The application of 3D printing in teaching human anatomy: Literature review

Jalles Dantas de Lucena
Santa Maria University Center (UNIFSM), Cajazeiras, PB
Postgraduate Program in Education, Federal University of Ceará (UFC), Fortaleza, CE
E-mail: jallesdantas@gmail.com

Gilberto Santos Cerqueira
Postgraduate Program in Education, Federal University of Ceará (UFC), Fortaleza, CE
Postgraduate Program in Morphofunctional Sciences, Federal University of Ceará (UFC), Fortaleza, CE
Department of Morphology, Faculty of Medicine, Federal University of Ceará (UFC), Fortaleza, CE
E-mail: giufarmacia@hotmail.com

ABSTRACT
Anatomy is essential to the physicians and health professions, by learning anatomy, medical students learn about the structure of the human body, providing them with the basic knowledge for understanding pathology and clinical problems (VACCAREZZA; PAPA, 2014).

Keywords: Anatomy, Learning, Teaching, Medical Education, 3D Printing.

1 INTRODUCTION

Anatomy is essential to the physicians and health professions, by learning anatomy, medical students learn about the structure of the human body, providing them with the basic knowledge for understanding pathology and clinical problems (VACCAREZZA; PAPA, 2014).

The cadaver dissection is one of the main methods used to teach anatomy. Cadaveric dissection, carried out during hands-on training, supports the theoretical lessons given to medical students and is currently considered the gold standard for learning anatomy (GHOSH, 2017). However, there are many obstacles to using human cadavers, such the storing expensive, preservation and reduced suitability for dissection due to illness, age or obesity; moreover, careful dissection is time-consuming and there is a lack of cadavers for study (VACCAREZZA; PAPA, 2014). Aside from biological and methodological matters, dissection and prosection have also issues relating to ethical convictions and legal restrictions (MCHANWELL et al., 2008).

In this way, instigation a search for new pedagogical tools for teaching anatomy (PAPA; VACCAREZZA, 2013). Some of these new tools are digital tools, extended reality, and 3D printing. Recent studies show that 3D printing appears to be one of the most relevant resources both in terms of its educational value to students and the feasibility of its implementation (SANTOS et al., 2022).

3D printing has, in the last three decades, been successfully utilized in different medical fields, including education. In anatomy, high-quality 3D-printed replicas of cadaveric material are produced for teaching purposes (MCMENAMIN et al., 2014).

Studies point out some advantages of using 3D printing, the visual or tactile qualities of their models (LOW et al., 2020; WILLIAMS et al., 2020; MOGALI et al., 2022), the strength and durability (CAI et al., 2019). Other advantages were that the students could manipulate the structures, the teacher could save time, they were easier to preserve than a cadaver (CASCIATO et al., 2018; BACKHOUSE et al., 2019).

Furthermore, the three-dimensional-printed anatomical models are effective as pedagogical tools in terms of achievement (SMITH et al., 2018; YI et al., 2019; CHEDID et al., 2020), long-term knowledge retention (O'BRIEN et al., 2021) and student satisfaction (YI et al., 2019; CHEDID et al., 2020).

Three-dimensional-printed anatomical models are a relevant tool due to their educational value and their feasibility. The objective of this review was to describe the advantages of the utilization of 3D printing in teaching human anatomy.

2 MATERIALS AND METHODS

This review of the literature was conducted in October and November 2023, with articles published in 2019-2023. A literature search was performed in the electronic PubMed database (National Library of Medicine, NCBI) to identify relevant studies published up to October 2023. The following search terms found in Descriptors in Health Sciences/Medical Subject Headings - DeCS/MeSH were used: Anatomy, Learning, Teaching, Medical Education and, 3D Printing. The Boolean operator AND was used to combine the search terms.

All research papers dealing with 3D printing in anatomy teaching/learning and, published in English were selected. Literature reviews, meta-analysis, letters, or articles studying pathological models, animal models, archaeological models, and medical/surgical training models were excluded.

3 RESULTS AND DISCUSSION

Three hundred and sixty-four studies were identified in the PubMed database; 235 articles were excluded by the filters: human, published in 2019-2023, literature reviews and, meta-analysis. Three hundred and sixty-four studies were identified in the PubMed database; 235 articles were excluded by the filters: human, published in 2019-2023, literature reviews and, meta-analysis. After the title and abstract were analyzed, 33 studies were selected for reading of the full text. A total of 27 articles were included in this review.

The articles studied since the cephalic region, the thoracic region, the abdominopelvic region and the limbs (CHEN et al., 2020; LOW et al., 2020; TANNER et al., 2020; LUGASSY et al., 2021; CHEN et

al., 2022; HOLM et al., 2022; MIAO et al., 2023). The cephalic region was the most studied, probably because its anatomical complexity makes it difficult for students to picture this anatomical region in 3D space, compared to the limbs or trunk.

Regarding the original model or file used for designing the 3D printing, the articles mentioned the use of patient data, the use of cadaver data, and the use of a database (LOW et al., 2020; HOLM et al., 2022; CHEN et al., 2022; MIAO et al., 2023). The 3D printings were designed from CT scans, optical scanners, MRI and from camera (LOW et al., 2020; HOLM et al., 2022; CHEN et al., 2020).

CT scan was by the most used image acquisition modality. This modality is widely available, especially in health services, but its spatial resolution is limited, and its soft-tissue contrast is low. These limitations make CT scan unsuitable for segmentation and modelling of the nervous system for example. MRI, on the other hand, was cited as the reference technology in terms of spatial resolution for the acquisition of images. Higher resolution preserves the subtleties of the anatomy (BANNON et al., 2018).

Cadaveric specimens were the most used comparator for 3D printing. Despite its drawbacks, the cadaveric model remains a valuable tool for teaching anatomy. A distinction needs to be made between cadaveric dissection and prosections. One study showed that 3D printing were significantly more effective than plastinated prosections based on learning tests (MOGALI et al., 2022). It is likely that few studies have been done on this topic because this comparison is difficult to set up.

The studies by Cai and Miao found significantly better test results for the groups who used associated 3D printing (CAI et al., 2019; MIAO et al., 2023). Holm and colleagues used anatomically accurate 3D models of real patient vasculatures, that accurately represent significant patient-to-patient variations, the learning is more translatable to what is seen in the clinic (HOLM et al., 2022). Tanner and colleagues (2020) demonstrated better post-test results for the group using a 3D printing of the pterygopalatine fossa. Finally, Chen and colleagues demonstrated that the 3D printing gastrocolic trunk model is a very effective teaching tool, which can help interns understand the anatomy of Henle trunk (CHEN et al., 2020).

This review identified other teaching tools: most common were augmented reality, virtual reality, and serious gaming (JAVAN et al., 2020; CERCENELLI et al., 2022). According to Mahrous et al. (2021), the anatomical model preference depends on the number of video game hours played by the student. On the other hand, the biggest challenge of new tools in anatomy education is haptic feedback, especially for virtual-only tools (WILLIAMS et al., 2020).

The educational relevance of 3D printing was evaluated mostly in medical students. In their pilot study, Wilk and colleagues (2020) reported that medical students felt 3D printing should be incorporated into their learning of anatomy. Eighty-seven percent of students surveyed in the Cercenelli study reported that their second year was the best time to use 3D printing (CERCENELLI et al., 2022). These data suggest

that the first years of medical school are the best time to incorporate 3D printing into the teaching of anatomy.

Ultimately, studies show that the 3D printing has effective as pedagogical tools in terms of achievement (CAI et al., 2019; TANNER et al., 2020; LUGASSY et al., 2021; HOLM et al., 2022), long-term knowledge retention (HOLM et al., 2022; MIAO et al., 2023) and student satisfaction (CHEN et al., 2020; TANNER et al., 2020; MIAO et al., 2023). Backhouse et al. (2019) judged 3D printing to be the best alternative to conventional anatomical models.

4 CONCLUSION

This literature review has demonstrated that the 3D printing is beneficial for anatomical education and can help in enriching students' learning experience.

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