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RESEARCH

Effectiveness of virtual reality on medical students' academic achievement in anatomy: systematic review

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Abstract

Introduction Virtual reality (VR) technology presents a promising alternative to medical education by creating an immersive and interactive learning environment. This research aimed to examine the effectiveness of virtual reality on medical students' academic achievement in anatomy.

Methods This systematic review included 24 full-text articles in both Persian and English from 10 databases. The search focused on experimental, quasi-experimental, and descriptive studies published between May 28, 2000, and May 24, 2022. At least two researchers reviewed all studies. In cases of disagreement between the two, a third researcher reviewed the article and made the final decision. Results were analyzed according to the four-level Kirkpatrick model. Also, the modified Buckley checklist was used to assess the quality of the study.

Results Twenty-four articles were included. Following Kirkpatrick's levels of evaluation, Nineteen studies explored the first level of training effectiveness (reaction). Twenty-four studies examined the second level (learning). One study investigated the efficacy of education (behavior). No studies have investigated the fourth level (impact).

Discussion This study argues that Virtual reality improves students' academic progress and learning in medical anatomy when used as a supplementary way to other methods. However, experimental studies are recommended to investigate the impact of various factors on the efficacy of this method.

Keywords Anatomy, Virtual reality, Medical student

Background

One of the courses in medicine is anatomy, which is considered one of the fundamental courses in terms of the large volume of terminology and the need to know the position of the organs and their proximity to the body [1–3]. Medical students must learn anatomy using sources such as cadaver dissection, visualization, textbooks, atlases, and tomographic scans. However, these resources have problems including restricted resource accessibility, challenges in large classroom settings, difficulties in comprehending anatomical structures from two-dimensional images [4], suboptimal quality of tomographic images [5], the time-consuming nature of cadaveric dissection,

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limited cadaver availability [6], and issues associated with formaldehyde odor [7]. As a result, the demand for modern technologies to improve this field of medical education has increased. Virtual reality (VR) is one of the most promising technologies [2, 8].

Virtual reality is a form of technology that enables multi-faceted, advanced, and dynamic interaction between humans and computers, in which the user has a conscious influence on the form or content of the simulated environment [9]. The use of this technology in medical sciences began in the 90s to visualize complex medical data, especially in surgery. This term has been introduced into medical education by Jaron Lanier since 1986 [10].

Although virtual reality has been used for several decades and has demonstrated that it is more attractive and enjoyable to learn anatomy than traditional methods, the evidence regarding virtual reality's educational effectiveness has shown conflicting results [3]. For example, contrary to the results of the study by Alfalah SF et al. [2] in the Faculty of Medicine of the University of Jordan, which showed the effectiveness of using virtual reality in teaching heart anatomy compared to the traditional teaching method, in the study of Shi Chen et al. [3], comparing three methods of teaching anatomy using corpses, atlas, and virtual reality, no significant difference was observed among the results of the three methods.

Moro C et al. [11] in America compared the effectiveness of three methods of learning structural anatomy using augmented reality, virtual reality, and tablet-based programs. The results of this study did not show a significant difference between the methods. Virtual reality, however, may cause side effects, such as headaches, blurred vision, and dizziness.

Additionally, Rosmansyah et al. (2012) have only examined virtual reality in anatomy education through PubMed studies. A comprehensive evidence search is lacking [12]. Zhao et al. browsed five databases from 1990 to 2019 and published a meta-analysis article of randomized controlled studies. They examined VR's general efficiency in teaching medical anatomy [13]. Accordingly, considering the growing demand for the use of virtual reality and the possibility of three-dimensional visualization of anatomy and physiology structures and its applications in this course [12], this study is looking for more extensive evidence about examining the effectiveness of virtual reality on the academic progress of medical students in anatomy. Effectiveness is defined in the present study as the extent to which virtual reality impacts the learner at least at one level of Kirkpatrick's model [14]. Kirkpatrick's model is a framework to evaluate educational courses, containing four levels: Reaction (evaluates participant satisfaction and engagement), Learning (measures the increase of knowledge or skills resulting from the training), Behavior (evaluates the application of learned concepts in the workplace), and Imacts (analyzes the training's overall effect on organizational objectives and performance) [15].

This study, using a review of the four levels of Kirkpatrick's model, can significantly contribute to assessing the relevance of virtual reality in medical anatomy education. This research, by providing comprehensive diverse evidence, may improve the comprehension of the positive or negative effects of virtual reality on the learning process, hence promoting the development of creative pedagogical approaches in this field.

Main text

Methods

This study is a systematic review. Based on the PRISMA framework all Persian and English articles in Eric, PubMed, Web of Science, Embase, Science Direct, Scopus, Springer, SIDS, Irandoc(https://irandoc.ac.ir), and Magiran(https://www.magiran.com) databases containin g the words effectiveness (program evaluation) - virtual reality - medical student - anatomy in their titles, keywords, subject, and MeSH were searched.

Eligibility criteria

Inclusion criteria

This review inclusion criterion was all experimental, quasi-experimental, descriptive full-text articles in both Persian and English and articles between 2000 and 2022 (Given that Zhao et al. had conducted the first reported study in 2004, our systematic review began its exploration in 2000).

Exclusion criteria

The exclusion criteria were as follows: Studies with insufficient details regarding the inclusion criteria; Review studies and letters to the editor; Studies that examined the effectiveness of virtual reality in other subjects; Studies that did not assess effectiveness or satisfaction; Studies conducted in other medical fields; Studies conducted on postgraduate medical students; Studies that focused on other supplementary learning tools.

Search strategy

Based on the mentioned keywords, with the presence of a library expert and the research team, the search strategy was written as follows(Fig. 1). The mentioned search strategy was searched in the Abstract/Title section of the Limit section of the Pubmed database. The initial search was on May 28, 2019, and the last search was on May 24, 2022. The strategy restrictions were modified if the article was not found in any databases using the mentioned search strategy.

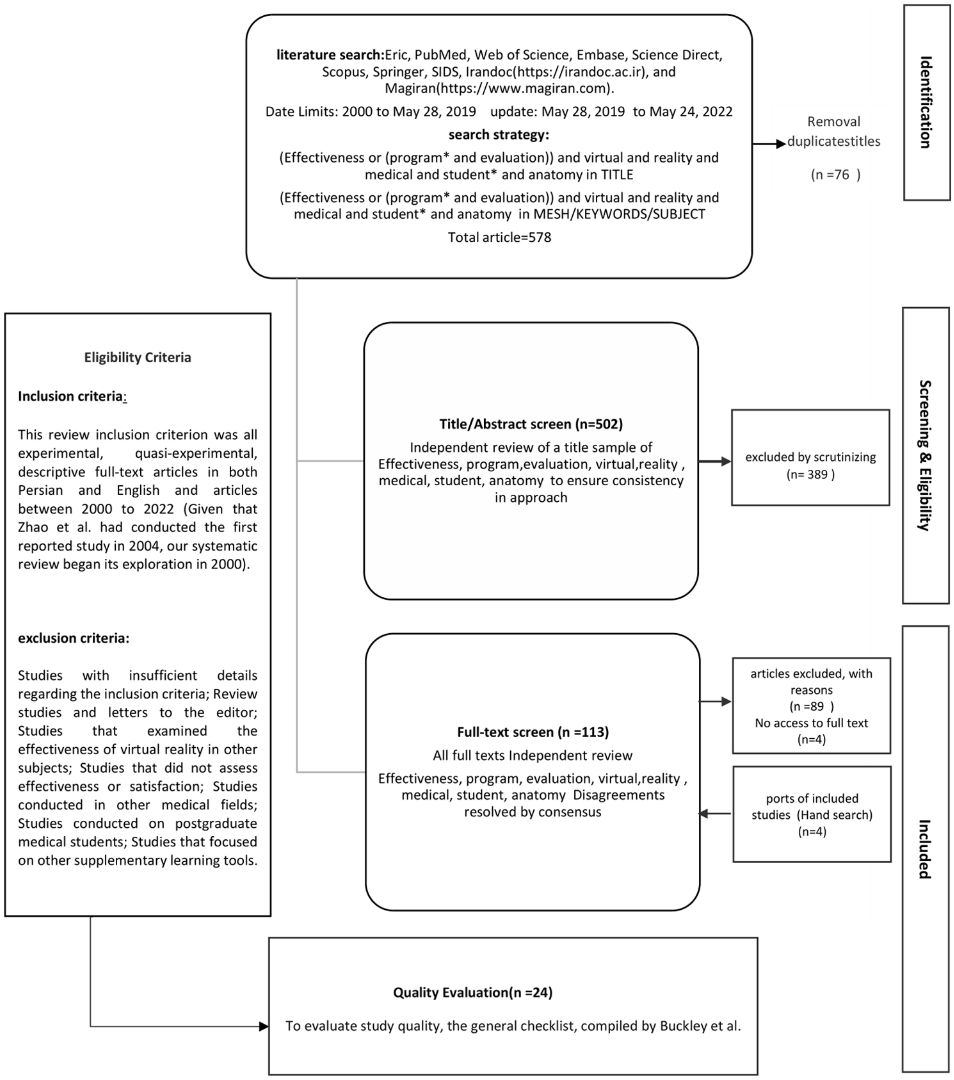

Fig. 1 PRISMA database search strategy. Screening process, quality evaluation, eligibility criteria (inclusion and exclusion criteria)

To obtain Persian articles, keywords including effectiveness, program, evaluation, virtual reality, medical students, anatomy, and the title "The effectiveness of virtual reality on the academic progress of medical students in the anatomy course" were searched in the data center of SID, Irandoc, Iranmedex, and Magiran. In the following, 578 articles were entered into Endnote resource management software. Duplicate cases were removed from the study, and 502 were examined.

In the screening phase, studies that examined the effectiveness of virtual reality in subjects other than anatomy, studies that did not investigate effectiveness or were conducted in other medical fields or on graduate medical courses, and also studies on other supplementary learning tools other than virtual reality were excluded from the study. In the first stage, titles and abstracts were reviewed. At this stage, 389 studies were excluded. A total of 113 experimental, semi-experimental, and descriptive English articles that investigated the effectiveness of virtual reality on medical students' anatomy learning were included in the study.

In the full-text screening stage, the remaining 113 articles were reviewed, and the articles that met the inclusion criteria and were related to the topic and purpose of the study were extracted. At this stage, 89 articles were excluded from the study due to non-compliance with the inclusion criteria and four due to lack of access to the full text. A total of 20 studies moved on to the next step(Fig. 1).

In the next step, references to the remaining 20 studies were checked. If encountered a study that was not found in the searches, these were also included in the study. A total of four studies were included at this stage of the study. The study included 24 studies in total. There were at least two researchers involved in the review of the remaining studies (M, S.M & A, M; M, S.M & H,

M) and controlled with (AO). In cases of disagreement between two researchers, a third person (AO) reviewed and finalized the decision. During this stage, two studies were disputed by two researchers, and the final decision was reached by a third person(AO) [2, 16]. Then, the researchers checked the references to the articles. When they came across a reference containing the desired keywords but not found in the search, they also considered it. At this stage, no articles were added to the study.

Data extraction method

To extract data from the studies, an initial form was designed. In a pilot study, three researchers extracted data from two studies before using the form to review all the studies. The initial form was filled out with data. Based on that, the necessary corrections were made. A fourth researcher then approved the revised form. The data extraction form includes the following information: study title, course name, review time, reference, author, study year, study place (country, university), research question/objective, sampling method, number of groups, random allocation (yes or no), participation type, study method, target population and samples, study duration, sample size, tools, statistical software, statistical tests, results, and conclusions. P-values were employed to determine the statistical significance of the findings in the reviewed studies. If the p-value was significant, the intervention was considered effective. Three researchers independently extracted data. All data were checked and confirmed by a fourth researcher to ensure accuracy.

Study quality evaluation

To evaluate study quality, the general checklist, compiled by Buckley et al. [17], was used. The checklist was included 11 items evaluated as "suitable" and "unsuitable".Three researchers assessed the study quality. If there was a disagreement, the fourth researcher reviewed the study. After negotiation with the other three researchers, they reached an agreement. All articles achieved a score greater than 7 (the minimum score was 7, and the maximum score was 9)(Fig. 1).

Results

This study included 24 articles in total. The studies were all written in English. Most studies were conducted in the United States (10 studies) [11, 18–26]. Most publications were related to 2020 (6 studies) [3, 22, 27–30]. Most studies were conducted on first-year medical students [16, 19, 20, 25, 26, 31–33]. In 6 studies, paper tests were employed to evaluate effectiveness [11, 31, 33–36]. Three studies employed unclear tools [20, 27, 32], seven used electronic tests [16, 18, 21, 22, 28–30], six studies used both paper and electronic tests [2, 3, 19, 24–26]. and one used an application [37]. In seven studies, the tool's validity was reported [23, 24, 26, 29, 30, 32, 37]. Tool reliability was reported in four studies [2, 3, 26, 28, 29, 36] (Table 1).

All of the studies were conducted in the anatomy course, with most focusing on general anatomy [11, 19–21, 28, 29, 32, 33, 37, 38]. There were nine semi-experimental studies [2, 11, 19, 20, 27, 31–34], five randomized controlled trials [18, 23, 24, 28, 30], two combined studies [3, 29], two experimental studies [25, 26], one developmental study [37], Three quasi-randomized control [16, 21, 36] and two prospective [22, 35].The highest number of participants was 200 [19], and the lowest was six [31]. 3D was used in nineteen studies [2, 3, 11, 16, 18–24, 26, 27, 29, 30, 32, 33, 35, 37]. Most of the comparisons were made with 2D (7 studies) [16, 19, 24, 26, 32, 37]. The maximum intervention time was 19 months (one study) [11], and the minimum was one hour (one study) [17] (Table 2).

Most studies used purposeful and random sampling (9 studies) [16, 19, 21, 23, 24, 31–34, 39, 40]. Participants were voluntary in eight studies [16, 19, 22–25, 28, 31, 32, 38, 40], and the participation method was unclear in five [2, 19, 27, 29, 35].

Based on Kirkpatrick's evaluation model, nineteen studies explored the first level of training effectiveness (reaction). At this level, seventeen studies reported a significant increase in effectiveness [2, 3, 16, 18–21, 24–32, 34, 35, 37], and one noted no effect [33]. In one study, vision problems were reported [11] .In other studies, this level was not examined. Twenty-four studies examined the second level (learning) The results of 20 studies showed increased learning [2, 3, 11, 16, 18–21, 23, 26–32, 34–37], and four reported no effect [22, 24, 25, 33]. Other studies did not report this level. One study investigated the effectiveness of education at the third level (behavior), and the results indicated a positive effect on behavior [34]. The fourth level (impact) has not been investigated in any studies (Table 3).

Discussion

This review study investigated the effectiveness of virtual reality on medical students' academic progress in the anatomy course based on Kirkpatrick's four-level effectiveness evaluation model. The findings obtained from the databases investigated in this research showed that out of the 24 final studies that met the inclusion criteria and were evaluated.

The predominance of studies conducted in the United States and the concentration of publications from 2020 suggest a burgeoning interest in innovative training methodologies during a pivotal time in medical education. Notably, first-year medical students were the primary subjects of these studies, indicating an emphasis on enhancing foundational anatomical knowledge early in

Table 1 Summary of included studies and quality evaluation

Name of the author/ date of study	Purpose of the study	Target group/ country	Data collection tool	tools validity/ reliability	General result	Quality evaluation
H. S. Maresky(2018) [31]	studying the effect of VR as an adjunct to enhance the traditional cardiac dissection experience	first-year undergraduate medical students / Canada	Paper: 10 MCQ*, subjective questionnaire	not mentioned	VR is a fun and effective tool for teaching normal cardiac anatomy, yielding a performance increase of 24.6% ($P < 0.0001$) in the experimental group over the control group.	9
Katelyn Stepan(2017) [18]	evaluate the effectiveness, satisfaction, and motivation associated with immersive VR simulation in teaching medical students neuroanatomy	first and second-year medical students/ USA	electronically: Subjective survey، Instructional Materials Motivation Survey (IMMS), quiz	not mentioned	There was no significant difference in anatomy knowledge between the 2 groups on preintervention, postintervention, or retention quizzes. The technology was equally as effective as the traditional textbooks in teaching neuroanatomy.	9
Dongmei Cui(2017) [19]	investigation of whether 3D stereoscopic models created from computed tomographic angiography (CTA) data were efficacious teaching tools for the head and neck vascular anatomy	first-year medical students/ USA	paper and electronic:15 questions, mental rotation test (MRT), 3D demo survey	not mentioned	3D viewing during a short lecture improves students' post-test knowledge scores more than an identical lesson using identical but 2D images.	9
Ralf A. Kockro(2015) [32]	Efficacy in terms of anatomical knowledge retained and a subjective evaluation by the students were recorded	Second-year medical students/ Germany	10 MCQ, Questionnaire	expert committee- not mentioned	This study demonstrates that the use of stereoscopic, computer generated, anatomical models delivered using a 3D projection system can enhance undergraduate neuroanatomy lectures	9
Zaid Khot(2013) [33]	whether computer-based virtual reality anatomy learning represents a real learning benefit when compared to a static atlas-type compendium of images	undergraduate students/ Canada	Paper: Mental Rotations Test (MRT), 25 questions:15 nominal questions, and 10 functional + Q8questions.	not mentioned	computer-based modalities are not as effective as physical models for self-study of pelvic anatomy	8
Nicholson DT(2006) [21]	to assess whether learning structural anatomy utilizing VR or AR is as effective as tablet-based (TB) applications	participants studying Anatomy/ Australia	electronic: 1.quiz:15-item, 2.15 questions:12MCQ, 3free-text data	not mentioned	Although cadavers are most commonly used for teaching anatomy to medical and biomedical science students, there are substantial financial, ethical and supervisory constraints on their use	9

Table 1 (continued)

Name of the author/ date of study	Purpose of the study	Target group/ country	Data collection tool	tools validity/ reliability	General result	Quality evaluation
Jose weber vieira de Faria(2016) [34]	construct, implement, and evaluate an interactive and stereoscopic resource for teaching neuroanatomy	graduate medical students/ Brazil	Paper: 1. Writing a list, 2.10 stations	not mentioned	VR and AR as effective teaching tools, where student learning is as successful as with tablet-based applications although educators should be cautious regarding the introduction of adverse effects However, both VR and AR provide additional intrinsic benefits	9
Salsabeel F. M. Alfalah(2019) [2]	This paper reports the outcome of a comparative study between traditional medical teaching modalities and virtual reality	third-year medical students /Jordan	Paper and electronic: questionnaire: 23 statements (ranging from strongly disagree = 1, disagree = 2, moderate = 3, agree = 4, and strongly agree = 5)	not mentioned-Physical Heart Model and VR heart anatomy system Questionnaires were assessed for reliability using Cronbach's alpha. The Physical Heart Model was 0.689. The VR heart anatomy system was 0.791.	The outcome of this paper demonstrates the huge potential of using novel technology in medical education. Virtual reality technology facilitates the delivery of information in a user-friendly environment, improving understanding and visualization of the complex anatomical structures and interrelations, thereby transforming the educational process into a more efficient and dynamic one.	9
Yuma Wada(2020) [27]	The aim of this study was to investigate the usefulness of the 3D imaging technique in laparoscopic TAPP as an educational tool for medical students	medical students /Japan	Questionnaire:30 MCQ	not mentioned	Pre-operative 3D simulation increases the understanding of detailed anatomy and virtual three-dimensional image analysis in laparoscopic TAPP is useful as an educational tool for medical students.	9
Petersson(2009) [20]	Investigate the value of web-based virtual reality learning on students' self-learning	1st and 5th-year medical students	questionnaire	not mentioned	visualization of the complex anatomical structures and i + X15nterrelations, thereby transforming the educational process into	8
Moro(2017) [11]	Does the use of augmented reality, gadgets, and tablets affect learning?	medical student/ USA	paper:20 questions: 10 questions "factual",10 questions "spatial questions". questions regarding their perceived engagement with the learning module	not mentioned	Both VR and AR are as valuable for teaching anatomy as tablet devices, but also promote intrinsic benefits such as increased learner immersion and engagement	9

Table 1 (continued)

Name of the author/ date of study	Purpose of the study	Target group/ country	Data collection tool	tools validity/ reliability	General result	Quality evaluation
Daren T Nicholson(2006) [16]	Does learning increase with the use of computer technology?	First-year medical students/ USA	electronic: 1.quiz:15-item, 2.15 questions:12MCQ, 3free-text data	not mentioned	The intervention group's mean score on the quiz was 83%, while that of the control group was 65%. This difference in means was highly significant ($P < 0.001$).	9
Katerina Bogomolova(2021) [37]	describe the development of a virtual 3D anatomy assessment and the perspectives from teachers and students on the use of this assessment tool in a medical curriculum.	medical undergraduates, postgraduate trainees, anatomy teachers/ London	application: 13 questions, scenario	five experts in the field of anatomy-	virtual 3D assessment can address several challenging aspects of the growing misalignment between learning, assessment, and clinical practice. The development of a virtual 3D assessment scenario was successfully demonstrated using the theoretical framework of design-based research.	9
Imai, T.(2022) [35]	To analyze the effectiveness of incorporating virtual reality (VR) in lectures on esophageal and mediastinal anatomy and surgical procedures for medical students	4-5Th grade medical students/ Japan	paper: written examination, post-lecture knowledge test, Questionnaire	not mentioned	Our findings suggest that VR enhances the learning process. The lecture incorporating the VR experience was more effective than the traditional lecture for promoting an understanding of CT images and interpretation of surgical images; thus, it enhances the learning experience for medical students studying surgery.	8
James D. Pickering(2021) [36]	Is there a difference between learning gain when compared to an anatomy drawing screencast that is focused on long spinal cord sensory and motor pathways?	2 years medical students/ UK	paper:10 MCQ. Short answer(Senario)	Not mentioned-Pre-test: α = 0.67 post- test: α = 0.73	This study adds important empirical data to the emerging field of immersive technologies and the specific impact on short-term knowledge gain for neuroanatomy teaching, specifically that of long sensory and motor pathways.	7
M. Stojanovska(2020) [22]	the effectiveness of an MR device to teach musculoskeletal anatomy to medical students compared with traditional cadaveric dissection	second-year medical students/ USA	Electronic:60-min MR (36 questions) and cadaver-based practical(78questions) exams	not mentioned	the results clearly indicate that medical students, regardless of the study modality, performed similarly on the MR and the cadaver practical exams	8

Table 1 (continued)

Name of the author/ date of study	Purpose of the study	Target group/ country	Data collection tool	tools validity/ reliability	General result	Quality evaluation
Yi-Chun Du(2020) [28]	explored the effect of a multiple-player virtual reality (VR) gaming system on anatomy learning	medical students/ Taiwan	Electronic: Game1, 2, MCQ, intrinsic Motivation Inventory	Not mentioned-α = 0.05	The results indicated that the proposed VR learning system had a positive impact on anatomy learning.	8
Shi Chen(2020) [3]	compare the results of teaching with VR to results of teaching with traditional teaching methods by administering objective questionnaires and perception surveys	medical students/ China	paper and electronic: 18 MCQ, 25 blank questions, perception survey	Not mentioned-α = 0.05	The participants in all three groups had significantly higher total scores on the post-intervention test than on the pre-intervention test; the post-intervention test score in the VR group was not statistically significantly higher than the post-intervention test score of the other groups (VR: 30 [IQR: 22–33.5], cadaver: 26 [IQR: 20–31.5], atlas: 28[IQR: 20–33]; $p > 0.05$). The participants in the VR and cadaver groups provided more positive feedback on their learning models than the atlas group (VR: 26 [IQR: 19–30], cadaver: 25 [IQR: 19.5–29.5], atlas: 12 [IQR: 9–20]; $p < 0.001$).	8
Alharbi(2020) [29]	determine the effectiveness of 3D-VR in knowledge retention in human anatomy courses as compared to traditional teaching methods among medical students.	third-year medical students/ Saudi Arabia	Electronic: objective structured practical examination (OSPE), focus group discussions	two expert anatomist-α = 0.80	Medical students described 3D-VR as a learning tool with a great deal to offer for learning human anatomy as compared to traditional methods. Therefore, we recommend adding the use of 3D-VR in the anatomy curriculum.	8
Bridget Copson(2021) [30]	the effectiveness of a virtual reality (VR), three-dimensional (3D) clinically orientated temporal bone anatomy module, including an assessment of different display technologies	first and second-year medical student/ Australia	Electronic questionnaire: demographic questions and 13 self-assessed questions	pilot study-Not mentioned	The developed VR temporal bone anatomy tutor was an effective self-directed education tool. 3D technology remains valuable in facilitating spatial learning and superior user satisfaction	8

Table 1 (continued)

Name of the author/ date of study	Purpose of the study	Target group/ country	Data collection tool	tools validity/ reliability	General result	Quality evaluation
Brittany Star Hampton(2010) [23]	Evaluate the effectiveness of an interactive computer trainer in enhancing medical students' knowledge and attitudes about female pelvic anatomy and pelvic floor dysfunction and participants' satisfaction.	third- and fourth-year students/ USA	questionnaire	Experts-Not mentioned	an interactive computer trainer to teach female PA(pelvic anatomy) and PFD(pelvic floor anatomy) improvers medical student knowledge and attitudes	8
Zachary A. Drapkin(2015) [26]	Evaluate the effectiveness of a 3D neuroanatomy teaching tool in improving medical students' ability to identify subcortical structures on MRI scans.	first-year medical student/ USA	paper and Electronic demographic survey,32 identification questions MRI, a survey of satisfaction & self rated confidence	CVR: dentification questions: (0.61 ± 0.028)-dentification questions: α = 0.88	In the post-test satisfaction survey, the 3D group expressed a statistically significantly higher overall satisfaction rating compared to students in the 2D control group. While the interactive 3D multimedia module received higher satisfaction ratings from students, it neither enhanced nor inhibited learning of complex hepatobiliary anatomy compared to an informationally equivalent traditional textbook-style approach	9
Alexander W. Keedy(2011) [24]	Compare the effectiveness of an interactive 3D presentation to a traditional textbook format in teaching medical students about liver and biliary anatomy.	first and fourth-year medical students /USA	paper and Electronic: background questionnaire, 10 MCQ(pre-test), 9 MCQ(post-test)	two radiographic anatomy experts-Not mentioned	the interactive 3D multimedia module received higher satisfaction ratings from students, it neither enhanced nor inhibited learning of complex hepatobiliary anatomy compared to an informationally equivalent traditional textbook style approach.	9
Alla Solyar(2008) [25]	Evaluated the efficacy of the E23 system for instructing junior medical students in sinus anatomy.	first-year medical students /USA	Electronic and Paper: identify the structures, student extent studying survey, students' satisfaction survey	not mentioned	The ES3 can be an effective tool in teaching sinonasal anatomy and EC is a remarkably effective tools to helping medical students learn nasal and paranasal sinus anatomy	9

their training [2, 3, 11, 16, 18–20, 22–24, 26–29, 31, 32, 34, 36, 37]. , The special focus of the studies was on the 3D virtual reality technologies [2, 11, 15, 17–23, 25, 26, 28, 30–32, 34, 40].

The results of all of these studies showed an increase in at least one of four Kirkpatrick's evaluation levels of participants [2, 3, 11, 17, 19–21, 23–25, 27–37]. Despite this, the third (behavior) and fourth (impact) levels have been relatively under-explored in the literature.

Positive feedback from the first level of Kirkpatrick's evaluation model (reaction) across most studies indicates high levels of student satisfaction with these

Table 2 Characteristics of included studies

First author	course	number of participants	Duration	study method	intervention	Comparator
H. S. Maresky(2018) [31]	Cardiac anatomy	42 14 control/ 28 variable	35days	Semi-experimental: 2 groups, pre-post test	VR	independent study
Katelyn Stepan(2017) [18]	neuroanatomy	66 33/33	Eight weeks	RCT: 2groups, pre-post- test	3D digital model	Independent study
Dongmei Cui(2017) [19]	anatomy	39 2D,18/3D,21	Not mentioned	semi- experimental: 2groups, pre-post test	3D stereoscopic models	2D
Ralf A. Kockro(2015) [32]	anatomy	169 2D.80/3D,89	Not mentioned	semi- experimental: 2 groups, post test	3D	2 D
Zaid Khot(2013) [33]	anatomy	60 model group,20/KV ,20/ VR,20	Not mentioned	semi- experimental: 3 groups, pre-post test	3D	model group/KV
Nicholson DT(2006) [21]	anatomy	57 29/28	Not mentioned	semi- experimental: 2 groups, post test	3D	2D
Jose weber vieira de Faria(2016) [34]	neuroanatomy	84 28/28/28	classes were 50–60 min in duration	semi- experimental: 3 groups, post test	VR	1 (conventional method) 2 (interactive non-stereoscopic), and 3 (interactive and stereoscopic)
Salsabeel F. M. Alfalah(2019) [2]	Heart anatomy	60 N.each group Not mentioned	Not mentioned	semi- experimental: 2 groups, post-test	3 D	physical
Yuma Wada(2020) [27]	surgical anatomy	A group of 30 medical students who filled out the questionnaire	15 month	Semi-experimental: one group - post-test	3 D	0
Petersson(2009) [20]	Anatomy	137	one semester	semi-experimental: one group, post-test	3D	0
Moro(2017) [11]	anatomy	59 VR,20/AR, 17/TB,22	19 month	semi- experimental: 3 groups, post test	3D	AR, ablet-based
Daren T Nicholson(2006) [16]	Anatomy(Ear)	57 control, 29/ 29	One semester	quasi-randomized control trial with a pre-post-test	3 D	tutorial
Katerina Bogomolova(2021) [37]	anatomy	four postgraduate trainees and two anatomy teachers	Not mentioned	developmental study: 2 groups, post-test	3D	2D
Imai, T.(2022) [35]	esophageal and mediastinal anatomy and surgery	2 groups each group 30 (60)	2 weeks	prospective observational: 2 groups, post-test	3D	VR(Image)
James D. Pickering(2021) [36]	neuroanatomy	200	Not mentioned	quasi- randomized control trial pre- post-test	VR	0
M. Stojanovska(2020) [22]	the gross anatomyand radiology	64 32/32	during the fall	prospective randomized controlled study: 2 groups, post-test	3D	Lab Anatomical
Yi-Chun Du(2020) [28]	anatomy	18 6/6/6	5 day	RCT:3 groups, post-test	VR I	(1) a textbook reading control group (2) a single-player VR (SP) roup (3) a multiple-player VR (MP) group
Shi Chen(2020) [3]	neurosurgery	73 VR, 25/cadaver, 25/atlas 23	Not mentioned	Mixed Methode: 3 groups, Pre-post test	3D	cadaver-atlas
Alharbi(2020) [29]	anatomy	170 85/85	Not mentioned	Mixed Methode: 2 groups, pre-post test	3D	traditional models

Table 2 (continued)

First author	course	number of participants	Duration	study method	intervention	Comparator
Bridget Copson(2021) [30]	bone anatomy	47 M3D16, / PPT,16 / S3D, 15	Not mentioned	RCT group, per-post test	3D	M3D, monoscopic 3D group; PPT, presented the same content; S3D, stereoscopic 3D group
Brittany Star Hampton(2010) [23]	obstetrics and gynecology	43 Usually teaching, 22/ intervention21	6 month	RCT: 2 groups, Per-post test.	3D	Traditional
Zachary A. Drapkin(2015) [26]	Neuroanatomy	62 29 control / 33 experimental)	2 h	experimental: 2 groups. Per-post test.	3D	2D
Alexander W. Keedy(2011) [24]	Radiology	46 23/23	Not mentioned	RCT:2 group, pre-post-test	3D	2D
Alla Solyar(2008) [25]	Anatomy	15 control7/experimental8	3-hour	experimental control: 2group, post-test	VR	Text-books

interventions. This is significant, as learner satisfaction is often linked to increased engagement and improved knowledge retention.

At the second level (learning), most studies indicated improved learning outcomes, highlighting VR's effectiveness in anatomy education. The third level (behavior) also showed positive effects suggesting the need for more research to clarify the links between educational interventions and real-world clinical performance. Variations in study design, participant demographics, and intervention specifics may contribute to these inconsistencies.

In this regard, the results of the scoping review conducted by Sinha et al. [40] to identify the potential determinants of anatomy learning in a multi-dimensional VR environment showed that various factors such as cognitive load, cybersickness, student perception, binocular vision, spatial perception, and interaction affect the learning of the anatomy course in the virtual reality environment.

In support of the present study results, a meta-analysis by Zhao Ji et al. [13] reviewed randomized controlled studies and showed that virtual reality could improve anatomy knowledge. Also, Rosmansyah et al. [12] found that virtual reality increased medical learners' knowledge and skills. In a systematic review conducted by Uruthiralingam, and Rea in two databases, PubMed and Web of Science, the effectiveness of virtual and augmented reality was investigated. Even though this systematic review was limited to two databases, PubMed and Web of Science, the results showed the effectiveness of both virtual and augmented reality. This article analyzes 45 articles on virtual reality. Findings from 45 support VR use, while 8 found no significant effect, and 3 indicated potential drawbacks [41].

considering the geographical distribution of the studies that presented, the effectiveness of virtual reality on the academic progress of medical students in anatomy and the increasing desire of universities for this technology in anatomy has been well confirmed in the studies reviewed.

Some similar studies also confirm the findings of the present study. As an example, Kockro et al. [32] in Germany investigated the effectiveness of the 3D virtual reality environment compared to more traditional methods. They found that it significantly improved medical students' satisfaction and learning with the application of this technology. The present study, as one of the first review studies in Iran regarding the effectiveness of virtual reality on medical students' anatomy learning, can provide helpful information for future researchers and those involved in medical education.

This study attempted to examine all studies related to the keywords with the broadest possible diversity of databases. Several studies demonstrating VR's ineffectiveness were also included to avoid publication bias. However, limiting the results to English/Persian articles was one of the limitations of this study; thus, future researchers should pay attention to this point.

Conclusion

This review highlights the effectiveness of virtual reality (VR) in enhancing anatomy education for medical students, noting high satisfaction and improved learning outcomes. However, inconsistencies at higher evaluation levels, such as behavior and impacts, suggest a need for further research on VR's effectiveness on clinical performance. The study provides valuable insights for future educational strategies as universities adopt VR technologies.

Table 3 Results of Kirkpatrick's four-level evaluation and tools

First author	Kirkpatrick's Level		
	Effect on Reaction/Tools	**Effect on Learning/Tools**	**Effect on behavior / impact**
H. S. Maresky(2018) [31]	Increased(subjective): A subjective questionnaire about the students' perceived learning and the effectiveness of VR	Increased ($P = 0.004$): 10 multiple choice questions; 5 conventional cardiac anatomy questions and 5 visual-spatial (VS) questions	Not investigated
Katelyn Stepan(2017) [18]	Higher likelihood of recommending the study material in VR group versus other students ($p < 0.01$). *No difference between the 2 groups in their responses to the ease of use of the study materials*: The Instructional Materials Motivation Survey (IMMS): 4 key aspects of motivation in education: attention, relevance, confidencedence, and satisfaction	Increased ($p < 0.01$): Three quizzes were administered: a pre-intervention quiz, a post-intervention quiz, and a retention quiz. The quizzes assessed knowledge of the ventricular system, arterial supply to the brain, and the brainstem using multiple-choice and fill-in-the-blank questions. The post-intervention quiz also included identification questions based on a 3D brain model. The quizzes were developed by an otolaryngologist and a resident.	Not investigated
Dongmei Cui(2017) [19]	Not investigated	Increased (Wilcoxon rank-sum, $P = 0.0033$): The study used two tests(pre and post-test), each with 15 questions about structure, function, and spatial relationships. Fewer than half of the post-test questions were repeated from the pre-test. Repeated questions either used the same question with different images or asked about the same structures in different spatial orientations. Students were not given correct answers to the repeated questions after the pre-test.	Not investigated
Ralf A. Kockro(2015) [32]	3D VR more highly compared to usual teaching versus the 2D presentation across all four evaluation domains (Fisher's exact test; $p < 0.001$ in all cases): Students were asked four questions to provide their personal opinions about their learning experience	Increased ($p < 0.0001$): Ten multiple-choice questions. (MCQs) relating to the topographical anatomy of the third ventricle.	Not investigated
Zaid Khot(2013) [33]	Not investigated	Not increased ($F = 0.96$, $P = 0.39$): After completing the learning phase, subjects were given a 25-item test and a cadaveric pelvic specimen as a guide. The test consisted of 15 nominal questions and 10 functional questions.	Not investigated
Nicholson DT(2006) [21]	Not investigated	Learning has increased($P < 0.001$): The quiz had 15 questions testing participants' understanding of 3D ear structure relationships. 12 were multiple-choice, and 3 required open-ended naming of structures.	Not investigated
Jose weber vieira de Faria(2016) [34]	Increased(Qualitative): Those who participated in the interactive sessions, with or without stereoscopic elements (Groups 2 and 3), were asked to comment on the efficacy and shortcomings of the instructional materials.	Increased($p < 0.05$): Pre-test: The students were asked to compile a list of the limbic system's components. Pedagogical evaluations were performed after each class	increased($p < 0.05$): In the practical assessment, students identified anatomical structures on real specimens at 10 stations / Not investigated
Salsabeel F. M. Alfalah(2019) [2]	Increased: participants' satisfaction (Qualitative): Collecting and analyzing participants' feedback and responses regarding the system. The overall mean values for Questionnaire results rose from 2.91 (physical model) to 4.51 (VR Anatomy System) (P = Not mentioned)	Increased(Qualitative): Participants' performance, and responses, were observed and recorded.	Not investigated
Yuma Wada(2020) [27]	90% of the participants have shown satisfaction of the Preoperative 3D simulation used: A multiple-choice questionnaire (MCQ) was created by the authors	Increased (P = Not mentioned): A multiple-choice questionnaire (MCQ) was created by the authors.	Not investigated
Petersson(2009) [20]	Increase((P = Not mentioned): The students also completed a questionnaire to assess their attitudes towards the EVA program.	Increase ($P = 0.0228$): The assessment evaluated second-semester students' knowledge of peripheral vessel anatomy and fifth-semester students' knowledge of neurovascular anatomy	Not investigated

Table 3 (continued)

First author	Kirkpatrick's Level		
	Effect on Reaction/Tools	**Effect on Learning/Tools**	**Effect on behavior / impact**
moro(2017) [11]	Nearly all participants (95%) reported difficulties visualizing anatomical structures in 3D space: An online survey was conducted to collect data on participants' comprehension of the learning material and their overall experience. A five-point Likert scale was used to measure understanding, while a four-point Likert scale was used to assess experience.	increase ($P˂0.05$): The 20-question multiple-choice assessment tested both factual and spatial anatomical knowledge. Ten questions required identifying specific bones or regions based on textual descriptions, while the other ten involved recognizing anatomical structures in images.	Not investigated
Daren T Nicholson(2006) [16]	Not investigated	Learning has increased($P<0.001$): The quiz tested participants' understanding of 3D ear structures. 12 questions were multiple-choice	Not investigated
Katerina Bogomolova(2021) [37]	Positive experience(Qualitative): Feedback received on personal experiences and practical use during evaluations.	Effectiveness (Qualitative): Three distinct components were designed, implemented, and evaluated simultaneously: a 3D anatomy test, an augmented reality application, and a virtual 3D assessment scenario that integrated practical application into the assessment setting. The anatomy test included questions ranging from basic factual recall to higher-order thinking skills, aligned with Bloom's Taxonomy.	Not investigated
Imai, T.(2022) [35]	More interested in mediastinal anatomy ($p=0.0165$) and surgery ($p=0.0135$) in the VR group: Lecture Assessment Questionnaire	Increase($0.0001<P<0.3111$): A written examination, comprised of four questions, was administered to assess the retention of the knowledge acquired.	Not investigated
James D. Pickering(2021) [36]	Not investigated	indicate between group significance and effect size; a$P>0.05$; b$P<0.05$; Cohen's effect size was calculated as 0.388 for screencast versus mixed reality, MCQ post-test; MCQ, multiple-choice question; SAQ, short-answer question no effect ($p=0.052$): Ten multiple-choice questions (MCQs) assessed lower-level Bloom's taxonomy skills (e.g., recall, comprehension). This was followed by a single short-answer question (SAQ).	Not investigated
M. Stojanovska(2020) [22]	Not investigated	No different between MR score and caviar ($p>0.05$): The practical exams were station-based and consisted of two short-answer questions per station. The exam questions were standardized and included both first- and second-order questions.	Not investigated
Yi-Chun Du(2020) [28]	increase($p<0.001$): Motivation Inventory. The inventory included four subtests: interest, competence, importance, and stress.	Increease($p<0.001$): Game: A two-phase approach was employed, incorporating both knowledge assessment and retention testing. Multiple-choice assessments were utilized to evaluate learning in both phases	Not investigated
Shi Chen(2020) [3]	The VR and cadaver groups: found their assigned learning models more enjoyable: A 5-point Likert scale was used to measure participants' perceptions of the tool's effectiveness, including its perceived enjoyment, learning efficiency, attitude, intention to use, and authenticity	Generally increase between the group no differnce ($p>0.05$): A theoretical test and an identification test to objectively assess students' learning.	Not investigated
Alharbi(2020) [29]	3D-VR is a beneficial tool, but its use comes with challenges(Qualitative): focus group discussions	Males who used the traditional methods. Meanwhile, females who used traditional methods showed significantly higher short-term knowledge scores than females who used 3D-VR ($p<0.001$): Objective Structured Practical Examinations (OSPEs) were used to assess short-term and long-term knowledge retention	Not investigated
Bridget Copson(2021) [30]	After completing their respective modules, students in all groups reported significantly increased confidence in their understanding of temporal bone and inner ear anatomy: Likert scale for subjective experience	increase ($p\leq0.005$, Cohen's $d=1.41$): The questionnaire contained 13 quiz questions	Not investigated

Table 3 (continued)

First author	Kirkpatrick's Level		
	Effect on Reaction/Tools	**Effect on Learning/Tools**	**Effect on behavior / impact**
Brittany Star Hampton(2010) [23]	95% of students believed that using the trainer would enhance patient care, while 81% felt it would improve their performance on the obstetrics and gynecology shelf exam: faculty members again questionnaire	The trainer group had significantly higher postintervention knowledge($P<0.05$): knowledge questionnaires	Not investigated
Zachary A. Drapkin(2015) [26]	the interactive 3D multimedia module received higher satisfaction ratings from students($P<0.05$): survey of satisfaction & self rated confidence	neither enhanced nor inhibited learning of complex hepatobiliary anatomy($P>0.05$): Pre-test: Previous experience survey .Purdue visualizations of Rotation test. Post-test: 32 identification questions MRI.	Not investigated
Alexander W. Keedy(2011) [24]	satisfaction survey the 3D group expressed a statistically significantly higher overall satisfaction rating($P<0.05$): satisfaction survey	Spatial ability did not statistically significantly correlate with post-test scores for the 3D group or the 2D group($P>0.05$).: questionnaire, 10 MCQ(pre-test), 9 MCQ(post-test)	Not investigated
Alla Solyar(2008) [25]	the statistically significant difference between the two groups ($P<0.05$): Two surveys: The first survey assessed the extent of students' study efforts. The second survey evaluated students' satisfaction with their study modality using a Likert scale, and students' perception of the study modality's effectiveness as a learning tool, likelihood of future use, ease of use, ease of learning, and image realism.	no statistically significant difference between the two groups ($P>0.05$): pre-test: Identification of anatomical structures from textbook images to establish a baseline knowledge level. Post-test: Completion of a nasal cavity endoscopic videotape session followed by a question-and-answer session.	Not investigated

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Author contributions
M.A.M., A.O., A.M., H.M., and A.R. provided the initial idea, and conceptualized and designed the study. M.A.M., A.M., H.M., performed the literature search, in consultation with A.O. and, A.R. assisted with study organization and performed critical revision of the manuscript. M. A.M. and A.O. provided writing and critical revision of the manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This research was approved by the Isfahan University of Medical Sciences with the codes of ethics of IR.MUI.RESEARCH.REC.1399.631.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Blali MM, Safaar MS, Shojayan S. The use of virtual reality technology in teaching anatomy. The second research congress of students of Hormozgan University of Medical Sciences. Hormozgan: Hormozgan University of Medical Sciences; 2020.
2. Alfalah SF, Falah JF, Alfalah T, Elfalah M, Muhaidat N, Falah O. A comparative study between a virtual reality heart anatomy system and traditional medical teaching modalities. Virtual Reality. 2019;23:229–34.
3. Chen S, Zhu J, Cheng C, Pan Z, Liu L, Du J, et al. Can virtual reality improve traditional anatomy education programmes? A mixed-methods study on the use of a 3D skull model. BMC Med Educ. 2020;20(1):1–10.
4. Barmaki RL, Kim K, Guo Z, Wang Q, Yu K, Pearlman R et al. A large-scale feasibility study of screen-based 3D visualization and augmented reality tools for human anatomy education: exploring gender perspectives in learning experience. arXiv preprint arXiv:230714383. 2023.
5. Chew FS, Relyea-Chew A, Ochoa ER Jr. Postmortem computed tomography of cadavers embalmed for use in teaching gross anatomy. J Comput Assist Tomogr. 2006;30(6):949–54.
6. Mutalik M, Belsare S. Methods to learn human anatomy: perceptions of medical students in paraclinical and clinical phases regarding cadaver dissection and other learning methods. Int J Res Med Sci. 2016;4(7):2536–41.
7. James J, Natarajan PS, Subramanian SP. Unveiling challenges in cadaveric dissection for medical education–a study of student perspectives. 2024.
8. mohajery s, mohajeri s. Horizons Med Educ Dev. 2010;4(1):69–74.
9. Roche K, Liu S, Siegel S. The effects of virtual reality on mental wellness: a. Ment Health. 2019;14:811–8.
10. Claudio P, Maddalena P, Overview. Virtual reality in medicine. J Virtual Worlds Res. 2014;7(1).
11. Moro C, Štromberga Z, Raikos A, Stirling A. The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ. 2017;10(6):549–59.
12. Rosmansyah Y, Putri A, Koesoema AP, Latief A, Amalia YS, editors. A systematic review of virtual reality application in anatomy studies. AIP Conference Proceedings; 2021: AIP Publishing LLC.
13. Zhao J, Xu X, Jiang H, Ding Y. The effectiveness of virtual reality-based technology on anatomy teaching: a meta-analysis of randomized controlled studies. BMC Med Educ. 2020;20(1):1–10.
14. Capps P. The use of Kirkpatrick's four levels of evaluation by performance improvement practitioners. Indiana University; 2008.
15. Alsalamah A, Callinan C. The Kirkpatrick model for training evaluation: bibliometric analysis after 60 years (1959–2020). Industrial Commercial Train. 2022;54(1):36–63.
16. Nicholson DT, Chalk C, Funnell WRJ, Daniel SJ. Can virtual reality improve anatomy education? A randomised controlled study of a

computer-generated three-dimensional anatomical ear model. Med Educ. 2006;40(11):1081–7.
17. Buckley S, Coleman J, Davison I, Khan KS, Zamora J, Malick S, et al. The educational effects of portfolios on undergraduate student learning: a best evidence Medical Education (BEME) systematic review. BEME Guide 11 Med Teacher. 2009;31(4):282–98.
18. Stepan K, Zeiger J, Hanchuk S, Del Signore A, Shrivastava R, Govindaraj S, et al. editors. Immersive virtual reality as a teaching tool for neuroanatomy. International forum of allergy & rhinology; 2017.
19. Cui D, Wilson TD, Rockhold RW, Lehman MN, Lynch JC. Evaluation of the effectiveness of 3D vascular stereoscopic models in anatomy instruction for first year medical students. Anat Sci Educ. 2017;10(1):34–45.
20. Petersson H, Sinkvist D, Wang C, Smedby Ö. Web-based interactive 3D visualization as a tool for improved anatomy learning. Anat Sci Educ. 2009;2(2):61–8.
21. Nicholson D. A randomized controlled study of a computer-generated three-dimensional model for teaching ear anatomy.
22. Stojanovska M, Tingle G, Tan L, Ulrey L, Simonson-Shick S, Mlakar J, et al. Mixed reality anatomy using Microsoft HoloLens and cadaveric dissection: a comparative effectiveness study. Med Sci Educ. 2020;30:173–8.
23. Hampton BS, Sung VW. Improving medical student knowledge of female pelvic floor dysfunction and anatomy: a randomized trial. Am J Obstet Gynecol. 2010;202(6):601. e1-. e8.
24. Keedy AW, Durack JC, Sandhu P, Chen EM, O'Sullivan PS, Breiman RS. Comparison of traditional methods with 3D computer models in the instruction of hepatobiliary anatomy. Anat Sci Educ. 2011;4(2):84–91.
25. Solyar A, Cuellar H, Sadoughi B, Olson TR, Fried MP. Endoscopic sinus surgery Simulator as a teaching tool for anatomy education. Am J Surg. 2008;196(1):120–4.
26. Drapkin ZA, Lindgren KA, Lopez MJ, Stabio ME. Development and assessment of a new 3D neuroanatomy teaching tool for MRI training. Anat Sci Educ. 2015;8(6):502–9.
27. Wada Y, Nishi M, Yoshikawa K, Higashijima J, Miyatani T, Tokunaga T, et al. Usefulness of virtual three-dimensional image analysis in inguinal hernia as an educational tool. Surg Endosc. 2020;34:1923–8.
28. Du Y-C, Fan S-C, Yang L-C. The impact of multi-person virtual reality competitive learning on anatomy education: a randomized controlled study. BMC Med Educ. 2020;20(1):1–10.
29. Alharbi Y, Al-Mansour M, Al-Saffar R, Garman A, Al-Radadi A. Three-dimensional virtual reality as an innovative teaching and Learning Tool for human anatomy courses in Medical Education: a mixed methods study. Cureus. 2020;12(2).
30. Copson B, Wijewickrema S, Sorace L, Jones R, O'Leary S. Development of a virtual reality clinically oriented temporal bone anatomy module with randomised control study of three-dimensional display technology. BMJ Simul Technol Enhanc Learn. 2021;7(5):352–9.
31. Maresky HS, Oikonomou A, Ali I, Ditkofsky N, Pakkal M, Ballyk B. Virtual reality and Cardiac anatomy: exploring Immersive three-Dimensional Cardiac Imaging, a pilot study in Undergraduate medical anatomy education. Clin Anat. 2019;32(2):238–43.
32. Kockro RA, Amaxopoulou C, Killeen T, Wagner W, Reisch R, Schwandt E, et al. Stereoscopic neuroanatomy lectures using a three-dimensional virtual reality environment. Annals Anatomy-Anatomischer Anzeiger. 2015;201:91–8.
33. Khot Z, Quinlan K, Norman GR, Wainman B. The relative effectiveness of computer-based and traditional resources for education in anatomy. Anat Sci Educ. 2013;6(4):211–5.
34. De Faria JWV, Teixeira MJ, Júnior LMS, Otoch JP, Figueiredo EG. Virtual and stereoscopic anatomy: when virtual reality meets medical education. J Neurosurg. 2016;125(5):1105–11.
35. Imai T, Tanaka Y, Hatanaka Y, Suetsugu T, Sato Y, Matsuhashi N, et al. Incorporation of virtual reality in the clinical training of medical students studying esophageal and mediastinal anatomy and surgery. Surg Today. 2022;52(8):1212–7.
36. Pickering JD, Panagiotis A, Ntakakis G, Athanassiou A, Babatsikos E, Bamidis PD. Assessing the difference in learning gain between a mixed reality application and drawing screencasts in neuroanatomy. Anat Sci Educ. 2022;15(3):628–35.
37. Bogomolova K, Sam AH, Misky AT, Gupte CM, Strutton PH, Hurkxkens TJ, et al. Development of a virtual three-Dimensional Assessment scenario for Anatomical Education. Anat Sci Educ. 2021;14(3):385–93.
38. Ferrer-Torregrosa J, Jiménez-Rodríguez MÁ, Torralba-Estelles J, Garzón-Farinós F, Pérez-Bermejo M, Fernández-Ehrling N. Distance learning ects and flipped classroom in the anatomy learning: comparative study of the use of augmented reality, video and notes. BMC Med Educ. 2016;16(1):1–9.
39. Tam M, Hart A, Williams S, Holland R, Heylings D, Leinster S. Evaluation of a computer program ('disect') to consolidate anatomy knowledge: a randomised-controlled trial. Med Teach. 2010;32(3):e138–42.
40. Sinha S, DeYoung V, Nehru A, Brewer-Deluce D, Wainman BC. Determinants of learning anatomy in an immersive virtual reality Environment—A scoping review. Med Sci Educ. 2022:1–11.
41. Uruthiralingam U, Rea PM. Augmented and virtual reality in anatomical education–a systematic review. Biomedical Visualisation: Volume. 2020;6:89–101.

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