Applications of Three-dimensional printing (3D) in anatomy education

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Résumé :

L'anatomie est l'étude de la structure du corps humain. Cela comprend des informations sur les vaisseaux sanguins, les organes, le squelette et les nerfs. C'est l'un des cours les plus complexes du programme médical, y compris la quantité de matériel dans le cours et des exigences en matière de visualisation spatiale.
La dissection cadavérique est la méthode de référence utilisée dans l'enseignement/l'apprentissage de l'anatomie. Cependant, la dissection cadavérique a souvent été associée à des préoccupations éthiques, culturelles et techniques. Ces raisons ont conduit les anatomistes à abandonner l'utilisation de la dissection et à rechercher de nouveaux outils éducatifs. De plus, les ressources d'apprentissage en anatomie humaine fournissent des illustrations anatomiques statiques bidimensionnelles (2D), ce qui rend le transfert des connaissances plus difficile.
Le développement de technologies telles que les modèles de réalité virtuelle générés par ordinateur crée de nouvelles opportunités dans l'éducation ainsi que dans de nombreux autres domaines. Les modèles imprimés en trois dimensions (3D) sont devenus de plus en plus populaires comme alternative à la méthode traditionnelle de dissection cadavérique dans l'enseignement de l'anatomie. Il fait référence à un certain nombre de technologies de fabrication qui génèrent un modèle physique à partir de l'information numérique.
L'objectif de cette revue est de résumer les études explorant l'utilisation de modèles d'impression 3D et leur impact sur les résultats d'apprentissage de l'anatomie.

Mots-clés : apprentissage de l'anatomie, impression 3D, dissection cadavérique, enseignement par modèle 2D, enseignement de l'anatomie par modèle 3D.

Abstract:

Anatomy is the study of the human body's structure. This includes information about blood vessels, organs, the skeleton, and nerves. It is one of the most complicated courses in medical curriculum including the quantity of material in the course and demands for spatial visualization.
Cadaveric dissection is the gold standard method used in teaching/learning anatomy. However, Cadaveric dissection has often been associated with ethical, cultural and technical concerns. These reasons led anatomists to abandon the use of dissection and search for new educational tools. Furthermore, Learning resources in human anatomy provide two-dimensional (2D) static anatomical illustrations, making knowledge transfer more difficult. Developing technology such as computer-generated virtual reality models creates new opportunities in education as well as in many other fields. Three-dimensional (3D)-printed models have become increasingly popular as an alternative to the traditional method of cadaveric dissection in teaching anatomy. It refers to a number of manufacturing technologies that generate a physical model from digital information.
The aim of this review is to summarize studies exploring the use of 3D printing models and their impact on anatomy learning outcomes.

Keywords: anatomy learning, 3D printing, cadaveric dissection, 2D model anatomy teaching, 3D model anatomy teaching,

Introduction:

Anatomy is a key component of medical education. It is one of the most complicated courses in the medical curriculum due to the vast levels of knowledge needed and demands for spatial imagination.
Anatomy is frequently taught using a range of cadaveric specimens, textbooks, didactic teaching sessions, and plastic models (1).

Spatial visualization is an essential key factor in learning anatomy. Students must learn not only anatomical structures and functions, but also the spatial relationships between them and the surrounding structures. While anatomy textbooks and atlases provide two-dimensional (2D) static anatomical illustrations, they are limited in their ability to expose three-dimensional (3D) anatomical structure dynamics. It may be difficult for students to visualize 2D images in 3D and to comprehend certain dynamic aspects of functional anatomy (2).

Anatomy teaching has changed over the past two decades (3) with the result being a reduction in the number of hours devoted to teaching anatomy and its context (4). Anatomical skills and knowledge were previously acquired through didactic lectures and complete body dissection. Special study modules, problem-based workshops, plastic models, and digital resources (videos, 3-dimensional reconstruction, etc.) have recently been added to this approach (5,6).

Cadaveric dissection has long been the "gold standard" for learning about the human body's structural details. It gives students hands-on experience with a three-dimensional (3D) view of complex anatomical structures and relationships, which will help them to understand pathologic and clinical problems. Importantly, dissection helps to develop compassion and empathy amongst learners (7). However, this teaching method has always been associated with ethical concerns, difficulties and potential risks of preservation and disposal of specimens. Further, the shortage of donors is another limitation associated with cadaveric dissection in some countries (8,9). For these reasons, certain medical schools have decided not to use cadaveric dissection (10).

With the introduction of reformed curricula, most health schools have reduced the total time allocated for anatomy course and dissection hours. Therefore, new and innovative teaching and learning strategies are required to maximize students' learning of anatomy course in the new context (2).

The aim of this review is to summarize studies exploring the use of 3D printing models and their impact on anatomy learning outcomes.

1. Three-Dimensional Printing:

Three-dimensional printing (3DP) has a wide range of applications, including applications in space science, technology, and medical education. For instance, technology can be used to scan the human body with magnetic resonance imaging and a computerized tomography scan. It can then replicate human structures with multiple layers of resin (11). In anatomy, high-quality 3D-printed replicas of cadaveric material were recently produced for teaching purposes (12). It is used to train residents for anatomy education. This technology has shown great potential as an educational tool in areas such as autopsy, plasticization, computer simulation, and anatomical modelling and images.In recent decades, 3DP has been employed in the teaching of anatomy to medical students(11).

2. Three-dimensional printing in anatomy education

In the era of communication, innovative changes in the science and technology industry have facilitated greater access to valuable information. Therefore, the educational system should focus on student-centered structural learning as it pertains to technology, to ensure continued synergy. A place for the teaching-learning process has begun with the idea of technology. The rapid advancement of science is influenced by computer technologies that are used in the education process and will remove the limitations of traditional education (13). Current evidence suggests that students may have different intellectual development and ultimately, learning styles (14). Moreover, digital technology has exerted a significant impact (positively or negatively) on the individuals learning styles in post-millennial student populations (15).

The VARK model measures the four sensory modalities used for learning, which are; Visual (V), Aural (A), Read/write (R), and Kinesthetic (K) (16). Learners can be classified according to their individual preference to learning style, as unimodal if they show predominantly one learning preference or multimodal if preference is shared between 2 or more learning styles (17).

The most common learning modes are multimodal combinations of audio-kinesthetic learners, and tri-modal audio-read/write-kinesthetic learners and that a multimodal anatomy curriculum can result in improved student outcomes (1).

Shah and Ahmed studied the importance of the variation in teaching for undergraduate dental education and found that the majority of students had a preference for kinaesthetic learning (ie, tactile learning). Those physical interactions or activities are the reasons why 3D printed models are essential in the training of medical professionals (18).

Only a few schools and universities use 3DP as an educational tool across the world. Additionally, educators have to detect, through their communication with students, what type of methods is appropriate for them. Now, with the new challenges of study courses arising, it will be very likely to see medical educators using 3DP and digital images in their courses (19).

Several studies have compared 3D printed models with cadaver specimens. A randomized controlled trial (RCT) study conducted by Chen et al. (8), to compare the learning efficiency of 3D printed skulls with that of cadaveric skulls and atlas. The authors concluded that the 3D printing group was better than the other two groups (cadaveric and atlas) in total score. In another double blind (RCT) study, Lim et al. (20) found that the post-test score of the (3D) printing group were significantly higher than that of the cadaveric materials for learning cardiac anatomy.

In a study which set out to determine the differences in answering time between the 3D printing group, two-dimensional computed tomography images (CT) and 3D groups, Li et al. (21) reported that, the 3D printing group spent less time in replying all anatomical questions and no sex-related differences were found. Furthermore, Yi et al.(22) Performed a RCT study, aimed to evaluate the educational effect of the 3 D printed models on anatomy education of the ventricular system, they found that both of the test results of the 3D printing and 3D images groups were higher than those in the 2D group (anatomy atlas and computed tomography) . In addition, students evaluated the 3D printing model more positively than the 3D images.

A perception of course learnability is required to motivate students to persist with their learning. The complex theme of motivation has been described by Keller (23). as reported by Keller, the five principles of motivation are as follows: Curiosity, Relevance, Success, Extrinsic and intrinsic motivators and Self-regulation strategies protect the intentions to learn when distracted and obstacles interfere with persistence (23).

Jordan et al.(24) studied the satisfaction of students in the 3D printing and conventional groups with their learning by using online five-point Likert scale surveys, they found that students in the 3D printing group were more satisfied compared to students in the conventional group.

The 3D-printed anatomical models could be effective for educational purposes and appear to be easier to handle, as well as is more cost-effective as compared to cadaveric models (25). Studies investigating the utility of 3D printing in learning found that 3D printed anatomical models was considered more useful compared with the other conventional models (26,27). For example, both students and instructors can explore a concept object by designing their own 3D model. This activity encourages active learning because the action of building offers hands-on learning experience and a more detailed look into the model. Moreover, 3D printed model gives a better spatial visualization because learners can pick up and rotate a model to view anatomical structures or pathologies (28). Other advantages mentioned included being able to touch the object with a gloveless hand and a higher availability and durability (29).

3. Summary of outcome of education assessment:

According to Smith et al. 2018;

1. The use of 3D printed modules in small group classes leads to an improved learning outcome.
2. There is a clear trade-off between detail and construction time/cost. Overall models made at 40-60% scale were suitable, but full scale was important for students to relate to the actual size of the structure, as it would be in situ
3. 3D printed models could be incorporated into large group teaching sessions to enhance interactivity.
4. 3D models could be used in formative and summative assessments (1).

4. Limitation of the 3D printing:

Finally, a number of important limitations need to be considered. Firstly, some of learners found 3D printed models are more flexible and durable in comparable to conventional plastic models. However, if learners only have access to 3 D printed models, it could lead to a deficiency of understanding the real size and the relation to other anatomical structures. (30). Secondly, 3D printed models are currently made of plastic or other solid materials and therefore lack specific tissue characteristics such as pliability. For example, there is no direction of muscle fibers that can be felt, nerves and arteries are solid, and tactile distinction of different tissues is lacking(29).

Another concern are the time costs necessary for production of 3DP models. This varies depending on the size of a model and the type of printer. A powder-based 3D printer takes three hours to produce a life-size hand prosection replica, complete with colour and neurovasculature , whilst the complex aneurysm model described above took seven days to print using an inkjet 3D (31).

In an article in this issue of ASE, Dr. McMenamin said "we advocate 3D printed anatomical replicas not as a replacement but an adjunct to actual dissection. If access to cadaver material is not an option or unavailable to students we maintain that 3D prints may offer a novel, accurate and effective substitute. Evaluation studies are planned to gather direct evidence of their value in teaching" (32).

Conclusion:

The present review shows that 3DP technology has led to promising results in teaching and learning of human anatomy, creation of complex anatomical models, which provided a similar experience compared to cadaveric dissection. This teaching method has shown positive results in terms of students' academic performance and most of the learners in the 3D printing group were more satisfied with their anatomy learning than those in the conventional group. This facilitates the assessment of the relationship and distance between anatomical structures and hence improves spatial knowledge acquisition more than other pedagogical methods. In addition, touching the object with a gloveless hand and a greater availability and durability. Despite potential benefits of this model, there were some barriers such as; a deficiency of understanding of real size and how it relates to other anatomical structures, lack specific tissue characteristics and the time costs necessary for production of 3DP models.

For these reasons, we suggest that 3D printed models should be considered as an adjunct educational tool to cadaver dissections in order to optimize teaching and learning human anatomy without replacing or reducing dissection sessions.

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