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USE OF ARTIFICIAL INTELLIGENCE IN ANATOMY

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ABSTRACT

Artificial intelligence (AI) and related digital technologies (virtual reality, augmented reality, virtual dissection tables, adaptive learning systems) are increasingly applied to undergraduate anatomy education to address limitations of conventional teaching (cadaver availability, time constraints, variable teaching quality) and to enhance spatial understanding and clinical integration. This narrative review synthesizes contemporary literature on AI-based anatomy education, searching PubMed/PMC, Google Scholar and institutional guidance (years 2000–2025). Inclusion criteria were studies, reviews and reports addressing AI/VR/AR/VDT/3D-models for undergraduate anatomy learning; non-English and animal-only reports were excluded. Key outcomes examined were spatial comprehension, retention, examination performance, student engagement and reported harms or limitations. Across systematic reviews, randomized and observational studies, and institutional reports, AI-assisted tools consistently improved learner engagement and 3-D spatial understanding and provided valuable radiology–anatomy integration; however, evidence for superiority in long-term knowledge retention and high-stakes exam performance is mixed, and heterogeneity in study designs and outcome measures is substantial. Barriers include cost, infrastructure, faculty training and risk of reduced cadaver exposure. We conclude that AI is a powerful adjunct to—but not a replacement for—cadaveric dissection; structured, evidence-based integration with clear learning objectives is recommended.

Keywords: Artificial Intelligence, Anatomy Education, Virtual Reality, Virtual Dissection, Augmented Reality.

I. INTRODUCTION

Anatomy is a core subject of undergraduate medical education, providing essential knowledge of human structure necessary for clinical reasoning, procedural skills, radiology interpretation and safe practice in surgery and internal medicine [1]. Traditionally, anatomy teaching relies on cadaveric dissection, prosections, didactic lectures and atlases; cadaver dissection has been widely regarded as the gold standard for experiential, tactile learning and appreciation of anatomical variation [1,9]. However, changing curricular structures (shortened contact hours), increasing student numbers, and reduced access to suitable donor bodies impose practical constraints on traditional approaches [2,16]. These resource pressures are global but are especially marked in low- and middle-income countries where facilities, donor programs and maintenance costs are limiting factors [2,16].

Concurrently, digital technologies and artificial intelligence (AI) have advanced rapidly and begun to transform health professional education [3,13]. AI in anatomy education includes machine-learning algorithms for adaptive learning, natural language interfaces, image recognition for automated labeling, and immersive visualisation tools such as virtual reality (VR), augmented reality (AR) and virtual dissection tables (VDTs) that allow interactive, layer-by-layer exploration of 3-D anatomy [4–8]. The World Health Organization has recognised the potential of digital education to extend and standardize training globally, while noting that effectiveness depends on implementation quality [5,12].

Several systematic reviews and randomized trials have evaluated VR/AR/VDT and 3-D models, showing improved engagement and short-term spatial understanding but mixed evidence on objective exam gains and long-term retention [4,6,7,11]. Meanwhile, concerns remain that excessive reliance on digital tools may reduce cadaver exposure and the development of tactile and professional competencies [9,16]. Given heterogeneity of evidence, an up-to-date synthesis focused specifically on AI and allied technologies within undergraduate anatomy teaching is necessary to guide curriculum planning for MBBS programmes.

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Study objective(s): To synthesize current evidence on the use of AI and related digital technologies (VR, AR, virtual dissection, adaptive learning, image-labeling AI) in undergraduate anatomy education, identify demonstrated benefits and limitations, and produce practical recommendations for MBBS curriculum integration.

II. METHODOLOGY

Study design

Narrative review of published literature with systematic search elements (search strategy and inclusion/exclusion criteria clearly stated). This approach was chosen to synthesise heterogeneous evidence across multiple technologies and study designs.

Data sources and search strategy

A structured search of PubMed/PMC, Google Scholar and Web of Science was undertaken for articles published between January 2000 and January 2025. Search terms included combinations of: "artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" AND "anatomy education" OR "anatomical education" OR "virtual dissection" OR "virtual reality" OR "augmented reality" OR "3D anatomy". Additional searches included terms for specific technologies (e.g., "virtual dissection table", "anatomy 3D models", "adaptive learning anatomy"). WHO guidance and major textbooks were also checked for context on digital education.

Inclusion criteria

- Studies, reviews or reports focused on undergraduate medical (MBBS) anatomy education where AI, VR, AR, virtual dissection tables, 3-D models, or adaptive learning tools were evaluated.
- Outcomes addressing spatial understanding, knowledge retention, examination performance, student engagement, usability, or barriers.
- English language articles.
- Primary studies (randomized, quasi-experimental, observational) and systematic or narrative reviews.

Exclusion criteria

- Studies limited to non-medical disciplines (e.g., veterinary anatomy only).
- Non-English publications.
- Commentary articles without empirical data (except where used for context).
- Studies focused purely on technical development without educational evaluation.

Study selection and data extraction

Titles and abstracts were screened for relevance; full texts were reviewed for eligible items. Data extracted included study design, population (institutional setting, student year), technology evaluated, outcomes measured, and key findings. Where systematic reviews/meta-analyses existed, their conclusions were recorded and primary trials referenced.

Quality assessment

Given heterogeneity, a formal meta-analysis was not performed. Study quality considerations (randomization, sample size, validated outcome measures, follow-up duration) were summarized narratively. Systematic reviews and randomized trials were prioritized for "best evidence".

Data synthesis

Findings were synthesized narratively and organized under themes: (a) types of AI/digital tools used in anatomy, (b) learning outcomes (spatial understanding, retention, exam performance), (c) learner perception and engagement, (d) harms and limitations (e.g., cybersickness, infrastructure cost), and (e) implementation considerations.

Statistical analysis

No primary quantitative analysis was conducted; summary statistics (where reported in primary studies/reviews) are presented in tables along with citation numbers.

Ethical considerations

This review used published data only and did not require primary participant recruitment or institutional review board approval. Proper citation and attribution to original sources were maintained.

III. RESULTS

The literature search identified systematic reviews, randomized and observational studies, institutional reports and guidance documents addressing AI and related technologies in anatomy education. Key findings are summarized below and in text-based tables. References cited correspond to the numbered reference list at the end.

Table 1. Types of AI / Digital Technologies used in Anatomy Education (with representative references)

Technology	Description	Representative evidence (ref. no.)
Virtual Dissection Tables (VDT)	Large touchscreens with CT/MRI data & manipulable 3-D models enabling layer-by-layer virtual dissection.	[7], [4], [15]
Virtual Reality (VR)	Immersive head-mounted displays for 3-D exploration of anatomy.	[4], [6], [14]
Augmented Reality (AR)	Overlay of 3-D structures onto real-world field; mobile/hololens apps.	[6], [4]
3-D interactive models / desktop software	Non-immersive 3-D models for rotation, annotation.	[5], [11]
Adaptive learning / AI tutoring systems	Machine-learning driven platforms that tailor content and feedback to learner performance.	[13], [3]
Image recognition / labeling AI	Automated segmentation/labeling of radiological images to aid anatomy–radiology correlation.	[10], [13]

Table 2. Summary of Systematic Reviews and Key Primary Studies (selected)

Study (year)	Design	Main finding(s)	Citation
Moro et al., 2017	Systematic review/meta-analysis of VR/AR	VR/AR improved learner engagement and was at least as effective as tablet devices for short-term learning; some adverse effects (cybersickness) noted.	[4]
Bölek et al., 2021	Meta-analysis on AR in anatomy	AR demonstrated variable effects; some studies showed no benefit or even worse performance vs 2-D methods — heterogeneity significant.	[6]
Emadzadeh et al., 2023	Controlled pre-post study of VDT integration (GI anatomy)	Improved student satisfaction and perceived understanding after VDT use; objective test improvements reported in some cohorts.	[7]
Azer & Azer, 2016	Review 3-D models	3-D models enhance visualisation; evidence quality variable and no conclusive superiority for long-term exam outcomes.	[5]
Kalthur et al., 2022	Review — benefits/pitfalls	Stressed that dissection remains fundamental; virtual tools valuable as supplements.	[8]

Table 3. Reported Educational Outcomes Across Studies (themes and representative sources)

Outcome	General trend in literature	Representative refs
Spatial understanding	Consistent short-term gains with immersive 3-D tools	[4], [5], [7]

	(VR/VDT/3-D models).	
Short-term retention	Generally improved or equivalent to conventional methods in many studies.	[4], [7], [5]
Long-term retention	Mixed evidence; few high-quality longitudinal studies exist.	[5], [6]
Exam performance	Heterogeneous results; some studies show improved scores, others no difference.	[4], [6], [7]
Student engagement/satisfaction	Strongly positive across most studies.	[4], [7], [8]
Adverse effects	VR-associated cybersickness in a subset; accessibility and cost concerns reported.	[4], [6], [8]

IV. NARRATIVE SYNTHESIS OF KEY FINDINGS

1. Spatial comprehension and visualisation: Multiple systematic reviews and primary studies show that immersive and interactive 3-D tools (VR, AR, VDT) consistently improve students' spatial understanding of complex anatomical regions compared to 2-D resources [4,5,7]. Improved ability to mentally manipulate structures is particularly evident for cranial base, pelvis and complex joint anatomy [5,11].

2. Engagement and learner satisfaction: High subjective satisfaction and perceived learning gains are reported widely; interactive tools increase learner motivation and time-on-task [4,7,8].

3. Objective knowledge outcomes: Evidence for objective improvements in high-stakes exam scores is mixed. Some controlled studies report short-term gains in test scores following VDT or VR sessions, while meta-analyses report heterogeneity and limited quality of trials, making conclusive statements difficult [4,5,6,7].

4. Long-term retention: Few studies perform follow-up beyond weeks or months; available data show mixed results and call for well-designed longitudinal trials [5,6].

5. Integration with clinical/radiological learning: A key strength of AI-enabled platforms is combining anatomy with CT/MRI/ultrasound overlays and case-based scenarios, improving applied/clinical anatomy skills [10,13].

6. Limitations and harms: Major barriers include financial cost, required IT infrastructure, need for faculty development and potential reduced exposure to cadaveric material; VR may cause cybersickness in up to a minority of learners [4,6,8,9].

7. Quality of evidence: Heterogeneous study designs, small sample sizes, lack of standardized outcome measures and short follow-up durations limit definitive conclusions. High-quality randomized trials with standardized endpoints are needed [5,6].

V. DISCUSSION

Interpretation of results

This review indicates that AI-enabled and digital 3-D technologies are effective adjuncts to undergraduate anatomy education, particularly for enhancing spatial understanding and student engagement. Immersive modalities (VR, VDT) allow multi-planar manipulation and interactive layering of structures, which aligns with cognitive theories of multimedia learning and reduced extraneous cognitive load [11,12]. The ability to overlay radiology on 3-D anatomy supports early clinical integration and may scaffold radiologic reasoning for preclinical students [10,13].

However, objective transfers to long-term retention and standardized exam performance are less clear. Several systematic reviews note significant heterogeneity in interventions and outcome measures — different exposure durations, variable assessment tools, and small samples — limiting meta-analytic synthesis [4,5,6]. Some meta-analyses suggest no clear superiority of AR over well-designed 2-D instruction in certain contexts, underlining that technology per se is not a panacea but an educational tool whose benefit depends on instructional design [6].

Comparison with previous studies

Findings here are concordant with prior syntheses that show consistent short-term benefits for spatial visualization with VR/VDT/3-D models but inconsistent results on preserved learning gains at longer follow-ups [4,5]. Emadzadeh et al. found improved GI anatomy learning outcomes and student satisfaction after VDT integration in a controlled educational setting [7]. Moro et al.'s broad review established improved engagement with VR/AR but also documented adverse effects (cybersickness) and called for caution in equating immersion with superior learning outcomes [4]. Azer's reviews emphasise that while 3-D models aid visualization, the evidence base lacks uniform high-quality trials [5].

Pathophysiological and cognitive underpinnings

Anatomy learning demands complex visuospatial processing. Cognitive load theory posits that reducing extraneous load (e.g., confusing 2-D-to-3-D translation) improves germane load devoted to schema construction [11]. Interactive 3-D representations and adaptive AI modules can reduce extraneous processing and promote active learning, enabling the formation of durable mental models of anatomical relationships [11,12].

Clinical significance for MBBS students

Enhanced spatial understanding translates to safer procedural skills (e.g., central venous access, regional blocks), better radiologic interpretation, and improved operative orientation for clinical rotations. Early incorporation of anatomy–radiology integrated modules can accelerate application of anatomy knowledge in clinical contexts, a core competency in outcome-based medical education [10,13,17].

Strengths and limitations of the evidence base

Strengths of the literature include multiple randomized and controlled studies and increasing institutional implementation reports demonstrating feasibility. Limitations include heterogeneity of technology, limited long-term follow-up, variable outcome measures, small sample sizes, and publication bias favoring positive studies. Resource disparities limit generalizability; low-resource settings may lack infrastructure to adopt AI widely [5,8].

Practical considerations and risks

- **Costs and infrastructure:** VDTs, VR headsets and high-performance computers require substantial capital and maintenance costs; cost-effectiveness analyses are sparse [7,8].
- **Faculty development:** Effective integration requires teacher training in pedagogical use of technology, not merely technology operation [5,13].
- **Ethical issues:** Use of AI also raises data privacy and algorithmic bias issues if platforms collect learner data for AI-driven personalization [13].

- **Preservation of cadaveric skills:** While virtual tools supplement visual learning, cadaveric dissection provides tactile, three-dimensional texture and inter-individual anatomical variability essential for surgical training; curricula should balance both [9,16].

VI. RECOMMENDATIONS

Practical, evidence-informed recommendations for MBBS curriculum planners and faculty:

- Integrate AI and digital tools as **complements** to, not replacements for, cadaveric dissection. Maintain cadaver contact for tactile skills, professional formation and appreciation of anatomical variability [9,16].
- Define **clear learning objectives** when deploying technology (e.g., improve 3-D spatial reasoning of skull base; enhance CT–anatomy correlation for chest imaging). Align assessments with these objectives.
- Use **blended learning models**: pre-dissection VDT/VR orientation, cadaveric dissection sessions for tactile practice, and post-dissection adaptive quizzes for reinforcement. Evidence suggests blended approaches optimize acquisition and retention [4,5].
- Implement **faculty development programs** focused on educational design and facilitation with AI tools (training in pedagogical use, not only technical operation) [5,13].
- Prioritize **accessible technologies**: where high-end hardware is unaffordable, deploy lower-cost mobile AR/desktop 3-D models and web-based adaptive platforms to broaden access [5,8].
- Incorporate **radiology–anatomy integration**: use CT/MRI overlays and case-based scenarios to strengthen clinical relevance early in training [10].
- Monitor and evaluate outcomes using **standardized metrics** (validated spatial ability tests, objective structured practical examinations, longitudinal retention measures) to contribute robust evidence. Standardization will enable cross-institution comparisons and meta-analyses.
- Address **student well-being** and safety: screen for cybersickness risk, provide alternatives for affected learners (non-immersive 3-D models) [4].
- Study **cost-effectiveness** and resource implications in diverse settings to guide equitable implementation; seek institutional partnerships or consortium purchasing for resource sharing.
- Research priorities: high-quality randomized controlled trials with adequate sample sizes, standardized outcome measures, and long-term follow-up; studies on adaptive AI tutor efficacy and ethical implications of learner data use.

VII. CONCLUSION

Artificial intelligence and allied digital technologies (VR, AR, virtual dissection, adaptive learning and automated image-labeling) are valuable adjuncts to undergraduate anatomy education. The current evidence indicates consistent short-term improvements in spatial understanding and strong gains in student engagement and perceived learning. Integration of AI enhances clinical relevance by enabling radiology–anatomy overlays and case-based simulations, which are especially beneficial for early MBBS students preparing for clinical rotations. However, heterogeneity of studies and limited long-term outcome data mean that AI cannot yet be considered a wholesale substitute for cadaveric dissection, which remains essential for tactile learning and appreciation of anatomical variation. For MBBS curricula, the recommended approach is structured, blended integration: use AI tools to prepare and consolidate anatomy learning while preserving dissection-based experiences. Faculty training, infrastructure planning, and rigorous outcome evaluation should accompany implementation. Future high-quality, longitudinal research and cost-effectiveness analyses are necessary to establish best practices and to ensure equitable access across diverse educational settings.

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