Review Article

3D Printing in Medical Education
A Review of the Current Technology for Future Trends

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ABSTRACT

Educational Technology plays an important role in learning facilitation for improving educational system. An effective, long lasting learning needs various technology and modern aids to be implemented in medical education. The effective technology of 3 dimensional printing had entered into the modern context of medical education. 3D printing is more appropriate to create various models for the purposes of teaching as well as training due to accuracy and physical representation of a processed data acquired from various sources such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT). The educational research with respect to 3D printing technology and its practical and theoretical benefits in teaching and training can be identified and implemented as full-fledged in medical education. Patient specific models with exact anatomy from imaging data set will significantly improve the knowledge and skills of future surgeons. This narrative review focuses on technical steps involved in 3D printing, primary research, utility of 3D printing in teaching, surgical training, implementation of the technology in medical education and as a supplement for traditional learning approaches.

Keywords : Medical Education, 3D printing, Multimedia, surgical training, learning modalities

INTRODUCTION:

The development of 3D printing has created a new learning and teaching tool in medical education. 3D printing is also known as additive manufacturing which refers to the process of creating three dimensional objects. 3D printing can be done with computer added design, 3D scanner, plain digital camera and photo grammetry software.[1] The 3D models can be printed in a multitude of materials, with potentials for customization after production. 3D models can be constructed from the existing 3D images that provide students and lecturers with the ability to manipulate and handle numerous anomalies and variations. The 3D printing as an educational tool with an appropriate construction and use of models is guided by educational objectives.[2]

Essential characteristics for 3D printing:

In planning the 3D printed models, four essential characteristics of the model should be addressed and aligned with the education need.[3]

1. Size:

It depends on how much of the organ or anatomical area is needed for demonstration, for example, to demonstrate anatomy of the heart, the instructor should be specific whether the whole heart or a chamber of the heart is demonstrated.

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2. Surrounding structures:
To describe the relationship of specific anatomical area of interest in case of tumours and invasive cancers.

3. Surgical manipulation:
When the learner requires a model to perform resection or dissection, the material used will be selected so that the learner can cut, resect and suture.

4. Accuracy and resolution of the model:
Depends on the granular detail required for teaching and learning where the resolution will be of even 1mm.

There are five important steps related to print process to create patient specific models which have anatomical tissue fidelity (Figure 1).

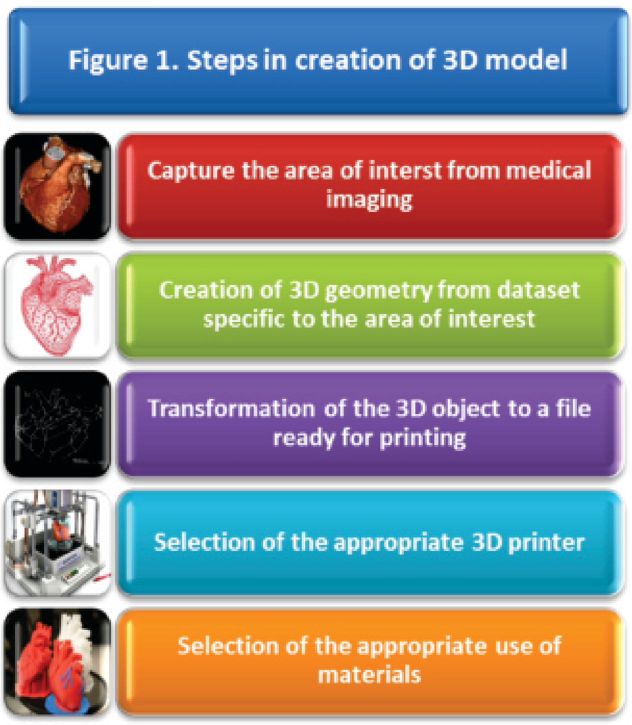


Figure 1. Steps in creation of 3D model

3D printing in teaching Anatomy:

3D printer will be a source to produce an endless variety of models in anatomy. The models can be printed using multitude materials that can be customized after production. A medical college can produce learning models suitable for wide range of use which extends from and beyond anatomy. The most important benefit of 3D printed models is reintroduction of anatomical variations in the advent of declining cadaveric dissection.[4] The currently used plastic models and atlases are idealized and do not include the anatomic variations found during cadaveric dissection. Earlier the digitization of cadaveric variations were stored virtually as 3D images[5,6] and now those existing 3D images could be constructed into 3D models thus providing the students and lecturers an ability to handle and manipulate those variations (Figure 2, 3 & 4). In future students can even be permitted to perform cadaveric dissection, scan the cadavers, use computed tomography and produce 3D models. The generated anatomical variations can be preserved and demonstrated to future generations of students.[4]

Figure 2. 3D printed anatomy models.

The 3D printed models provide students with a vast learning experience in gross anatomy which will be of similar effect to that of cadaveric dissections. A recent exploration as to whether anatomical teaching resources could be produced at suffcient resolution to provide metrics of high concordance with the original specimen has been conducted. Apart from visuals, the models can be printed accurately with all neuro-vasculature structures that are easily identifiable.

Figure 3. 3D Printer

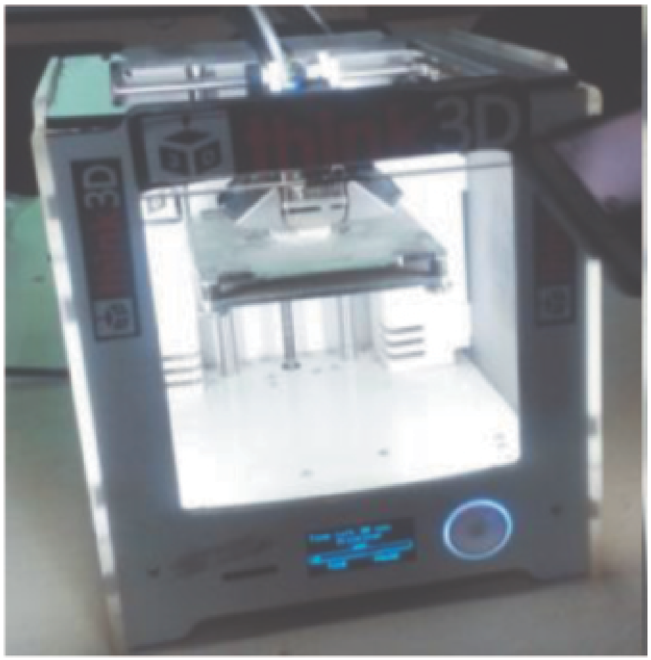
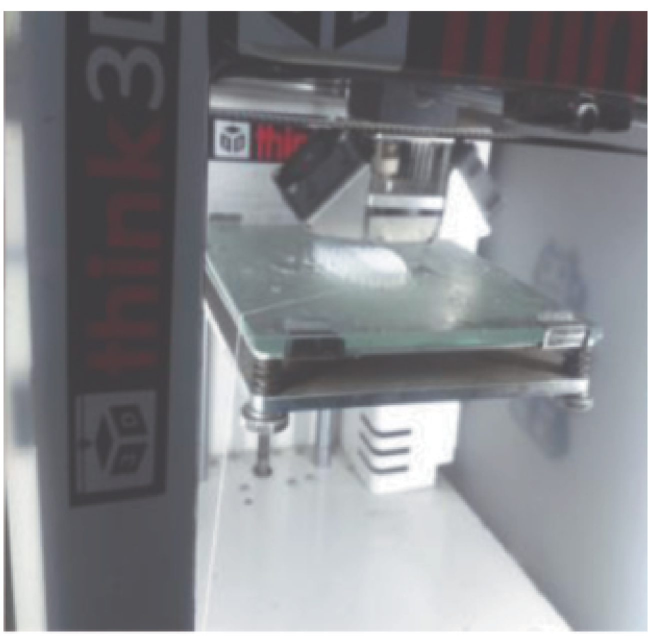


Figure 4. 3D Printing



The model can be reproduced in several sizes so that a larger model can be kept permanently at the anatomy laboratory, whereas smaller ones can be easily manipulated and taken outside classroom for self-directed learning. It is also important to note that 3Dp models could mitigate health and ethical concerns surrounding biological specimens, conferring the advantage of extending anatomy learning opportunities outside the anatomy laboratory and into a clinical environment.[6] In case of embryology and development where dynamic changes occur in 3D, ultrasound can be used in conjunction with MRI to construct an accurate image of a fetus within the uterus.[7] In this manner, normal and abnormal development can be captured, providing students with a 3D visual aid while reducing ethical concerns. This method can also be used to produce physical fetal models for various anomalies from cleft lip to achondroplastic dwarfism.[7]

3D Printing in Teaching Pathology:

Pathology has the benefit of introduction of 3D printed models through provision of an extra dimension to this traditionally didactic discipline. Data can be sourced from a variety of locations, such as healthy volunteers, patients and cadavers. Surgical specialties would most likely become a primary source of educational models, as those created for pre-operative planning can be re-used in the classroom.[8] A variety of 3D printed models have been produced by numerous specialties,[9] ranging from comminuted distal tibial fractures[10] to pulmonary vasculature[11] and the renal system.[12]

Medical students generally observe tumours through textbook, presentation slide, CT slice, or in a preserved sample. A 3D printed model can provide a multi-sensory learning experience.

Highly accurate bone, 13 kidney, 14 lung, liver and breast tumours[15] have been printed and used. Such models are complemented by contrast CT, which can present surrounding vasculature and 'negative' structures such as air sinuses.[16] To provide a more tactile experience, there is potential for constructing soft-tissue along with tumours from different materials. For example, a 'soft breast' with 'rigid mass' model constructed in this manner could be used to teach the clinical skill of palpation.[17]

Various innovative educational models such as aneurysms which can be opened to reveal internal structure,[17] calcified aortic valves[18] and the partitions to illustrate hepatic segments[16] have been developed and used in various medical schools of foreign countries.

3D-printing in Surgical Training:

The use of 3Dp models as pre-operative training tools provides multi-planar visualisation of anatomy and its relevant pathology. When integrated with patient-specific models, 3D printed models display clear advantages over traditional cadaveric models since they allow surgeons to undergo a realistic simulation of the individualized procedure required before the actual surgery.[19] Such training clearly has many benefits including a reduction in operation time and the ability to predict intra-operative complications.[20] They also assist in pre-operative planning.[21] Therefore, when 3D models are used in tandem with other resources such as video recording and feedback, this approach provides optimal training across many fields, both surgical and medical.[22]

3D printed models have been used in various surgical training approaches but they do have various limitations such as difficulty in replicating very small structures, and even if it is done, it is not always practical to include every structure in the region of interest. For example, in the case of cerebral aneurysm clipping training, blood vessels smaller than one millimeter cannot be produced, and cranial nerves are excluded in the model.[23] Next, even though it is possible to utilize a combination of materials in varying proportions to mimic real-life tissues, 3D printed models do not reproduce tissue in real to the same extent as cadaveric specimens and therefore do not provide the equivalent tactile experience.[24] However, surgeons still describe 3D printed models as useful training tools, especially when utilised for learners who are early in their surgical careers.[23] With future advancements in technology and increasing wider popularity, it is perhaps reasonable to expect fidelity to be improved, and costs and production times to be further reduced to the extent that 3D printed models will become essential resources in the context of surgical training.[25]

3D-printing in Medical Practice:

3D printing technology has been used in medicine, where patients with conditions such as cleft palate could receive patient-specific implants.[26] 3D printing has many advantages for surgical usage and has become particularly popular in orthopaedic, maxillofacial, cranial and spinal surgery.[27] The 3D printed models involve the creation and use of implants that are specific to the patient's pathology. For soft-tissue replacement, a model of the lesion can be printed and used as a mould for further processing.[28] Printing a life-size 3D printed model may simply be used to test the best-fitting implants available, reducing operative time and saving on costs. It is a common site to see a 'wasted' implant when the surgeon decides upon using a different sized implant. The advantages of adding this extra step have been reported for complex orthopaedic hip replacements[29] and occlusion of congenital septal defects.[30] The importance of 3Dp models has also been highlighted by interventional radiologists. When repairing lesions in the ascending aorta, testing the model allows the clinician to determine whether or not the supra-aortic vessels would be occluded by a patch or stent. Upon seeing the result, additional steps could be added to the operation to perforate specific areas of the implant[31] and custom-made devices could be ordered to access the lesion more easily.[32] In the future, living cells could be incorporated into these 3D printed structures and may eventually solve one of the greatest problems of transplantation medicine, i.e. donor shortage. Taking a major step towards producing human visceral analogues, animal bone, cartilage and skeletal muscle have been printed, while achieving vascularization of synthetic tissues.[33]

3D-printing in Pharmacology:

3D printing has become an effective method for producing various devices that have been used in various fields such as bioengineering, pharmacology, medical instrument production, forensic science and medical science.[34] In the pharmaceutical industry, 3D printing in-vitro models can be used to generate multiple pharmacokinetic profiles simultaneously which are then used to develop a prediction model for the pharmacokinetic properties of particular drugs.[35]

Stem Cell Research:

Tissue engineering, a practice of combining biomaterials and stem cells, is used to restore damaged tissues and organs. In regenerative medicine technology the polymer-based scaffolds on which cells grow to produce a matrix must be manufactured.[36] 3D printing allows detailed control of various aspects of scaffolds such as pore geometry, size, inter connectivity and spatial distribution.[37] In one of the studies poly ε-caprolactone (PCL) was used as the main material to evaluate stem cell interaction with the scaffold which showed that the stem cells were indeed interacting with the biomaterial and with each other.[38] Additionally, due to the hydrophobic nature of PCL, such 3D printed scaffolds can take up to three years to degrade, hence rendering them potentially suitable for use in regenerating large defects.[39]

Role of 3D printing in Medical Technology:

The development of surgical instruments by 3D printers is one of the rapid advances in medical technologies. To effectively produce new instruments which confer certain benefits over their classical counterparts, it is necessary to have a rapid work flow from design to prototyping.[40] Using 3D printing technology, instrumental designs can be conceptualised, especially since it is possible to manufacture individual parts and then assemble them to generate the final product. Prototypes of fully functional medical instruments can be produced if the appropriate materials are used.[41] Even cases where it is not possible or practical to do so, 3D printed instruments can still support the concept for instrumental design.[40]

Experimental research in 3D printed models:

The addition of 3D printers to the modern array of educational approaches in anatomy is promising and may eventually replace other adjuncts but not cadaveric dissection. 3D virtual (3Dv) models have been used in an educational setting for a number of years. Within this context, 3Dv refers to the use of modern imaging modalities to convey the impression of a 3D space. When compared to 2D representations of human structures, the use of 3Dv results in improved outcomes in terms of understanding spatially demanding anatomical knowledge.[42] A randomised-controlled trial was carried out to compare the effectiveness of an anatomical atlas, a coloured 3Dv model and a coloured 3D printed model when teaching hepatic segment anatomy.[43] Having received a pre-exposure test and short introductory lecture, first year medical students spent an hour with one of three tools before being assessed on theory and labelling of structures.

The two 3D groups achieved a statistically significant higher post-exposure score than the '2D' anatomical atlas group. However, as no comparison to cadaveric specimens have been made, these studies primarily promote usage of 3D-printed models for home or classroom-based learning, outside of the anatomical laboratory. A consistently elicited result relates to that of student perception and satisfaction. 3D models in any form are preferred over 2D images.[42] An important gender disparity has been observed with respect to 3Dv images,[44] with females shown to learn less effectively. This difference has not been observed with 3Dp models.[45] When compared to cadaveric prosections, results consistently illustrate 3Dp models are equally beneficial teaching tools and may be more beneficial in teaching practical anatomy.[45]

CONCLUSION:

Medical specialists are utilizing 3D printing in more advanced ways as the medical use of 3D printing is evolving at a rapid pace. Patients globally will definitely experience improved quality of health care as 3D printing makes advent into implants and prosthesis as well. Since 3D printing helps manufacture products using less material than traditional manufacturing methods, it is cost effective. The products can be customized making the end user more self-sufficient. Hence this new wave of advancement in healthcare that is 3D printing is an asset that would positively impact millions of lives.

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