Review Article

The Resurgence of 3D printing: As a tool in advance medical education

Akriti Gupta[1], Veerendra Arya[2*], Rajay Bharshankar[3], Santosh Wakode[3]

[1]Senior Resident Department of Physiology, AIIMS Bhopal,India
[2]Assistant Professor, Department of medicine, LN medical college Bhopal, LNMC campus JK hospital Kolar road Bhopal,India
[3]Professor Department of Physiology, AIIMS Bhopal,India

Received: 04-09-2020 / Revised: 06-10-2020 / Accepted: 21-10-2020

Abstract

The purpose of this paper is to provide a comprehensive understanding of how to take best advantage of three-dimensional (3D) printing in medical education in favor to increase the medical student's ability to provide out-of-the-box medical care for unexpected challenges in clinical competencies. Is there need to purchase 3D printer in each medical college? With changing needs, educational advancements, and technological revolutions, we need to update the method of imparting knowledge and skills to medical students.3D printing is one of them, a strategy to facilitate active learning. Studying the literature by searching articles in PubMed related to implementation of 3D printed models in different subjects of MBBS undergraduate curriculum, we found that there has been the creation of multiple models in every field of medical science. The designing of a 3D model allows the student to study from multiple angles and find the solution of medical problems, cut down operating time, surgical planning, enhancing motor skill, no ethical issue, decreasing the cadaveric dissection, help in understanding the physiological process, etc. Concerning the limited use of the living cells as a material in bioprinting is challenging but a promising area to continue to explore.

Key Words: 3D Printing, medical education, active learning, anatomical models, Bioprinting

Introduction

Traditional two-dimensional (2D) presentation techniques in medical education such as textbooks, chalkboards, and photographic projection are transmogrifying to relatively high-tech three-dimensional (3D) solutions such as rotatable 3D models displayed on computer screen [1]. 3D printing models are as advancing as simulation, virtual patients, and e-learning in pedagogical strategies to facilitate active learner-centred educational resources.We can move a one step ahead with 3D printing (3DP) technology, from the virtual world to the real one [2].

**Correspondence*
Dr. Veerendra Arya
Assistant Professor, Department of Medicine,
LN Medical College Bhopal, LNMC Campus
JK Hospital Kolar Road, Bhopal, India.
E-mail: drveerendraarya@gmail.com

It is possible to attenuate health and ethical problems surrounding biological specimens, conferring the advantage of extending learning opportunities outside of the laboratory and into a clinical environment with 3D printing models.We will begin with a brief introduction to 3D printing and then describe some of the applied aspects of it in different branches of medical education.

3D Printing

Prof. Emanuel Sachs coined the term 3D printing in 1995.Other term used for this process areadditive manufacturing (AM), rapid prototyping (RP), or solid free-form technology (SFF) [3]. Additive manufacturing (AM) most commonly used for 3D printing as it is a manufacturing methodfor different types of objects made by fusing or depositing materials—such as plastic, metal, ceramics, powders, liquids, or even living cells(Bioprinting)—in layers to produce a 3D object [4-6].These 3D objects can be of any imaginable shape as defined in a computer-aided design (CAD) file.On the basis of different printer technologies, speeds and resolutions and materials, various types of 3D printing processes are available [3].

CAD file helps to build the basic structure of the object by giving a command to the 3D printer which follows the instructionof it. For construction of educational 3D model primary requirement is to set the educational objective which guides in the construction process. Once objectives have established there are five essentially important steps (Fig 1) to the 3D printing process to create patient-specific models which have anatomical and or tissue fidelity [7].

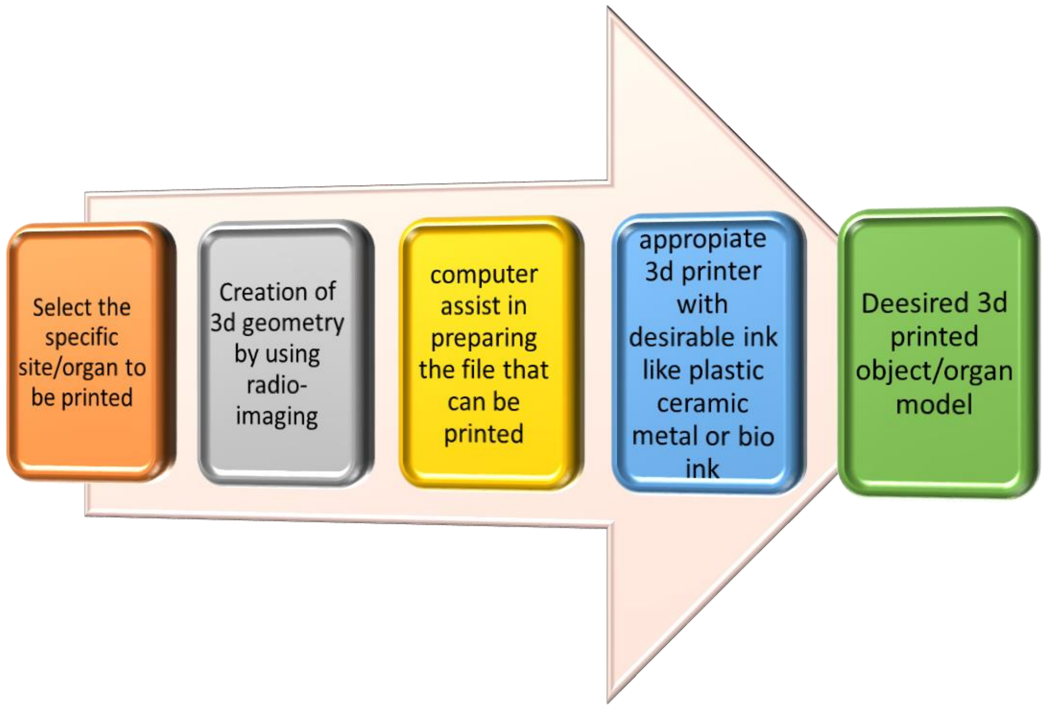

Fig 1: Steps required in the creation of 3D printed model in medical education.

1.Application of 3D printing in the surgical branches of medical education

1) IN ANATOMY

Anatomy is the fundamental of medical science. There is a need to explore new technologies to improve the learning of new generations. By scanning the patient's data, patient customize model creation may possible that simulate the patient anatomy and can provide a cost-effective, innovative, and valuable anatomy education.

a) Teaching Osteology - In 3D printing of bones is the first and foremost success in anatomy education. It has been used in different region of the anatomy. Monochromatic nature and comprised of hard tissue make the bone naturally appropriate for 3D printing. Incomparison to other structures of human body it is easiest component to duplicate in 3D printing with high level of accuracy, preserving both visual and haptic values of the real tissue [8].Osteometric analysis manifests no significant differences in the shape and dimensions of 3D printed bones and real bones in spite of difference in composition. One another earlier study also showed the same result regarding the accuracy of 3D prints of cadaveric material [9].

b) Cadaveric models – In anatomydigitization of cadaveric variations which can store as 3D images and possible to develop as high-quality 3D printed replicas of cadaveric material, thus providing the students and lecturers an ability to handle and manipulate those variation [9,10].The currently used plastic models and atlases are idealized and do not include the anatomic variations found during cadaveric dissection. The most important benefit of 3D printed models is reintroduction of anatomical variations in the advent of declining cadaveric dissection [11].

c) Specimens – Printing of 3D models or Bioprinting makes possible for students to handle and examine all specimens, especially the rare and fragile elements previously not available for inspection. In comparisons of previous methods of teaching anatomy these models are without any ethical/legal issue and with no storage issue, reproducible,relatively cheap, scalable, and capable of showing rare cases, dissectible [12].

d) Embryology - As far as embryology is concerned foetal development occurs with dynamic changes in 3D. With the help of ultrasound and MRI images of the foetus within the uterus, 3D printing models of this can be prepared [13]. These 3D printed models constructed by capturing the normal and abnormal development of foetus which provided 3D visual aid to the students while reducing ethical concerns.This method can also be used to produce physical foetal models for various anomalies from cleft lip to achondroplastic dwarfism [13]

2) IN SURGERY

a) Preoperative planning - Advent of patient-specific replica models facilitate the training of surgeons in terms of view, assess and plan surgical procedures for particular diseases or morbidity, conditions requiring surgical intervention. As 3D prints models becoming popular in surgical planning, it is must that, surgeons should have knowledge about this technology with potential and its limitations.Proper tools selection and proper guidance of technique for particular surgery may be a promising benefit of 3D prints and it may help in planning and preparation, and for effective team communication.Gerstle et al. [14] showed that the handling of this 3D model enhanced the understanding of the complex underlying condition and possible complication, which was appreciated by the whole staff and it also, helped to cut down the operating time and increased efficiency.One recent study used 3D printing as an alternative to the development of breast phantoms for training purposes. They found that these 3D printed breast phantoms anatomically as accurate as traditional breast phantoms. Out of the three phantoms chicken breast phantom provided acceptable US beam penetration and material hardness for simulation of human breast tissue integrity [15].

b) Intra-operative guidance – 3D models may act as a reference in the operation theatre during the procedure. Color coding can be done to highlight certain areas of the model; that will indicatean area of pathology which is planned for excise or avoid by the surgeon.

c) Postoperative evaluation - Physicians may use the patient model to assess the accuracy of a particular surgery they performed.

3) IN OPHTHALMOLOGY

3D printed high-resolution duplications of cadaveric orbital dissections from different sections is appropriate for education and training. This approach has the prosperity of circumventing cultural and ethical issues associated with dissecting and studying real cadaver specimens [9]. By using 3D printing technology, a similar process for creating low-cost personalized orbital models for use in orbital surgery training was described by Scawn et al [16].

3D printed models are acting as an invaluable gift in the field of eye surgery, like contact lenses and intraocular implant creation made possible, and helping in staff education and surgical planning which is crucial in this field. It also enhancing retinal imaging techniques and visualization of optical coherence tomography (OCT) images which are trending for analysis of the 3D structure of the retina. It provides extensive knowledge about the anatomy and pathology of lesions and surrounding tissue which is very useful for teaching point of view as well as for learners to correlate the 2D imaging with the 3D model of retina.

Bioprinting is exhibiting the future of 3D printing in medical care and education in general, and in ophthalmology in specifically with the evolving probability of printing viable tissue and finally the creation of a functioning cornea and later retina. ‘Printing’ an entire eye shows a sign of a great viable option for rehabilitate vision in the distant future.

4) IN ORTHOPAEDICS

There are hefty challenges in cases of orthopaedic surgery, with extensive primary injuries with multiple bone fragmentation, as well as in cases presenting with bone deformities. Inadequate information on the precise 3D extent of bone defect is still a problem even with radiographs, used routinely for orthopaedic surgical planning [17]. 3D printing models being applied rapidly in the last few years in various places within the orthopaedic field, including to assess the surgical approach for corrective osteotomies, to gain more information regarding overviews of anatomy and to enhance the planning especially in cases of minimally-invasive surgery. The approach has been immersed in a case of forearm deformity [18] and to treat the recurrent instability of the anterior shoulder. The advent of the 3D printed model may be basic assistance in the placement of screws or surgical plate, and in the testing of the advancement of the procedure, like pedicle screw placement in a clinical case of severe congenital scoliosis [19] to focus on designing the patient-specific surgical guides.

5) IN PAEDIATRICS- The additive manufacturing aid the spatial orientation to the surgeon in small infant heart cavities and duplicate thesurgical approach and procedure of the operation with high precision. This is beneficial to shorten the timing of the surgery that may decrease the complication rate, blood loss, postoperative hospital stay time, and hospital expenditure. In one paediatric study a patient of aortic arch hypoplasia, has been treated with the use of 3D model for improving the interventional simulation and planning. It is also feasible to use 3D model of stent in interventional surgery for stent placement. 3D printing model also found to be very beneficial for selecting the appropriate stent dimension and position in complex cardiovascular interventional surgical procedures. [20].

2. Application of 3D printing in the medicinal branch of medical education

1) IN PHARMACOLOGY

a) DRUG DISCOVERY - Evolution of in vitro tissue models hold a great pledge for drug discovery studies [21]. However, technologies for development of artificial organs may hamper due to regulatory obstacles but drug discovery is likely to be one of the major promising and intensifying area in medical applications of 3D bioprinting.

3D tissue models have a high aptitude to appraise and predict the success or failure of drug candidates in preclinical stages [22]. Drug discovery may become a potential application of the 3D printing for preparing a medical products and drugs according to patient particular need and specific drug response and enhanced drug discovery output, and less expenses for preclinical trials.

b)DRUG SCREENING - Different bioprinting platforms are used in many drug screenings studies for example cell spheroids [23-26], cell encapsulation [27,28], and microfluidic systems [29,30]. Lately for droplet bioprinting technology to produce sub-nanolitre droplets another type of platform was used i.e. an array type drug screening platform [31]. Which gives details of the microfabrication of CYP3A4 based protein array for multiplexing studies. One another study utilized a valve-based bioprinter to fabricate a 3D lung model for drug screening [32].

c)DRUG DEVELOPMENT AND EVALUATION- Utilization of 3D tissue constructs could impart better results in drug development and evaluation, thanks to their ability to mimic cellular structures, while the utilization of animal's number may be reduced for drug development studies [33].

Recently one approach reported bio-fabrication of in-vitro 3D liver model. This multi-layered tissue constructs or cellular architecture of rat and human hepatocytes cells with endothelial cell layers used as a liver analogue for drug studies and other biomedical applications [34].

2) IN PATHOLOGY

3D Printed models made of anatomic and autopsy pathology specimens are often used for displaying pathology entities in museum for learning of undergraduate medical, dental, and biomedical students, as well as for postgraduate learning in examination of gross specimens for anatomic pathology residents and pathology assistants, aiding clinicopathological correlation at integrative team meetings, and directing as a reference in reconstructive surgical procedures [35].

3) IN RADIOLOGY

The radiology "three-dimensional (3D) laboratory" evolved from pedagogical radiologists who created and implemented software tools to reformat diagnostic images, most frequent basis from computed tomography (CT), in anatomic as opposed to traditional planes [36,37]. Volume rendering portrayed on a two-dimensional (2D) monitor has entitled 3D visualization of anatomy and pathologic conditions, which has predominantly impacted radiology and delivered a cardinal technique for radiologists to impart relevant findings to medical care teams.

4) IN PHYSIOLOGY

3D printing has the potential to significantly improve research knowledge by increasing the level of understanding of various physiological processes.

With the use of a 3D printing system, it is possible to construct the physical three-dimensional (3D) models of biomolecules that can contribute to the study of the structure-function relationship [38]. 3D printers have the ability to dispense biological materials making bio-printing possible which is achieved with layer by layer positioning of biomaterials including the living cells [39]. It is possible to understand and probably control the growth of the tissue and behaviour of the cell by incorporating the living cell in the delicate 3D framework.

The understanding of the biomolecular structure can be achieved by the 3D printing; the physical model of the biomolecules can make easy their study. A 3D physical model can aid not only in research activities but can augment the learning outcomes [40-41].

Thus, bioprinting can play a crucial role in understanding the function and interaction of the extracellular molecules with the tissue and cell behaviour by creating the tissue and biomolecules.

5) IN MEDICINE

According to Matthew Marks et al [43] there is a requirement for effective educational tools to help patient's families, medical practitioners, and policymakers understand the nature and impact of the disease. They used patients' Digital Imaging and Computing in Medicine magnetic resonance brain images and created 3D–printed brain and hippocampus models that clearly demonstrate the progressive degenerative changes caused by Alzheimer's disease.

3. Application of 3D printing for patient education

Van de Belt et al. [44] found that 3D printed models assist in education for a small cohort of 11 patients with glioma. Patients turned up that it was very simple to ask questions from their surgeon based on their customized model and that it holds up their selection about appropriate treatment.Sander et al. [45] showed that the use of their single 3D printed educational model of the nasal sinus was able to fulfil the understanding of treatment option, anatomy and disease in surgical candidates, in comparison to without using the model in the control group.Nicole Wake et al. [46] investigated impact of patient-specific 3D printed and augmented reality kidney and prostate cancer models on patient education.Patients mentioned that overall, all types of the 3D models were helpful in learning about anatomy, disease, cancer location, and treatment plan. 3D computer models also enhanced patient comprehension of their cancer and surgical technique compared to imaging only. Although Augmented Reality models were reported to be precious by the patients, were not increase patient understanding with regard to the anatomy, disease, or treatment option.

Conclusion

3D printing is an engaging, herculean, multifaceted technology which has the potential to be very accessible to learn about anything for everyone. Forming a precise model of a particular patient by 3D printing enhances the learning process and success in treatment, and built the confidence, and increases the efficiency of trainees in the expertise area.3D haptic modelling of current work is being possible, as medical and specifically surgical education is a major advantage of 3D printing. Physical interaction has been proven to be the key to gaining motor skills required for surgical intervention refining operating room outcomes.Medical training programs could aid 3D modelling to help teach medical subjects and allow students to have a more hands-on approach. Availability of 3D printer provides the better atmosphere for students to create and print, models which advances their research pursuits and self-directed learning.We have combined the application of 3D printing in all the subjects under medical field. As far as limitation is concerned use of living cell as a material in bioprinting is still challenging but a promising area to continue to explore. Secondly cost is again a concern for its use.

References

1. Trelease RB. From chalkboard, slides, and paper to e-learning: How computing technologies have transformed anatomical sciences education. Anatomical sciences education. 2016 ;9(6):583-602.
2. Moran J, Briscoe G, Peglow S. Current technology in advancing medical education: perspectives for learning and providing care. Academic Psychiatry. 2018 ;42(6):796-9.
3. Lipson H. New world of 3-D printing offers" completely new ways of thinking": Q&A with author, engineer, and 3-D printing expert Hod Lipson. IEEE pulse. 2013;4(6):12-4.
4. Dodziuk H. Applications of 3D printing in healthcare. Kardiochirurgiaito rakochirurgiapolska Polish journal of cardio-thoracic surgery. 2016 ;13(3): 283.
5. Schubert C, Van Langeveld MC, Donoso LA. Innovations in 3D printing: a 3D overview from optics to organs. British Journal of Ophthalmology. 2014;98(2):159-61.
6. Wren K. Science and society. Experts warn against bans on 3D printing. Science. 2013; 342 (6157) :439.
7. Justine G, ZhiLin Y, Rosaire M. Leask Richard L, Lachapelle Kevin. 3D printing materials and their use in medical education: A review of current technology and trends for the future. BMJ Simul TechnolEnhanc Learn. 2018;4:27-40.
8. Abou Hashem Y, Dayal M, Savanah S, Štrkalj G. The application of 3D printing in anatomy education. Medical education online. 2015 ;20(1):29847.
9. Adams JW, Paxton L, Dawes K, Burlak K, Quayle M, McMenamin PG. 3D printed reproductions of orbital dissections: a novel mode of visualising anatomy for trainees in ophthalmology or optometry. British Journal of Ophthalmology. 2015 ;99(9):1162-7.
10. McMenamin PG, Quayle MR, McHenry CR, Adams JW. The production of anatomical teaching resources using three-dimensional (3D) printing technology. Anatomical sciences education. 2014 ;7(6):479-86.
11. Fasel JH, Aguiar D, Kiss-Bodolay D, Montet X, Kalangos A, Stimec BV, Ratib O. Adapting anatomy teaching to surgical trends: a combination of classical dissection, medical imaging, and 3D-printing technologies. Surgical and radiologic anatomy. 2016;38(3):361-7.

12. O'Reilly MK, Reese S, Herlihy T, Geoghegan T, Cantwell CP, Feeney RN, Jones JF. Fabrication and assessment of 3 D printed anatomical models of the lower limb for anatomical teaching and femoral vessel access training in medicine. Anatomical sciences education. 2016;9(1):71-9.
13. Werner H, Dos Santos JR, Fontes R, Daltro P, Gasparetto E, Marchiori E, Campbell S. Additive manufacturing models of fetuses built from three-dimensional ultrasound, magnetic resonance imaging and computed tomography scan data. Ultrasound in Obstetrics and Gynecology. 2010 ;36(3):355-61.
14. Gerstle TL, Ibrahim AM, Kim PS, Lee BT, Lin SJ. A plastic surgery application in evolution: three-dimensional printing. Plastic and reconstructive surgery. 2014 ;133(2):446-51.
15. Ali A, Wahab R, Huynh J, Wake N, Mahoney M. Imaging properties of 3D printed breast phantoms for lesion localization and Core needle biopsy training. 3D Printing in Medicine. 2020 ;6(1):1-6.
16. Scawn RL, Foster A, Lee BW, Kikkawa DO, Korn BS. Customised 3D printing: an innovative training tool for the next generation of orbital surgeons. Orbit. 2015 ;34(4):216-9.
17. Potamianos P, Amis AA, Forester AJ, McGurk M, Bircher M. Rapid prototyping for orthopaedic surgery. Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine. 1998 ;212(5):383-93.
18. Frame M, Huntley JS. Rapid prototyping in orthopaedic surgery: a user's guide. The Scientific World Journal. 2012 May 1;2012.
19. Wu ZX, Huang LY, Sang HX, Ma ZS, Wan SY, Cui G, Lei W. Accuracy and safety assessment of pedicle screw placement using the rapid prototyping technique in severe congenital scoliosis. Clinical Spine Surgery. 2011 ;24(7):444-50.
20. Valverde I, Gomez G, Coserria JF, Suarez-Mejias C, Uribe S, Sotelo J, Velasco MN, Santos De Soto J, Hosseinpour AR, Gomez-Cia T. 3 D printed models for planning endovascular stenting in transverse aortic arch hypoplasia. Catheterization and Cardiovascular Interventions.2015;85 (6): 1006-12.
21. Prodanov L, Jindal R, Bale SS, Hegde M, McCarty WJ, Golberg I, Bhushan A, Yarmush ML, Usta OB. Long-term maintenance of a microfluidic 3D human liver sinusoid. Biotechnology and bioengineering. 2016 ;113(1):241-6.
22. Asghar W, El Assal R, Shafiee H, Pitteri S, Paulmurugan R, Demirci U. Engineering cancer microenvironments for in vitro 3-D tumor models. Materials Today. 2015 ;18(10):539-53.
23. Oliveira MB, Neto AI, Correia CR, Rial-Hermida MI, Alvarez-Lorenzo C, Mano JF. Superhydrophobic chips for cell spheroids high-throughput generation and drug screening. ACS applied materials & interfaces. 2014;6(12):9488-95.
24. Friedrich J, Seidel C, Ebner R, Kunz-Schughart LA. Spheroid-based drug screen: considerations and practical approach. Nature protocols. 2009;4(3):309.
25. Chang TT, Hughes-Fulford M. Monolayer and spheroid culture of human liver hepatocellular carcinoma cell line cells demonstrate distinct global gene expression patterns and functional phenotypes. Tissue Engineering Part A. 2009;15(3):559-67.
26. Charoen KM, Fallica B, Colson YL, Zaman MH, Grinstaff MW. Embedded multicellular spheroids as a biomimetic 3D cancer model for evaluating drug and drug-device combinations. Biomaterials. 2014 ;35(7):2264-71.
27. Zhang X, Wang W, Yu W, Xie Y, Zhang X, Zhang Y, Ma X. Development of an in vitro multicellular tumor spheroid model using microencapsulation and its application in anticancer drug screening and testing. Biotechnology progress. 2005;21(4):1289-96.
28. Fong EL, Martinez M, Yang J, Mikos AG, Navone NM, Harrington DA, Farach-Carson MC. Hydrogel-based 3D model of patient-derived prostate xenograft tumors suitable for drug screening. Molecular pharmaceutics. 2014; 11(7) :2040-50.
29. Wu LY, Di Carlo D, Lee LP. Microfluidic self-assembly of tumor spheroids for anticancer drug discovery.Biomedical microdevices.2008;10(2) :197-202.
30. Buchanan CF, Voigt EE, Szot CS, Freeman JW, Vlachos PP, Rylander MN. Three-dimensional microfluidic collagen hydrogels for investigating flow-mediated tumor-endothelial signaling and vascular organization. Tissue Engineering Part C: Methods. 2014 ;20(1):64-75.
31. Arrabito G, Galati C, Castellano S, Pignataro B. Luminometric sub-nanoliter droplet-to-droplet array (LUMDA) and its application to drug screening by phase I metabolism enzymes. Lab on a Chip. 2013;13(1):68-72.
32. Horváth L, Umehara Y, Jud C, Blank F, Petri-Fink A, Rothen-Rutishauser B. Engineering an in vitro

air-blood barrier by 3D bioprinting. Scientific reports. 2015;5(1):1-8.
33. Tung YC, Hsiao AY, Allen SG, Torisawa YS, Ho M, Takayama S. High-throughput 3D spheroid culture and drug testing using a 384 hanging drop array. Analyst. 2011;136(3):473-8.
34. Chang R, Emami K, Wu H, Sun W. Biofabrication of a three-dimensional liver micro-organ as an in vitro drug metabolism model. Biofabrication. 2010 Nov 15;2(4):045004.
35. Mahmoud A, Bennett M. Introducing 3-dimensional printing of a human anatomic pathology specimen: potential benefits for undergraduate and postgraduate education and anatomic pathology practice. Archives of pathology & laboratory medicine. 2015 ;139 (8) :1048-51.
36. Fishman EK, Drebin B, Magid D, Scott Jr WW, Ney DR, Brooker Jr AF, Riley Jr LH, St Ville JA, Zerhouni EA, Siegelman SS. Volumetric rendering techniques: applications for three-dimensional imaging of the hip. Radiology. 1987;163(3):737-8.
37. Rubin GD, Dake MD, Napel SA, McDonnell CH, Jeffrey Jr RB. Three-dimensional spiral CT angiography of the abdomen: initial clinical experience. Radiology. 1993 ;186(1):147-52.
38. Beltrame ED, Tyrwhitt-Drake J, Roy I, Shalaby R, Suckale J, Krummel DP. 3D printing of biomolecular models for research and pedagogy. JoVE (Journal of Visualized Experiments). 2017 ;13(121):e55427.
39. Oliveira SM, Reis RL, Mano JF. Towards the design of 3D multiscale instructive tissue engineering constructs: Current approaches and trends. Biotechnology advances. 2015;33(6):842-55.
40. Roberts JR, Hagedorn E, Dillenburg P, Patrick M, Herman T. Physical models enhance molecular three-dimensional literacy in an introductory biochemistry course. Biochemistry and Molecular Biology Education. 2005;33(2):105-10.
41. Jittivadhna K, Ruenwongsa P, Panijpan B. Beyond textbook illustrations: Hand-held models of ordered DNA and protein structures as 3D supplements to enhance student learning of helical biopolymers. Biochemistry and Molecular Biology Education. 2010 ;38(6):359-64.
42. Herman T, Morris J, Colton S, Batiza A, Patrick M, Franzen M, Goodsell DS. Tactile teaching: Exploring protein structure/function using physical models. Biochemistry and Molecular Biology Education. 2006 ;34(4):247-54.
43. van de Belt TH, Nijmeijer H, Grim D, Engelen LJ, Vreeken R, van Gelder MM, Ter Laan M. Patient-specific actual-size three-dimensional printed models for patient education in glioma treatment: first experiences. World neurosurgery. 2018;1 (117):e99-105.
44. Sander IM, Liepert TT, Doney EL, Leevy WM, Liepert DR. Patient education for endoscopic sinus surgery: preliminary experience using 3D-printed clinical imaging data. Journal of functional biomaterials. 2017 ;8(2):13.
45. Wake N, Rosenkrantz AB, Huang R, Park KU, Wysock JS, Taneja SS, Huang WC, Sodickson DK, Chandarana H. Patient-specific 3D printed and augmented reality kidney and prostate cancer models: impact on patient education. 3D printing in medicine. 2019 ;5(1):4.
46. Marks M, Alexander A, Matsumoto J, Matsumoto J, Morris J, Petersen R, Jack C, Oishi T, Jones D. Creating three dimensional models of Alzheimer's disease. 3D printing in medicine. 2017;3(1):1

Source of Support:Nil
Conflict of Interest: Nil