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3D Printing Applications for Radiology: An Overview

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Abstract

Three-dimensional (3D) printing technologies are part of additive manufacturing processes and are used to manufacture a 3D physical model from a digital computer-aided design model as per the required shape and size. These technologies are now used for advanced radiology applications by providing all information through 3D physical model. It provides innovation in radiology for clinical applications, treatment planning, procedural simulation, medical and patient education. Radiological advancements have been made in diagnosis and communication through medical digital imaging techniques like computed tomography, magnetic resonance imaging. These images are converted into Digital Imaging and Communications in Medicine in Standard Triangulate Language file format, easily printable in 3D printing technologies. This 3D model provides in-depth information about pathologic and anatomic states. It is useful to create new opportunities related to patient care. This article discusses the potential of 3D printing technology in radiology. The steps involved in 3D printing for radiology are discussed diagrammatically, and finally identified 12 significant applications of 3D printing technology for radiology with a brief description. A radiologist can incorporate this technology to fulfil different challenges such as training, planning, guidelines, and better communications.

Keywords
- 3D printing
- 3D printing applications
- imaging
- medical
- radiology

Introduction

In the 1980s, three-dimensional (3D) printing came into the picture for industrial and medical purposes and is commonly known as an additive manufacturing technique. This technology can produce 3D finished products from the input of the 3D computer-aided design (CAD) model. The technology involves an additive process, in which there is an addition of layers of required materials under computer-controlled conditions. The printed part can have any different geometry, including the complex shapes based on data collected from the digital 3D model. 3D printing technology is helpful for research and development in the medical field. The medical field's significant applications in the medical field are producing cheaper surgical tools, prosthetic limbs, transplants of human organs, and help perform appropriate surgical procedures.[1-3]

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In radiology, it helps create a 3D model of medical imaging that shows appropriate information regarding the disease or fracture in soft or hard tissues. These 3D printed patient-specific models are used to minimize the patients' trauma and speed up the surgical procedures. This technology plays an essential role in surgical operations and seems to become the best medical field practice. Doctors can deal with very complex cases with this new treatment method with a higher degree of care and preciseness through 3D printing technology. Various other industries are dependent on 3D printing technology because of its extensive applications.[4,5] The major technologies of 3D printing are stereolithography, selective laser sintering, direct metal laser sintering, fused deposition modeling, digital light process, multi jet fusion, PolyJet, laminated object manufacturing, binding jet 3D printing, and electron beam melting.

3D printing technology is being used to print tissues, surgical tools, surgical models, and custom prosthetics in current scenarios. It brings doctors and patients closer by severing a customized remedy for each individual precisely and rapidly. 3D printing technology enhances its medical industry contribution for comfort during treatments with innovative tools and devices. It is extensively used to print or produce various implants and has applications from surgeries to prosthetic operations. Big pharmaceutical companies are also eying to deploy 3D printing technology to manufacture new drugs because of their lesser production cost.[6-8]

With the requirements of cost reduction and quality improvement in radiology, doctors are encouraged to adopt 3D printing technology. There are various types of 3D printing technologies available in the market. Each technology can be categorized based on the application, raw material, and manufacturing process involved in manufacturing the product. Various research is performed using anatomical 3D printed model for intraoperative visualization, preoperative planning, and sizing or prefitting the surgical tool by various hospitals, research organizations, and health care professionals.[9-11]

The demand for personalized and precision medicine is to rise. There are vast applications of 3D printing in the medical field that depend on developing new appropriate materials for diagnostic and therapeutic use under controlled guidelines. Anatomical 3D models based on patient scanned data are handy tools for personalized practice and precision medicine. This technology improves operating room efficiency, including routine cases and visual and tactical reference models. It improves the interaction and understanding with patients and within the operation room team.[12,13] This study tries to address the following research questions:

RQ1: To discuss 3D printing in the context of the medical field;

RQ2: To study the features of 3D printing necessary for radiology;

RQ3: To study significant advancement of 3D printing and study the process chart of employing 3D printing for radiology;

RQ4: To study the 3D printing applications in the area of radiology.

3D Printing in The Medical Field

- Various industries, including the medical industry, adopt this 3D printing technology to reshape the traditional manufacturing of various medical implants, tools, and devices. This technology has a wide range of applications to become an integrated part of the medical field, ranging from assistive tool production to cell-derived tissues and organ transplants. Doctors and researchers take advantage of this emergence, 3D printing technology in medical and its associated fields.[14-16] Some of the beautiful examples of 3D printing technology that became a reality are:
- Specially designed 3D printed airway splints specifically for children with condition confined to intensive care and only survived for a week.
- Production of medical devices and tools at lesser cost and better finish.
- Anatomical models for complicated cases for hospitals as a training tool.
- Implants of various types, including dental implants with surgical guides.
- Bioprinting of organ tissues for surgical purposes.

3D printing is proving itself a beneficial technology for the medical field that has increased the capabilities, preciseness, and reduced the cost and time in the medical field. Easiness of adopting this technology makes it popular among the manufacturing of new medical tools, devices, and other surgical instruments.[17,18] Intricate design can be iterated by 3D printing technology in days instead of weeks.

Bioprinting and Its Difference from 3D Printing

Bioprinting is one of the techniques used for the printing of tissues and organs. It uses bioink to print living cells instead of metal or plastic using layer by layer technique. Patients' specific organs are easily printed, which helps perform complicated cases. Bioink is an essential component of bioprinting made up of living cell structure used to print specific live tissues layer by layer.[19,20] The fundamental difference between bioprinting and 3D printing is that bioprinting is used to print several tissue types, while 3D printing is applicable for producing or printing medical tools and devices.

Need for 3D Printing in Radiology

A patient-specific implant requires a 3D physical model for better understanding and treatment, which is not possible by just capturing images by different medical imaging technologies. 3D printing technology has conceded with the best-suited technologies to perform the appropriate medical treatment process in radiology. It involves customized manufacturing of parts in lesser time and cost as compared with traditional manufacturing methods. Due to its time-saving benefits, pharmaceutical companies take economic advantages to complete personalized treatment. 3D printing technology provides great research and development opportunities in radiology because of its high resolution and

possibility to print multimaterial during the same printing operation.[21,22] Based on its biocompatibility and conductivity, researchers propose this manufacturing system for personalized treatments.

Features of 3D Printing Important for Radiology

The major features of 3D printing, which have made radiologists' capabilities more impactful and impressive, are exemplified in ►**Fig. 1**. The accuracy and precision in the design and development are always sought as the crucial elements and base for improving the product quality. The features like image acquisition, segmentation, image pre- and postprocessing, editing in the segmentation details as per the need and its further validation, accuracy of the model are the more commonly known and highlighted ones when we move toward the applications of 3D product/part development in radiology.[23-25]

The 3D digital model to be printed can also be scaled as per the necessity, and the complexity can be minimized by using the fundamentals of rapid prototyping technique. The segmentation process is being developed in a manual and automated manner. When it comes to visualizing any data in the plane, 3D printing enables us with specific imaging pre- and postprocessing features. Furthermore, the traits like validation and accuracy of the developed model provide significant depths through the applications of 3D printing in radiology.[26,27]

Significant Advancement of 3D Printing Related to the Medical Field

The application of bioprinting is to reproduce several kinds of human tissues. Stem cells are like progenitor for the printing of several other types of tissues and can provide the possibility to print the cells directly into the body. Printed skin grafts can help patients with burn injuries, skin cancer, afflictions, and diseases that affect the epidermis. 3D printing technology is also being used for the treatment of cancer. It is used for disease cells to study their mechanism of growth and development more effectively and systematically. This kind of approach provides better scope and analysis of cancer cells, drug testing, and therapy development.[28-30]

The developments in 3D printing can lead to the discovery of curing the cancer-like disease. 3D printing uses advanced software to meet the various challenges for creating a blueprint. The software can create a digital model of a heart, liver, or kidney to print them via 3D technology like printing technology. Scientists and researchers are working hard to maximize the benefit of 3D printing technology to serve and save humankind from various diseases. In the future, various innovative developments and advancements are taking place with 3D printing technology, especially for the medical field.[31,32]

Process Steps of 3D Printing for Radiology

3D printing technology has already been proven effective in versatile applications of umpteen industrial requirements. ►**Fig. 2** reflects the overall workflow process of 3D printing methodology for its employability in the radiology domain. The processing begins with the data, facts, details, etc., about the image to be processed with, and after gaining the details, some processing steps can be started.

Several soft tools, like 3D slicer, vital images, 3D doctors, and mimics, are deployed to complete the images' processing steps. Then, the transformation of a digital data-based model into a 3D mesh is performed. It also consists of the process of mesh refinement for any possible improvement at this stage. The final stage is termed as the model development or the manufacturing of the model for the purpose.[33-35]

3D Printing Applications for Radiology

3D printing is used to create customized bone and soft tissue prosthesis, which provides appropriate information regarding any fracture. It is used to produce biomedical parts having natural tissue characteristics. Their different steps involve converting medical images into 3D physical models. First of all, captured computed tomography/magnetic resonance imaging (CT/MRI) images are converted into a 3D CAD model and further exported into STL format. 3D printing technology is used to print precise anatomy, which can be used for required planning and clinical applications. The current 3D printing applications in health care are manufacturing medical implants, tools, and devices that help surgery, medical training, simulation, and research. It is also successfully used to print tissue and organs using bioink and living cells. This technology is used to improve patient care and enhance diagnostic quality.[36-38] ►**Table 1** discusses the significant applications of 3D printing in radiology.

3D printing is used to print the patient's 3D physical model with imaging data input, creating detailed information

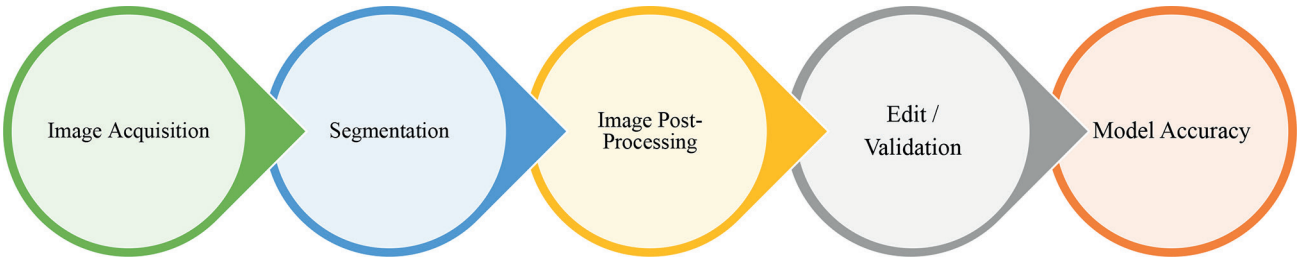

Fig. 1 Specific features of three-dimensional (3D) printing for radiology.

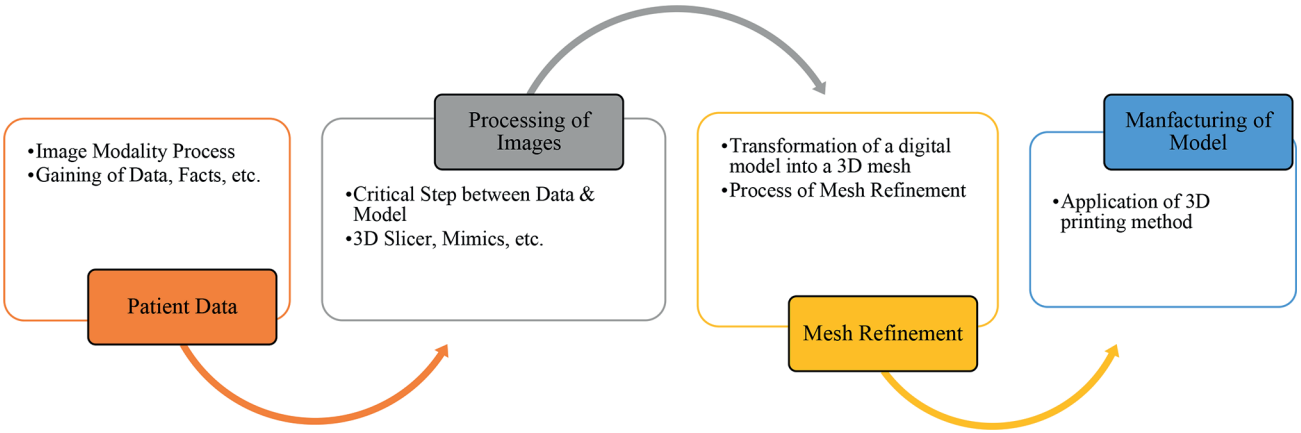

Fig. 2 Process steps of three-dimensional (3D) printing for radiology.

Table 1 3D printing applications for radiology

S. No	Applications	Description	References
1	Physical 3D model of medical image	• A radiologist can take full advantage of this technology to create a patient-specific physical 3D model from medical imaging • Radiologists can now print the patient's imaging data in a 3D physical model to solve complex surgical problems and develop better training processes • 3D medical model printed by this technology provides precise and appropriate information as compared with CT/MRI	39–42
2	Colorful tissue and organ 3D model	• 3D printing plays a major role to create a colorful patient-specific model of organ and tissue • With the application of this technology, detailed information is quickly available • 3D printed model can be sectioned to enhance clarity during the treatment process • It is useful to analyze the biological functions of organs • A colorful model of tissue and organs provides a physical feeling about the ongoing situation of the patient disease	43–45
3	Helpful to identified abnormalities	• It identifies apparent abnormalities as compared with imaging techniques • A radiologist can use this technology for preoperative planning during the transplantation of the patient body part • It identifies the correct defect with the help of 3D printed model • It is useful to provide clarity during the planning and treatment process of any abnormalities	45–48
4	Communications	• 3D printed patient-specific model is suitable to understand patient anatomy as compared with a 2D scan • A radiologist can take advantage of this 3D model for better communication with patients, their family, and surgical teams • It provides accurate communication during presurgical planning • It creates an innovative way to communicate new ideas regarding the better treatment process	49–54
5	Identify heart defect	• 3D printing applications are for congenital heart disease • It is used to provide proper information regarding the blockage in the heart • It is useful for the analysis of blood flowing in the heart and specific diagnosis process • Its applications are also applied to identify cardiac abnormalities like cardiac tumors and ventricular aneurysms • It is used to identify the heart diseases of the complex anatomy of the patient	54–57
6	In teaching and learning	• 3D printing proves the best tool for teaching and learning for medical students • This is helpful for better radiological education with proper learning of complex human anatomy • The proper learning of soft and hard tissue is easily provided with the help of a patient-specific 3D printed model • 3D printing technology reported high satisfaction to enhance the medical teaching and learning process	58–62
7	Patient pathology	• This technology is used to understand and analyze the patient-specific pathology • It helps to identify and facilitates complex surgical problems • Models printed by this technology are helpful to understand the musculoskeletal pathologies and vascular anatomy • It is useful to study various types of disease and explain them in a better way	63–67

(*Continued*)

Table 1 (*Continued*)

S. No	Applications	Description	References
8	To identify the tumor	• 3D printing expands its capability to identify the tumor in the patient body • Doctors can also examine the growth of a tumor and can achieve better ideas for the treatment, and they can make comparative analysis by comparing two 3D printed model, developed at a different time of the disease • It is useful to identify the mini tumor with accurate size • This technology also used to test tumor for different drugs • It is useful for better planning regarding kidney cancer surgery	68–70
9	Printing of blood vessel	• This technology is used to print blood pool and vessels, which provide innovative ideas to the radiologist • 3D printing is useful to increase the rate of success during the transplantation of heart • It is an essential tool to create an artificial blood vessel that can save a patient from cardiovascular disease • It is also applicable to fabricate multilayer blood vessels with multimaterials	71–73
10	Blood flow dynamic	• It is used for the proper analysis of blood flow dynamics, which helps to predict the symptom of heart attack accurately • 3D printed models are helping to perform experimental flow studies • High-resolution 3D models printed by this technology are used to visualize blood flow in a patient body • It provides detailed information as compared with 2D medical images	76–79
11	Evidence-based guidelines	• 3D printing provides an innovative concept to the radiologist through evidence-based guidelines • It is used to perform appropriate anatomic modeling for clinical trial • 3D printed medical models improve the daily work of medical professionals • It enables doctors to create better fitting and higher performing implants	74–77
12	Complex studies	• It is helpful for complex cases by which 3D printed model provides better-detailed information • It provides appropriate clinical indications to the radiologist • This technology creates patient anatomy for appropriate planning of surgery • It is used to manufacture complex medical geometry for complicated medical case	78–81

Abbreviations: 3D, three-dimensional; CT/MRI, computed tomography/magnetic resonance imaging.

regarding its status. It is a useful technology for a surgeon to do better surgical planning and minimize the operating time. There are more innovative applications of this technology in health care. A surgeon can now touch the patient-specific model and do the appropriate analysis before performing actual surgery.[82-84] This technology can print complicated geometries for a variety of medical applications.

Major Contributions of the Study

In health care, 3D printing technological applications are rapidly growing. In radiology, imaging of various hard and soft tissue can be printed precisely with 3D printers' help. Nowadays, researchers can print small strips of organs and tissues for various medical applications. This technology has applications to print patient-specific implants for better treatment of the patient. 3D printed models are used to identify the tumor in the patient's body, which helps to understand the surgery's goal. The major applications of 3D printing for radiology are the manufacturing of physical 3D model of medical image, colorful tissue and organ 3D model, identification of abnormalities, proper communications, identify heart defect, teaching and learning, patient pathology, identification of tumor, the printing of blood vessel, blood flow dynamic, evidence-based guidelines, and complex studies. This technology provides higher satisfaction regarding the treatment plan by presenting data in the physical form. It reduces the burden and imaging time for the radiologist. This represents the proper pathologic process to improve the interaction between radiologists and physicians. This technology's role is growing for highly complex interventions that reduce errors during the treatment process. The major benefit of this technology is to manage the treatment procedure related to patient care. Now individualized patient data are used to perform precise surgery and create better opportunities to treat various diseases.

Limitations and Future Scope

There is a requirement for appropriate patient data captured by CT, MRI, or other medical imaging technologies. Accurate segmentation of the patient image is required for 3D printing technology. Specialized software is required for this purpose; additional cost is acquired. Thus, to convert the imaging data, there is a requirement for a skilled workforce to create CAD digital model precisely. 3D printing technology acquires extra cost during the multimaterial printing process.

In the future, the shortage of tissue and organ can be dealt with quickly by using bioprinting with the input of biomaterial and living cells. Chemical customization of alginate hydrogels is the key to printing visualizable micro-organs. With bioresorbable hydrogels' help, cells' countenance printing against gravity and countenance the cell growth, interact, and function physiologically. Bioprinter is being developed to print various cell types simultaneously to create an intricate or complex tissue structure. 3D printing seems a little

indecipherable to some people in the case of biomedical engineering. This technology is used to manufacture aeroplane parts or appliances for electrical use. Researchers are continuously working on 3D printing technology, and in the future, this technology will come into the picture for more innovative medical applications.

Though the printing of a fully functional organ is a bit far for scientists and researchers today, they have achieved some very encouraging results toward printing kidney cells, the foundation of the human liver, cardiac tissue sheets that beats precisely like a real heart, and several other organ tissues. Although the printing of the whole human organ transplanted readily is in the lap of the future, researchers and scientists' efforts are well on the way to make it possible.

Conclusion

3D printing quickly prints any volumetric image, which helps to contrast different tissue of the human body. It enhances the planning with a precise understanding of human soft and hard tissue with the 3D printed model's help. This 3D printed model is also useful for maxillofacial applications. For the radiologist, it enhances the capability of demonstration and communications. This provides better ideas to radiologists as compared with CT and MRI images. It addresses the various aspect of the radiology field by making meaningful contributions and patient care. This technology is effectively used to produce custom-made implants. 3D printing efficiently manufactures colorful 3D models for the radiologist, which provide appropriate information and save operating time. It is also useful to provide full-face transplantation using 3D scanning technologies. It quickly prints a 3D model from the standard radiologic images. This technology provides better visualization of patient anatomy and other pathologic conditions. Now radiologists can rapidly create an accurate 3D printed model to improve technical skills during the treatment process. In the future, this technology incorporates its advanced applications for the betterment of radiology and patient care.

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Nil.

Conflicts of Interest
There are no conflicts of interest.

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