The Impact Of 3D Printing Technology In Radiology For Surgical Planning And Patient Education

Faisal Hamad Almutairi , -Manal Abdullah Al Raki , Mohammed Ahmed Ageeli ,Ammar Ali Hakami , Abdullah Mohammed Abdullah Alomaish , Faisal Mohammed Aljabri , Abdullah Mohammed Alasadi , Ebtisam Rashid Mohammed Alsehly , Ohoud Hasan Alraguib , Fawaz Obaid Alshammari , Abdullah Ali Almutairi , Saad Freih Alharbi

Abstract

As a component of additive production, three-dimensional (3D) printing methods create a three-dimensional (3D) material representation from an electronic computer-generated representation with the desired size and form. These techniques are currently utilized for sophisticated radiology purposes by delivering comprehensive information via a three-dimensional physical model. It offers innovative solutions in radiography for clinical usage, planning treatments, operational modeling, and physician and patient training. Significant progress has been achieved in the field of radiology with regards to detection and interaction, thanks to the use of medical imaging methods such as computed tomography as well as magnetic resonance imaging (MRI). The photos are transformed into Digital Imaging and Telecommunications in Medicine (DICOM) files, which are compatible with Standard Triangulate Language (STL) format. These files may be simply used for 3D printing technologies and can be printed in a three-dimensional manner. This 3D model offers comprehensive insights into pathological and anatomical conditions. Creating new possibilities in patient care is beneficial. This article explores the prospective applications of 3D printers in the field of radiography. The process of 3D printing for radiology is explained using diagrams, and a total of 12 significant uses of 3D printing as a tool for radiology are highlighted, each with a concise explanation. A radiologist may use this technology to address several

difficulties, including training, organizing, instructions, and enhanced interaction.

Keywords: 3D printing Medical, imaging radiology, magnetic resonance imaging, surgical planning, patient education.

1. Introduction

In the 1980s, the technology of three-dimensional (3D) printing emerged as a method of additive manufacturing, mostly used in industrial and medical fields. This technology has the capability to manufacture three-dimensional finalized items based on the input of a three-dimensional computer-aided design (CAD) model. The method utilizes an additive process, whereby layers of necessary components are added under computer-controlled circumstances. The printed component may possess a wide range of geometries, including intricate forms derived from data obtained from the digital 3D model. 3D printing technology is advantageous for conducting research and advancing development in the medical domain. The medical sector has made major advancements in manufacturing cost-effective surgical instruments, prosthetic limbs, human organ transplants, and facilitating proper surgical procedures.[1-3]

In the field of radiology, the use of 3D modeling techniques aids in the creation of a visual representation of medical imaging data. This model provides accurate and relevant information about diseases or fractures in both soft and hard tissues. These patient-specific models, created using 3D printing technology, are used to reduce patient trauma and expedite surgical operations. This technology is crucial in surgical procedures and seems to be the leading practice in the medical industry. Doctors may effectively manage intricate situations using this innovative therapeutic approach, using 3D printing technology to enhance precision and meticulousness. Several additional sectors rely on 3D printing technology due to its wide range of uses.[4,5]. The primary technologies used in 3D printing include stereolithography, selective laser sintering, direct metal laser sintering, fused deposition modeling, digital light process, multi jet fusion, PolyJet, laminated item production, binding jet 3D printing, and electron beam melting.

Currently, 3D printing technology is used to fabricate tissues, surgical instruments, surgical models, and personalized

prostheses. It facilitates a deeper connection between physicians and patients by efficiently and accurately providing a tailored treatment for each person. 3D printing technology improves its contribution to the medical business by creating unique equipment and gadgets that promote comfort during treatments. It is widely used for printing or manufacturing different implants and is applicable in surgeries and prosthetic procedures. Major pharmaceutical corporations are also considering the use of 3D printing technology for the creation of new pharmaceuticals due to its lower manufacturing costs. [6-8].

Doctors are urged to use 3D printing technology in radiology to meet the demands of cost reduction and quality enhancement. Multiple 3D printing technologies are now accessible on the market. Every technology may be classified according to the application, raw material, and manufacturing method used to produce the product. Hospitals, research organizations, and healthcare professionals use anatomical 3D printed models for many purposes such as intraoperative visualization, preoperative planning, and sizing or prefitting surgical tools. [9-11]

There will be an increase in the demand for customized and precision medicine. The medical industry has several uses for 3D printing that rely on the development of novel materials suitable for diagnostic and therapeutic purposes, following certain rules. 3D anatomical models derived from patient scanned data are useful tools for individualized medical practice and precision medicine. This technology enhances the productivity of operating rooms, including both routine cases and the use of visual and tactical reference models. It enhances the engagement and comprehension with patients and within the surgical team.[12,13]

2. Application of 3D printing in the medical domain

Multiple businesses, including the medical sector, use this 3D printing technology to transform the conventional manufacture of diverse medical implants, instruments, and gadgets. This technology offers a broad spectrum of applications that may be seamlessly incorporated into the medical profession, including the manufacturing of assistive tools as well as the creation of tissues and organs produced from cells for transplantation. Doctors and researchers use the emerging technology of 3D printing in the medical industry and

related areas. [14-16]. Here are some stunning manifestations of 3D printing technology:

- These are custom-made 3D printed airway splints that are particularly created for children who are in critical care and have a disease that limits their survival to just one week.
- Efficient manufacturing of medical equipment and instruments at a reduced cost and improved quality.
- Anatomical models serve as a teaching tool in hospitals, particularly for complex patients.
- Various kinds of implants, including dental implants with surgical guidance, are used.

3. Bioprinting organ tissues for surgical applications

3D printing has emerged as a valuable tool in the medical profession, enhancing capabilities, precision, and cost and time efficiency. The ease of implementation of this technology contributes to its popularity in the production of new medical equipment, gadgets, and other surgical instruments. [17,18] 3D printing technology enables the rapid iteration of intricate designs, reducing the time required from weeks to days.

4. Bioprinting is a distinct process from 3D printing

Bioprinting is a method used to print tissues and organs. The process involves using bioink to print live cells, as opposed to metal or plastic, by employing a layer-by-layer procedure. The ability to print patients' individual organs facilitates the execution of complex medical procedures. Bioink is a vital component of bioprinting, consisting of living cell structures that are used to print precise layers of live tissues.[19,20]. The primary distinction between bioprinting and 3D printing lies in their respective applications. Bioprinting is specifically used for the printing of various tissue types, whilst 3D printing is mostly utilized for the production of medical instruments and devices.

5. Importance of 3D Printing in Radiology

In order to enhance comprehension and treatment, a patient-specific implant necessitates the use of a three-dimensional physical model. This cannot be achieved just via the acquisition of pictures using various medical imaging technologies. 3D printing technology has emerged as one of the most suitable technologies for performing precise medical treatment

processes in radiology. It entails the production of bespoke components in a shorter period and at a lower cost compared to standard manufacturing processes. Pharmaceutical businesses exploit the economic benefits of individualized therapy due to its time-saving advantages. The excellent resolution and ability to print many materials simultaneously make 3D printing technology very advantageous for research and development in radiology. [21,22]. Researchers suggest using this manufacturing technology for tailored therapies because of its biocompatibility and conductivity.

6. Key attributes of 3D printing in radiology

The significant attributes of 3D printing, which have enhanced the effectiveness and awe-inspiring powers of radiologists. Seeking accuracy and precision in design and development is vital for enhancing product quality. The commonly recognized features in the applications of 3D product/part development in radiology include image acquisition, segmentation, image pre- and postprocessing, editing of segmentation details as needed, and model accuracy validation.[23-25]

Noteworthy progress in the use of 3D printing in the medical field. Bioprinting is used to replicate several types of human tissues. Stem cells serve as precursors for the fabrication of many kinds of tissues and provide the potential to directly implant cells into the body. Printed skin grafts have the potential to assist patients suffering from burn injuries, skin cancer, ailments, and conditions that impact the outermost layer of the skin, known as the epidermis. The use of 3D printing technology is being utilized in the medical field for the purpose of treating cancer. It is used to examine the growth and development mechanisms of disease cells in a more efficient and systematic manner. This technique offers enhanced opportunities for comprehensive examination and evaluation of cancer cells, medication experimentation, and the advancement of therapeutic strategies.[28-30]

The advancements in 3D printing have the potential to facilitate the finding of a cure for cancer-like diseases. 3D printing utilizes sophisticated software to address the many obstacles involved in generating a design. The program has the capability to generate a digital representation of a heart, liver, or kidney, which may then be produced using 3D printing technology. Scientists and researchers are diligently striving to optimize the utility of 3D printing technology in order to

benefit and safeguard humanity from a multitude of ailments. 3D printing technology is undergoing several new advances and advancements, particularly in the medical industry, in the future.[31,32]

7. Limitations Future studies

CT, MRI, and other medical imaging systems must record patient data accurately and in a suitable manner. Precise delineation of the patient picture is necessary for the use of 3D printing technology. Specialized software is necessary for this function, resulting in increased expenses. Therefore, in order to transform the imaging data, it is necessary to have a proficient workforce that can accurately generate a CAD digital model. The use of multimaterial printing in 3D printing technology incurs additional expenses.

In the future, the scarcity of tissue and organs may be efficiently addressed via the use of bioprinting, which involves the incorporation of biomaterials and live cells. The crucial factor in the creation of visible micro-organs by printing is the chemical modification of alginate hydrogels. Bioresorbable hydrogels enable the printing of cells in defiance of gravity, allowing for their development, interaction, and physiological functioning. A bioprinter is currently in development with the capability to concurrently print many cell types in order to produce elaborate and complicated tissue structures. Biomedical engineering might make 3D printing seem perplexing to some individuals. This technique is used for the production of aircraft components or electrical appliances. Scientists are always studying and developing 3D printing technology, and in the future, this technology will be used for more advanced medical applications.

While the ability to print a fully functional organ remains a distant goal for scientists and researchers, they have made significant progress in printing kidney cells, the building blocks of the human liver, sheets of cardiac tissue that mimic the precise beating of a real heart, and various other organ tissues. While the ability to print whole human organs for transplantation is still a future possibility, researchers and experts are actively working towards achieving this goal.

8. Summary

3D printing rapidly produces three-dimensional representations of volumetric images, facilitating the

differentiation of various tissues inside the human body. The use of 3D printed models aids in improving the planning process by providing a detailed comprehension of both the soft and hard tissues of the human body. This 3D printed model is also beneficial for maxillofacial applications. It improves the radiologist's capacity to demonstrate and communicate. These findings provide superior insights to radiologists in comparison to CT and MRI pictures. It focuses on several facets of the radiology discipline via valuable contributions and patient care. This technique is efficiently used for the production of personalized implants.

3D printing is an effective method for producing vivid 3D models that give relevant information to radiologists and help save time during operations. Utilizing 3D scanning technology is advantageous for doing full-face transplants. It rapidly produces a three-dimensional model using the conventional radiologic pictures. This technology enhances the clarity and accuracy of seeing patient anatomy and detecting other abnormal situations. Radiologists now have the ability to quickly generate a precise 3D printed model, which may enhance their technical proficiency throughout the treatment procedure. In the future, this technology will use its sophisticated applications to enhance radiography and improve patient care.

References

1. Itagaki MW. Using 3D printed models for planning and guidance during endovascular intervention: a technical advance. Diagn Interv Radiol 2015; 21 (04) 338-341
2. Jahnke P, Schwarz FB, Ziegert M. et al. A radiopaque 3D printed, anthropomorphic phantom for simulation of CT-guided procedures. Eur Radiol 2018; 28 (11) 4818-4823
3. Yang DH, Kang JW, Kim N, Song JK, Lee JW, Lim TH. Myocardial 3-dimensional printing for septal myectomy guidance in a patient with obstructive hypertrophic cardiomyopathy. Circulation 2015; 132 (04) 300-301
4. Jahnke P, Schwarz S, Ziegert M, Schwarz FB, Hamm B, Scheel M. Paper-based 3D printing of anthropomorphic CT phantoms: feasibility of two construction techniques. Eur Radiol 2019; 29 (03) 1384-1390
5. Ogden KM, Morabito KE, Depew PK. 3D printed testing aids for radiographic quality control. J Appl Clin Med Phys 2019; 20 (05) 127-134
6. Christensen A, Rybicki FJ. Maintaining safety and efficacy for 3D printing in medicine. 3D Print Med 2017; 3 (01) 1

7. Mihić MS, Pavelić L, Kortmiš MV, Šiško J, Maltar-Strmečki N, Prlić I. 3D-printed eye lens dosemeter holder for use in interventional radiology and interventional cardiology. Radiat Meas 2020; 135: 106385
8. Javaid M, Haleem A. Additive manufacturing applications in medical cases: a literature based review. Alex J Med 2018; 54: 411-422
9. Weadock WJ, Heisel CJ, Kahana A, Kim J. Use of 3D printed models to create molds for shaping implants for surgical repair of orbital fractures. Acad Radiol 2020; 27 (04) 536-542
10. Newcomb TL, Bruhn AM, Giles B, Garcia HM, Diawara N. Testing a novel 3D printed radiographic imaging device for use in forensic odontology. J Forensic Sci 2017; 62 (01) 223-228
11. Tack P, Victor J, Gemmel P, Annemans L. 3D-printing techniques in a medical setting: a systematic literature review. Biomed Eng Online 2016; 15 (01) 115
12. George E, Barile M, Tang A. et al. Utility and reproducibility of 3-dimensional printed models in pre-operative planning of complex thoracic tumors. J Surg Oncol 2017; 116 (03) 407-415
13. Mitsouras D, Liacouras P, Imanzadeh A. et al. Medical 3D printing for the
14. Squelch A. 3D printing and medical imaging. J Med Radiat Sci 2018; 65
15. Kim GB, Lee S, Kim H. et al. Three-dimensional printing: basic principles and applications in medicine and radiology. Korean J Radiol 2016; 17 (02) 182-197
16. Massat III MB. Printing is bridging the gap between radiology and surgery. Appl Radiol 2020; 49: 38-41
17. Ballard DH, Mills P, Duszak Jr R, Weisman JA, Rybicki FJ, Woodard PK. Medical 3D printing cost-savings in orthopedic and maxillofacial surgery: cost analysis of operating room time saved with 3D printed anatomic models and surgical guides. Acad Radiol 2020; 27 (08) 1103-1113
18. Takao H, Amemiya S, Shibata E, Ohtomo K. 3D printing of preoperative simulation models of a splenic artery aneurysm: precision and accuracy. Acad Radiol 2017; 24 (05) 650-653
19. Murphy SV, De Coppi P, Atala A. Opportunities and challenges of translational 3D bioprinting. Nat Biomed Eng 2020; 4 (04) 370-380
20. Matai I, Kaur G, Seyedsalehi A, McClinton A, Laurencin CT. Progress in 3D bioprinting technology for tissue/organ regenerative engineering. Biomaterials 2020; 226: 119536
21. Goudie C, Kinnin J, Bartellas M, Gullipalli R, Dubrowski A. The use of 3D printed vasculature for simulation-based medical education within interventional radiology. Cureus 2019; 11 (04) e4381
22. Vukicevic M, Mosadegh B, Min JK, Little SH. Cardiac 3D printing and its future directions. JACC Cardiovasc Imaging 2017; 10 (02) 171-184

23. Solc J, Vrba T, Burianova L. Tissue-equivalence of 3D-printed plastics for medical phantoms in radiology. J Instrum 2018; 13: P09018
24. Michalski MH, Ross JS. The shape of things to come: 3D printing in medicine. JAMA 2014; 312 (21) 2213-2214
25. Veneziani GR, Corrêa EL, Potiens MPA, Campos LL. Attenuation coefficient determination of printed ABS and PLA samples in diagnostic radiology standard beams. J Phys Conf Ser 2016; 733: 012088
26. Cohen A, Laviv A, Berman P, Nashef R, Abu-Tair J. Mandibular reconstruction using stereolithographic 3-dimensional printing modeling technology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009; 108 (05) 661-666
27. Friedman T, Michalski M, Goodman TR, Brown JE. 3D printing from diagnostic images: a radiologist's primer with an emphasis on musculoskeletal imaging-putting the 3D printing of pathology into the hands of every physician. Skeletal Radiol 2016; 45 (03) 307-321
28. Ballard DH, Trace AP, Ali S. et al. Clinical applications of 3D printing: primer for radiologists. Acad Radiol 2018; 25 (01) 52-65
29. Javan R, Herrin D, Tangestanipoor A. Understanding spatially complex segmental and branch anatomy using 3D printing: liver, lung, prostate, coronary arteries, and circle of Willis. Acad Radiol 2016; 23 (09) 1183-1189
30. Giannopoulos AA, Mitsouras D, Yoo SJ, Liu PP, Chatzizisis YS, Rybicki FJ. Applications of 3D printing in cardiovascular diseases. Nat Rev Cardiol 2016; 13 (12) 701-718
31. Andrade MAB, Fin APC, de Oliveira Alves C, Soares FAP, Savi MBB, da Penha Albuquerque Potiens M. Visual impact of infill percentages for 3D printed radiologic simulators.. Braz J Radiat Sci 2020; 8
32. Murakami T, Tajika Y, Ueno H. et al. An integrated teaching method of gross anatomy and computed tomography radiology. Anat Sci Educ 2014; 7 (06) 438-449