Section: Anatomy

Review article

THE TRANSFORMATIVE IMPACT OF 3D PRINTING TECHNOLOGY IN ADVANCING EDUCATION AND SURGICAL PRACTICES- A COMPREHENSIVE REVIEW

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Abstract
Human Anatomy is a cornerstone of healthcare education, traditionally taught through cadaveric dissections. However, ethical, cultural, and technical challenges, along with limited cadaver donations, have prompted a shift towards alternative educational methods. 3D printed anatomical models have emerged as a valuable tool in anatomy education, providing students with the ability to visualize and interact with complex structures based on CT/MRI data. This study reviews the role of 3D printing in healthcare, focusing on its applications in anatomy education and clinical practice. It examines various 3D printing technologies—such as vat photo polymerization, material extrusion, and powder bed fusion—and their use in creating both educational models and patient-specific surgical aids. The review also highlights the post-processing steps necessary for model refinement and assembly. Despite its advantages, including improved surgical planning and enhanced educational resources, 3D printing has limitations related to model accuracy, cost, and potential misuse. Future trends indicate promising advancements in bio printing, potentially revolutionizing organ transplantation and personalized medicine. Overall, while 3D printing presents significant benefits, ongoing research and development will be crucial to addressing its current limitations and fully realizing its potential in medical education and practice.

INTRODUCTION

Human Anatomy is a fundamental discipline in every healthcare curriculum.[1] Cadaveric dissections have been the foundation for teaching and learning anatomy for decades. However, handling cadavers raises several ethical, cultural, and technical issues in addition to the danger of infection. Low donation rates in some nations limit access to dissection for many medical students.[2-5] Few medical colleges have thus abandoned the use of cadaveric dissection and have advanced towards some novel technologies such as plastinated models, three-dimensional printed anatomical models, etc.

3D printed models help provide value education to the students.[6] Using images from standard textbooks or CT/MRI of normal subjects, physically accurate 3D models are created that presents a priceless chance for trainees and students to visualize and interact with intricate anatomy, providing a certain level of realism.[7]

3D printers have been used in the clinical practice to create sophisticated prosthetic devices, surgical intervention implants and surgical planning aids. The creation of 3D printed model customised for each patient has been used to plan intricate procedures. Physicians also utilize models to practice procedures, hone skills, and improve communication with patients before surgery. They use models for guidance while surgery to minimize recovery times and lower risk. 3D printing and organ model applications have seen an unprecedented advancement in recent years. An increasing number of doctors, engineers, and researchers are collaborating to construct a variety of organ models which are unique for every patient.[8,9]

MATERIALS AND METHODS

In this study Data were collected from a variety of scientific sources using electronic databases such as PubMed, Medline, Google Scholar, Google Advance Search, Psyc INFO, ROAJ, DOAJR, PED ro, CINAHL, the Cochrane database, ISI Web knowledge, and Web science. Each relevant article was then critically examined in accordance with the study's objectives. The Boolean method was used to search keywords as 3D printed models in anatomy education or Three-dimensional printing models in medical or medicine or role of 3D printing in education. Figure 1 shows the method of selection of the articles for the review.

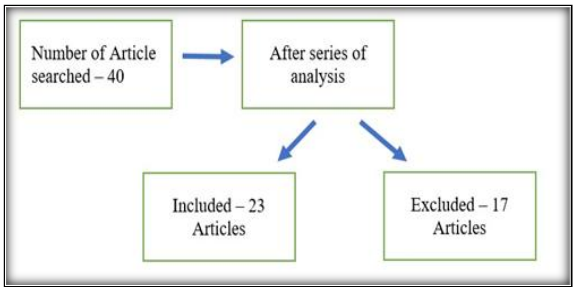

Figure 1: Shows method of selection of articles

3D Printing Processes and Technologies

3D printing is a process that creates solid physical models from digital data. Multiple layers are deposited one over the other to form a complete object. The materials used can be Polymers, metals, ceramics etc. 3D printer has a printing bed which is a platform where the models are placed and sometimes heated in order to allow the layers to adhere. An extruder is the main part which melts the material which with the help of a nozzle is deposited to build a model.[10]

Diverse 3D printers and technologies have been created, each serving a distinct purpose.[8] Different types of 3D printing processes, include vat photo polymerization, material jetting, sheet lamination, powder bed fusion, material extrusion, and binding jetting.[11] Most common methods chosen are vat photo polymerization, material jetting and material extrusion.

Vat photopolymerization: It uses liquid photosensitive polymer ingredients that are cured in successive layers under a UV light source for creating entity. The materials utilized in this process are collectively called photopolymers since they solidify from a liquid condition in certain light source.

Material extrusion: The material is heated and deposited one over the other after being forced through a nozzle. Following the deposition of each new layer, a platform travels up and down vertically and the nozzle can move horizontally.

Sheet lamination: It uses ultrasonic welding to bring together metal sheets or ribbons.

Powder bed fusion: It is based on powders that use high power laser / electron beam to melt and bind the material particles at a set location to create a solid object.

Binding Jetting: It uses powder base and jetting head, difference is that it uses binder substances instead of lasers.[8]

Material Jetting: It is also known as Inkjet printing. 3D Systems CJP (ColorJet Printing) 3D Printer (860 Pro) as shown in [Figure 2 A & B] adopts material jetting for printing 3D models and is used in AIIMS, Rishikesh. The anatomy models made in our department are taken from the textbooks as well as retrieved from the patients.

Figure 2: A & B: Shows CJP (Color Jet Printing) 3D Printer (860 Pro)

The steps followed for manufacturing of 3D printed models using Systems CJP (Color Jet Printing) 3D Printer (860 Pro) are:

- The 2 main parts of manufacturing process are the core and binder. With the help of a roller thin coats of the Core material are applied throughout construction platform.
- After the application of each layer from the color binder the core solidifies as a result of selective blasts from inkjet print. A 3D, full-color model is produced as each successive layer is printed and distributed, lowering the construction platform.
- Parts can be coated with wax to make the surface smooth or further clear coated to create strong, smooth coating using inkjet printing method.

Some of the inbuilt gross models taken from the anatomy text books. The models shown in the figure are of neuroanatomy showing different horizontal sections of brain, extraocular muscles of eye, cartilages of larynx, ear and its anatomy [Figure 3] (A-E) and [Figure 4] (A-B) represent the embryology models related to development of Vascular System and Central Nervous System.

Figure 3A: Shows 3D model of neuroanatomy of different horizontal sections of brain

Figure 3B: Shows 3D model of extraocular muscles of eye and its anatomy

Figure 3C: Shows 3D model cartilages of larynx, ear and its anatomy

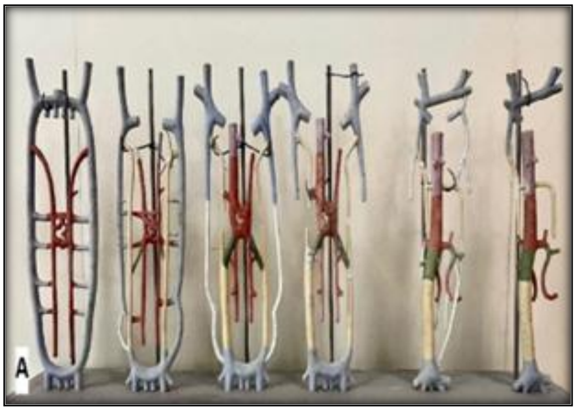

Figure 4A: Shows the embryology models related to development of Vascular System.

Figure 4b: Shows the 3D Printed Embryology Models of development of Central Nervous System.

In order to print clinical models for surgery purpose, software used is D2P™ from DICOM-to-PRINT. Here are the steps that are followed in the department of Anatomy, AIIMS Rishikesh for printing 3D models [Figure 5(a-b)].

Step-1: Open D2P Software

Step-2: Import Patient CT Scan data in form of DICOM file then click 3D as per given below image.

Step-3: After the 2nd step as per given below image software automatic reconstruct the DICOM file of patient into 3D model.

Step-4: Select the required area of print (fractured bone/pelvis) by using tools of D2P software & generate mesh.

Step-5: Once mesh is generated, convert the selected bone into 3D.

Step-6: Then convert it to a 3D printable standard tessellation language (STL) file.

Step-7: Final generated model exported to 3D print software & Printed as per following image

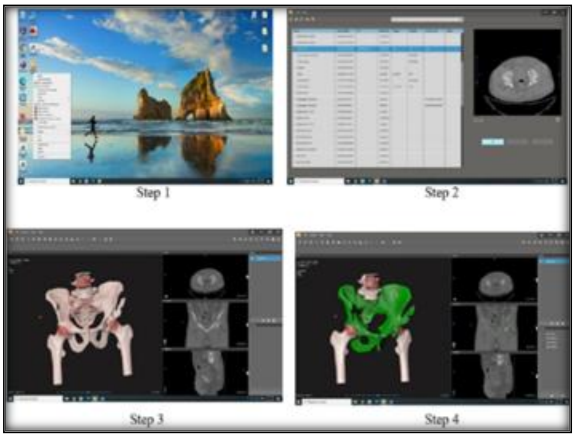

Figure 5a: Shows printing models using DICOM steps 1-4.

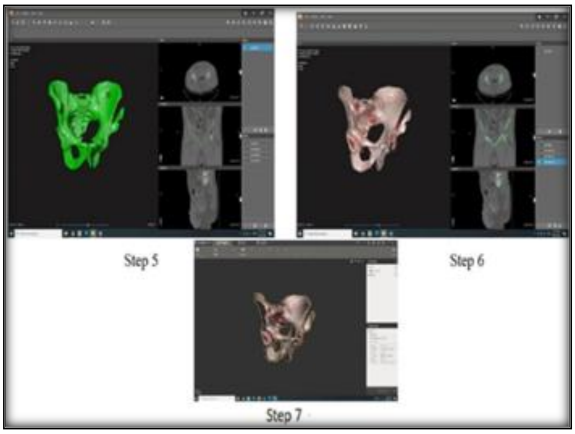

Figure 5b: Shows printing models using DICOM steps 5-7.

In our experience models can be created from images through appropriate software application with a little bit of designing. A model can be prepared in parts which can be assembled together and taught that way revealing various components e.g. Model of eye shown in [Figure 3B].

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A coat of wax keeps the surface smooth and avoids any fungal growth.

Post Processing: Post-processing is always required for the physical model once the 3D printing process is finished. Surface treatment, colouring, and assembly are the typical post-processing steps for most organ models. However, specific post-processing steps are needed for organ models with specific needs, the main one being sterilization.

The models that are manufactured in many components must be assembled. The pieces are often bonded together using variety of glues, suturing and piecing together. Error may be minimized during assembly by comparing the model to the computerized CAD data at any point.

Applications of 3D Printed models in Medical Field

The following are the primary direct uses of 3D printing in medicine and clinical applications:

- Pre-surgical planning- 3D printing is now used in making prosthetics or surgical tools based on anatomy of individual patient.[12-15] This helps in planning the surgeries and making it convenient and easy to operate. Thus, reducing time on OT table, reduced hospital stay duration and earlier recovery.
- Enhancing the Quality of Medical Education- 3D printed models are made from a large dataset of images, and can be shared between institutions, in case of limited resources. Rare clinical cases can also be preserved for training the surgeons and for teaching purposes.[16]
- Making synthetic organs - There is severe shortage of organs for transplantation. 3D printing may help in reducing the number of patients on the waiting list for transplants by customizing synthetic organs. Pharmaceutical companies in future may also possibly utilize bio printed organs to assess the toxicity of drugs instead of using animal models.
- Personalized medication 3D printing - To make a drug layer dissolve more quickly than usual, 3D printing involves printing out the drug layer tablets. Additionally, it enables customization of the patient's required dosage.[17]

3D printing is thus a revolutionary technology with the ability to profoundly alter the clinical sector, enhancing medicine and healthcare and enabling more accessible, economical, and customized treatment.

Limitations

Even while 3D printing has a lot of potential benefits, the media, governments, and even scholars tend to overestimate its potential. An excessive dependence on anatomically realistic models may lead to erroneous understandings of the intricacies in the study given the variety in human anatomy. Furthermore, the colour and physical characteristics of 3D-printed replicas differ from those of cadaveric specimens and actual body organs. The resolution of CT and MRI scans that serve as their basis determines how much detail is included as well.[18]

Furthermore, it is important for educators to consider the trade-off between expenses and model authenticity.[19]

Moreover, inferior pharmaceuticals or medical equipment might be counterfeited via 3D printing. While outright banning 3D printing is not necessary, it will undoubtedly need to have its long-term safety closely watched.[20]

Future Trends

One of the significant use of 3D printing is bio printing of organs. We should have a printed heart that works perfectly in less than 20 years, according to estimates.[21] However, the printing of tissues such as liver and kidneys is not as tough as printing the cardiovascular networks. The initial steps are encouraging as technology is advancing. This gives a direction for the creation of functional living organ implants.[22]

CONCLUSION

The availability of the material, quality and resolution of the printer have made the application of 3D printing more efficient in various fields [23]. It's Ideal for preoperative surgical planning. Increase precision with results overlaying patient's images. Even though 3D printing has already produced substantial and exciting medical advancements, some of the most ground-breaking uses, like organ printing, will take some time to develop. Colleges with shortage of cadavers for dissecting can use 3D printed models for teaching. Therefore, have both advantages and limitations to it. It is an upcoming technology which will gain significance in future.

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