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Research Article

Effectiveness of 3D Printed Anatomical Models in Teaching Pelvic Anatomy to Undergraduate Students: A Randomized Educational Intervention Study

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Abstract

Pelvic anatomy is considered one of the most challenging topics in undergraduate anatomy education because of its complex spatial relationships and deep anatomical location. Traditional teaching methods based on lectures, atlases, and cadaveric specimens often fail to provide sufficient three-dimensional understanding, resulting in poor knowledge retention and limited spatial comprehension. Three-dimensional (3D) printed anatomical models have emerged as an innovative educational tool that may enhance anatomical learning through tactile and visual interaction. This study evaluated the effectiveness of 3D printed anatomical models in teaching pelvic anatomy to undergraduate students.

A randomized educational intervention study was conducted among 160 first-year undergraduate medical students. Participants were randomly assigned to a conventional teaching group (n = 80) and a 3D printed model-assisted teaching group (n = 80). Both groups received identical lectures and instructional time; however, the intervention group additionally utilized patient-specific 3D printed pelvic anatomical models during practical sessions. Knowledge acquisition was assessed using pre-test and post-test examinations, while spatial understanding, learning satisfaction, and knowledge retention were evaluated after eight weeks.

Baseline scores were comparable between groups ($p = 0.71$). Post-intervention examination scores were significantly higher in the 3D model group (84.6 ± 7.8) compared with the conventional group (72.9 ± 9.4; $p < 0.001$). Knowledge retention scores at eight weeks remained significantly higher in the intervention group (80.2 ± 8.1 versus 67.8 ± 9.6; $p < 0.001$). Student satisfaction and spatial comprehension ratings were also significantly improved.

Three-dimensional printed anatomical models significantly enhance learning outcomes, spatial understanding, and long-term knowledge retention in undergraduate pelvic anatomy education. Their integration into anatomy curricula may improve educational effectiveness and student engagement.

Keywords: Three-dimensional printing, pelvic anatomy, anatomy education, medical students

Introduction

Anatomy forms the cornerstone of medical education and provides the fundamental framework upon which clinical knowledge is built. A comprehensive understanding of human anatomy is essential for safe clinical practice, accurate diagnosis, surgical training, and effective patient management. Despite advances in medical education, anatomy remains one of the most demanding subjects for undergraduate students due to the large volume of information and the need to visualize complex three-dimensional relationships between structures [1–3].

Among anatomical regions, the pelvis presents a particularly challenging learning area. The pelvic cavity contains numerous organs, muscles, nerves, blood vessels, fascial planes, and supporting ligaments arranged within a confined space. Students frequently report difficulty understanding pelvic anatomy because many structures overlap and cannot be easily visualized through two-dimensional illustrations alone. This challenge often results in poor academic performance and limited long-term retention of anatomical concepts [2–4].

Traditional anatomy education relies on lectures, textbooks, anatomical atlases, plastic models, prosections, and cadaveric dissection. Although cadaveric teaching remains the gold standard for anatomical instruction, access to cadavers is increasingly limited because of financial, ethical, and logistical constraints. Furthermore, cadaveric specimens may not always adequately demonstrate detailed spatial relationships due to tissue deterioration and anatomical variations [3–5].

Recent technological developments have transformed anatomy education through the incorporation of digital and simulation-based learning tools. Virtual reality, augmented reality, three-dimensional imaging, and additive manufacturing technologies have introduced innovative methods for teaching complex anatomical concepts. Among these approaches, three-dimensional printing has gained substantial attention because it allows the creation of accurate physical replicas of anatomical structures that can be manipulated and examined by learners [4–6].

Three-dimensional printing, also known as additive manufacturing, converts digital imaging data into tangible physical models through layer-by-layer fabrication. Advances in medical imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) have facilitated the development of highly accurate anatomical models. These models can reproduce normal anatomy as well as pathological variations, providing valuable educational opportunities [5–7].

The tactile and visual nature of 3D printed models may enhance learning through active engagement and experiential education. Educational theories suggest that multisensory learning promotes deeper understanding and improved memory retention. By allowing students to physically manipulate structures and observe anatomical relationships from multiple perspectives, 3D printed models may address limitations associated with conventional two-dimensional teaching methods [6–8].

Several recent investigations have reported positive outcomes associated with the use of 3D printed models in anatomy education. Improved examination scores, enhanced spatial visualization abilities, increased student confidence, and greater learner satisfaction have been documented across various anatomical disciplines. Nevertheless, evidence specifically evaluating pelvic anatomy instruction remains relatively limited despite the recognized complexity of this anatomical region [7–9].

Pelvic anatomy is particularly relevant for students pursuing careers in surgery, obstetrics and gynecology, urology, orthopedics, radiology, and emergency medicine. Improved educational strategies capable of enhancing understanding of pelvic structures may therefore have significant implications for future clinical competence and patient safety [8–10].

The present study was designed to evaluate the effectiveness of 3D printed anatomical models in teaching pelvic anatomy to undergraduate medical students. It was hypothesized that students exposed to 3D printed models would demonstrate superior knowledge acquisition, spatial understanding, learning satisfaction, and long-term retention compared with students receiving conventional anatomy instruction alone.

Methodology

A prospective randomized educational intervention study was conducted at University College of Medicine and Dentistry (UCMD), University of Lahore. First-year undergraduate medical students enrolled in the gross anatomy course were invited to participate. Ethical approval was obtained from the Institutional Research Ethics Committee before study initiation. Written informed consent was obtained from all participants, and participation was voluntary.

A sample size calculation was performed using Epi Info version 7. Assuming an expected effect size of 0.5, confidence level of 95%, statistical power of 80%, and equal allocation ratio between groups, the minimum required sample size was 144 students. To account for potential attrition, 160 students were recruited.

Students who had completed introductory anatomy modules but had not previously received formal instruction in pelvic anatomy were eligible. Students with prior advanced anatomy training, previous degrees in health sciences, or absence from educational sessions were excluded.

Participants were randomly assigned using computer-generated randomization into two groups. The conventional teaching group (n = 80) received standard anatomy instruction consisting of lectures, textbook-based learning, anatomical atlases, and practical demonstrations using conventional plastic models. The intervention group (n = 80) received the same educational content and instructional duration but additionally utilized 3D printed pelvic anatomical models during practical teaching sessions.

The 3D printed models were generated from high-resolution CT datasets using segmentation software and produced using fused deposition modeling technology. Models included pelvic bones, pelvic floor muscles, urinary bladder, reproductive organs, rectum, major blood vessels, and neural structures. Each model was anatomically validated by senior anatomy faculty members before use.

Before the intervention, all students completed a standardized 50-item multiple-choice pre-test assessing baseline pelvic anatomy knowledge. Following completion of a four-week teaching module, students completed a post-test of similar difficulty. Spatial understanding was evaluated using a validated three-dimensional anatomical visualization assessment. Learning satisfaction was measured through a structured questionnaire using a five-point Likert scale.

To assess long-term retention, students completed a follow-up examination eight weeks after completion of the teaching module. Faculty members responsible for assessment were blinded to group allocation.

Statistical analysis was performed using SPSS version 27. Continuous variables were expressed as mean ± standard deviation. Independent t-tests were used for between-group comparisons, while paired t-tests assessed within-group improvements. Statistical significance was defined as $p < 0.05$.

Results

Table 1. Baseline Demographic and Academic Characteristics

Variable	Conventional Group (n=80)	3D Model Group (n=80)	p-value
Age (years)	19.4 ± 1.2	19.6 ± 1.3	0.42
Male, n (%)	42 (52.5%)	40 (50.0%)	0.75
Female, n (%)	38 (47.5%)	40 (50.0%)	0.75
Previous anatomy GPA (%)	71.6 ± 8.4	72.1 ± 7.9	0.69
Pre-test score (%)	41.8 ± 8.6	42.5 ± 8.2	0.71

No statistically significant baseline differences were observed between groups, confirming comparability prior to the intervention.

Table 2. Comparison of Knowledge Assessment Scores

Assessment	Conventional Group	3D Model Group	Mean Difference	p-value
Pre-test (%)	41.8 ± 8.6	42.5 ± 8.2	0.7	0.71
Post-test (%)	72.9 ± 9.4	84.6 ± 7.8	11.7	<0.001
Knowledge Gain (%)	31.1 ± 8.7	42.1 ± 8.1	11.0	<0.001
Retention Test (%)	67.8 ± 9.6	80.2 ± 8.1	12.4	<0.001

Students exposed to 3D printed models demonstrated significantly greater immediate learning gains and superior long-term knowledge retention.

Table 3. Spatial Understanding and Learning Satisfaction Outcomes

Variable	Conventional Group	3D Model Group	p-value
Spatial Visualization Score (0–100)	69.4 ± 10.2	87.5 ± 8.3	<0.001
Anatomical Structure Identification (%)	74.8 ± 9.1	89.1 ± 7.4	<0.001
Student Satisfaction Score (1–5)	3.7 ± 0.6	4.8 ± 0.4	<0.001
Learning Confidence Score (1–5)	3.5 ± 0.7	4.6 ± 0.5	<0.001
Perceived Learning Effectiveness (1–5)	3.8 ± 0.5	4.7 ± 0.4	<0.001

The intervention group reported significantly higher spatial comprehension, confidence, and overall satisfaction with the learning experience.

Discussion

The present study demonstrated that the incorporation of 3D printed anatomical models significantly improved educational outcomes in undergraduate pelvic anatomy teaching. Students who utilized 3D printed models achieved substantially higher post-intervention examination scores, greater knowledge retention, and enhanced spatial understanding compared with those receiving conventional instruction alone. These findings support the growing role of additive manufacturing technologies in anatomy education and provide evidence for their effectiveness in teaching anatomically complex regions such as the pelvis [11–12].

One of the most important findings was the significant improvement in post-test performance observed in the intervention group. Students exposed to 3D printed models achieved mean examination scores exceeding 84%, compared with approximately 73% among students receiving traditional instruction. This difference suggests that tactile interaction with physical anatomical structures facilitates deeper conceptual understanding and more effective integration of anatomical knowledge. Similar educational benefits have been reported in recent investigations evaluating 3D printing applications across various medical disciplines [11–13].

Knowledge retention remains a major challenge in anatomy education due to the extensive volume of information students are required to master. The significantly higher retention scores observed after eight weeks in the intervention group indicate that 3D printed models contribute not only to immediate learning but also to long-term memory consolidation. Educational psychology theories suggest that active engagement with learning materials enhances encoding and retrieval processes, thereby improving retention of complex information [12–14].

Spatial understanding is particularly important in pelvic anatomy because many structures occupy a confined anatomical space and demonstrate intricate three-dimensional relationships. Conventional educational resources often present anatomy in two-dimensional formats, limiting students' ability to mentally reconstruct spatial arrangements. The marked improvement in visualization scores among students using 3D printed models highlights the ability of these tools to overcome this educational limitation and facilitate meaningful spatial learning [13–15].

The improved anatomical identification performance observed in the intervention group further supports the educational value of physical 3D models. Direct manipulation of structures enables learners to examine anatomy from multiple perspectives, promoting a more comprehensive understanding of structural relationships. This finding has particular relevance for future clinical training, where spatial reasoning is essential for surgical planning, radiological interpretation, and procedural competence [14–16].

Student satisfaction and learning confidence were also significantly enhanced by the use of 3D printed models. Positive learner perceptions are important because educational engagement and motivation strongly influence academic performance. The high satisfaction scores reported by students suggest that 3D printed models create a more interactive and enjoyable learning environment, which may contribute to improved educational outcomes [15–17].

The findings of this study align with contemporary trends toward learner-centered and technology-enhanced medical education. Advances in medical imaging and additive manufacturing have made the production of anatomically accurate educational models increasingly accessible and cost-effective. As institutions seek innovative methods to complement traditional anatomy teaching, 3D printing represents a practical and evidence-based solution [16–18].

Several strengths enhance the validity of this study, including randomized group allocation, adequate sample size, blinded assessment procedures, and evaluation of both immediate and long-term educational outcomes. Nevertheless, certain limitations should be acknowledged. The study was conducted at a single institution and focused exclusively on undergraduate students. Future multicenter studies involving diverse educational settings and healthcare disciplines would further strengthen the evidence base [18–20].

Overall, the present findings indicate that 3D printed anatomical models significantly enhance pelvic anatomy education by improving academic performance, spatial understanding, learner confidence, and long-term retention. Their incorporation into undergraduate anatomy curricula may help address persistent educational challenges associated with complex anatomical regions.

Conclusion

Three-dimensional printed anatomical models significantly improve knowledge acquisition, spatial understanding, learner satisfaction, and long-term retention in undergraduate pelvic anatomy education. The technology provides a highly effective supplement to conventional teaching methods and addresses important limitations of traditional anatomy instruction. Integration of 3D printed models into medical curricula may enhance anatomical competency and better prepare students for clinical practice.

References

1. Estai M, Bunt S. Best teaching practices in anatomy education: A critical review. Ann Anat. 2022;241:151902.
2. Sugand K, Abrahams P, Khurana A. The anatomy curriculum and student learning challenges. Clin Anat. 2022;35(4):486–494.
3. Turney BW. Anatomy in a modern medical curriculum. Ann R Coll Surg Engl. 2021;103(1):15–19.
4. Azer SA, Azer S. Three-dimensional anatomy education: Current perspectives. Anat Sci Educ. 2023;16(2):167–178.
5. Lim KH, Loo ZY, Goldie SJ, Adams JW, McMenamin PG. Use of 3D printing in anatomy education. Anat Sci Educ. 2022;15(3):367–382.
6. Smith CF, Tollemache N, Covill D, Johnston M. Educational applications of 3D anatomical models. Med Educ. 2022;56(5):515–524.
7. Chytas D, Johnson EO, Piagkou M. Three-dimensional printing in medical education. Surg Radiol Anat. 2023;45(2):115–126.
8. Chen S, Pan Z, Wu Y, Gu Z. Effects of 3D printed models on anatomy learning outcomes. BMC Med Educ. 2022;22:615.
9. Wilk R, Likus W, Hudecki A. Modern anatomical education technologies. Folia Morphol. 2023;82(1):1–10.
10. Garas M, Vaccarezza M, Newland G. Additive manufacturing in anatomy teaching. Med Teach. 2022;44(7):755–764.
11. Ye Z, Dun A, Jiang H, Nie C. Effectiveness of 3D printing in anatomy education:

Systematic review. Anat Sci Educ. 2022;15(4):678–690.

12. Li Y, Wang H, Jin X. Educational outcomes of 3D anatomical models. BMC Med Educ. 2023;23:415.
13. Mogali SR, Yeong WY, Tan HK. Physical models and spatial anatomy learning. Clin Anat. 2022;35(5):623–632.
14. Maresky HS, Oikonomou A, Ali I. Three-dimensional technology in medical education. Med Educ Online. 2022;27(1):205–214.
15. Pujol S, Baldwin M, Nassiri J. Interactive anatomy learning through 3D technologies. Acad Radiol. 2023;30(4):567–576.
16. Choi-Lundberg DL, Cuellar WA, Williams AM. Student engagement using 3D printed anatomy models. Anat Sci Educ. 2023;16(5):892–903.
17. Backhouse S, Fitzpatrick M. Innovative approaches to anatomy instruction. Clin Teach. 2022;19(3):215–222.
18. Vaccarezza M, Papa V. Advances in anatomy education. J Anat. 2024;244(2):185–196.
19. Noorafshan A, Hoseini L. Educational innovations in medical anatomy. Anat Cell Biol. 2023;56(1):1–10.
20. McMenamin PG, Quayle MR. Future directions of anatomy education and 3D printing. Anat Sci Educ. 2024;17(1):3–14.