also printed in a single time because in this process both the print bed and head move. It manufactures a stronger product with a complex shape and does not require any postprocessing.

The main limitation of this technology is the extra cost of two axes, and people are not so aware of this disruptive technology. Precise software and hardware are required to run the customised machine. Another limitation is the requirement of highly skilled human resources required for operating and maintaining the machine.

In future, 5D printing could print self-assembling materials with better strength. It will become the essential technology to print smart curved medical parts which can change the shape concerning time. In future, this technology will become essential for engineering, medical, dentistry and other field. Owing to its efficient printing of stronger parts in curved layers, it will prove as the best disruptive technology in the medical field.

Therefore, 5D printing creates advancement in the medical field by providing stronger 3D parts in curved layers with lesser wastage of materials. Thus, 5D printing has good capability to manufacture essential tools, devices, implants, medical pipes, valves, and prosthetics with improved strength as per patient requirements. This technology has the potential to provide innovative solutions to applications in the medical field.

#### Conflict of interest

None.

#### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cmrp.2019.07.011>.

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19 April 2019

Available online 27 July 2019

<sup>1</sup> <https://scholar.google.co.in/citations?user=4047148AAAAJ&hl=en>.

<sup>2</sup> <https://scholar.google.co.in/citations?user=rfyiwvsAAAAJ&hl=en>.