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Research article

Efficacy of three-dimensional models for medical education: A systematic scoping review of randomized clinical trials

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ABSTRACT

Objectives: To estimate the efficacy of three-dimensional (3D) models for medical education. Methods: A systematic scoping review was performed containing diverse databases such as SCOPUS, PubMed/MEDLINE, SCIELO, and LILACS. MeSH terms and keywords were stipulated to explore randomized clinical trials (RCTs) in all languages. Solely RCTs that accomplished the eligibility criteria were admitted. Results: Fifteen RCTs including 1659 medical students were chosen. Five RCTs studied heart models, 3 RCTs explored facial, spinal and bone fractures and the rest of the trials investigated eye, arterial, pelvic, hepatic, chest, skull, and cleft lip and palate models. Regarding the efficacy of 3D models, in terms of learning skills and knowledge gained by medical students, most RCTs reported higher scores. Considering the test-taking times, the results were variable. Two RCTs showed less time for the 3D group, another RCT indicated variable results in the response times of the test depending on the anatomical zone evaluated, while another described that the students in the 3D group were slightly quicker to answer all questions when compared with the traditional group, but without statistical significance. The other 11 experiments did not present results about test-taking times. Most students in all RCTs indicated satisfaction, enjoyment, and interest in utilizing the 3D systems, and recognized that their abilities were enhanced. Conclusions: Higher efficacy in terms of learning skills and knowledge gained was observed when the 3D systems were used by medical students. Undergraduates also expressed great satisfaction with the use of these technologies. Regarding the test-taking times, the results favored the 3D group.

1. Introduction

The implementation of information and communication technologies is undergoing augmented development [1,2]. Regarding education, innovative and contemporary tendencies are being accepted by professors [2,3], thus traditional education and learning prototypes founded on lectures are being accompanied, and even substituted by some technologies [2–5]. In this regard, it was accentuated emerging values in undergraduates that permit them to utilize educational resources and media conscientiously and favorably for the acquisition of information in addition to the resulting fundamental values for education: to incite functional knowledge, to offer opportune feedback, to stimulate interaction between learners and trainers, to inspire collaboration between

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scholars, to motivate the correct use of time, to incite undergraduate's great prospects, and to respect dissimilar learning styles [2,4]. These technologies-based education models are contemplated as a modern instrument that may increase enthusiasm for scholar's learning, helping as a complementary educational source for the implementation of usual instruction models [6,7]. This progression in the application of technologies in education also had a field around health-related education, in which technology can support improving educational practice by rising understanding and psychomotor abilities [2,8]. Moreover, the presence of technologies admits the formation and diffusion of digital media learning to increase knowledge gaining and to acquire "collaboration, communication, critical thinking, and creativity" [2,9].

The cumulative attention to and omnipresence of technologies-based learning was complemented by an investigation into how such approaches compared with traditional education on a broad range of educational endpoints [10]. In this regard, it was evaluated that the medical evidence on technologies reported that investigators must focus on determining in which sceneries these systems are most suitable, instead of comparing them with the context of the classroom [11]. Consequently, these researchers postulated that technologies propose implements that cannot be replicated by other resources, thus, the usual classroom scenery cannot be contemplated as a sound comparison group [12,13].

Virtual learning settings involved notable attention for decades and that interest improved with the increase of enhanced reality functions incorporating virtual and physical worlds [14–16]. The services of three-dimensional (3D) virtual domains have a great portion in the expansion of this situation. They warrant handlers to design interactive settings with the content they desire [16,17]. They also make it probable to view a particular issue from diverse perceptions and may incorporate virtual activities that are arduous to practice securely in real life. Students are competent to access virtual topics concurrently, share material [18], obtain multidimensional feedback [19], and plan exercises by interacting with items and persons from online connection points in dissimilar sites [16,20].

Considering the above, the advent of 3D models has brought much innovation to medicine. This technology has been incorporated during diagnosis and treatment plans. 3D models facilitate a fully digital workflow; moreover, protocol studies have postulated clinical reliability, and it has been indicated that this technology permits prompt and cost-effective prototyping of models [21–23].

Digital technology has been successfully adopted in many areas of medicine, reaching from basic anatomy to surgical training and leading research utilization. Educational prototypes involving the skull, bone, cerebral aneurysm, heart, lateral ventricles, liver, kidney, and duodenum, have been created by adopting 3D systems. Excellent replicas with efficacy equivalent to or superior to cadavers are expectant implements in compelling challenges related to ethics and sanitation linked with dissection [24–29]. Furthermore, 3D printing of anatomical models has been indicated to resolve the limitations of present visualization systems [28].

Digital enablement is likewise touching medical learning. Medical programs need to be digitally updated and must incorporate medical procedures with virtual technologies and software elucidations [27–29]. Besides, the implementation of 3D models in education accepts the creation of various identical models that can be scaled to reach the dimension required [23]. Currently, medical science students diverge from their previous peers in that they are, as participants of a digitally intermediated generation, recognizable with the knowledge of simulation virtual experience. The undergraduates habitually implement computerized devices in a virtual setting [28], which is why it is usually expected that they will consent and even select digital purposes to standard procedures and that they will certainly study or instinctively utilize digital systems [29]. Furthermore, virtually all universities are examining for more competent forms to instruct learners, incorporating digital skills [30].

Besides, medical institutions have described the outcomes of operating several tools in the training of their undergraduates [29]. Consequently, it has been settled that its efficiency is related to time, effectiveness, and faculty insights into medical student implementation [31].

Considering the best available scientific evidence through randomized clinical trials (RCTs) that compare 3D models with conventional strategies for medical student education will allow medical science schools to make better decisions to implement these technologies in their programs. Therefore, it is pertinent to perform a systematic scoping review of RCTs which permits for assessment of the efficacy of 3D models for medical education. To complete this aim was planned to answer some questions linked to the efficacy, in terms of learning skills and knowledge gained, test-taking times, and perceptions of using 3D systems by medical students.

2. Materials and methods

The present review of RCTs was implemented by contemplating the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) extension for scoping reviews [32]. The scoping configuration covered multiple databases such as PubMed/MEDLINE SCOPUS, LILACS, and SCIELO, incorporating the gray literature. Keywords and MeSH terms were stipulated to inspect RCTs performed in medical education in all languages, without considering publication dates, contemplating the terminologies CAD/CAM procedures, computer-aided design, 3D management organization, 3D models, medical students, medical education, intervention reports, and randomized clinical experiments. Then, a process was implemented to research databases, utilizing Boolean operators (AND, OR): "computer-aided design" OR "3D models" OR "CAD/CAM systems" AND "3D treatment planning" AND "medical students" OR "medical education" AND "intervention studies" OR "randomized clinical trial".

Solely RCTs that satisfied the eligibility criteria were acknowledged. Research related to the student's cognitive field, learning styles, resident students, case reports and series, and duplicate investigations were omitted.

2.1. Questions

This investigation responded the next interrogations: Do 3D models for medical education present higher efficacy, in terms of learning skills and knowledge gained, than conventional methodologies? Does 3D technology for medical education need less test-taking time? Which is the perception of medical students when they use 3D systems?

2.2. Evaluation method

Two researchers explored the titles and abstracts and chose RCTs to evaluate the full text for probable suitability. In case of discrepancy between scholars, trial admissibility was finished by the accord. The Kappa statistical analysis was applied to measure the proportion of arrangement among authors (>94).

2.3. Information compilation

A tool was organized to integrate the most appropriate information from the chosen RCTs. This method was executed autonomously by each of the investigators. Later, the information was contrasted. Verified data embraced authors' information, period of publication, gender and age of students, amount of students, 3D procedures, and control, contrast among the groups (principal considered outcomes), test-taking times, and perceptions of medical students regarding 3D systems.

2.4. Risk of bias

Two investigators evaluated the quality and risk of bias of the entered RCTs was completed following a tool for RCTs [33].

3. Results

The initial electronic exploration generated 1826 studies of which 1749 were omitted because they were not RCTs. After revising

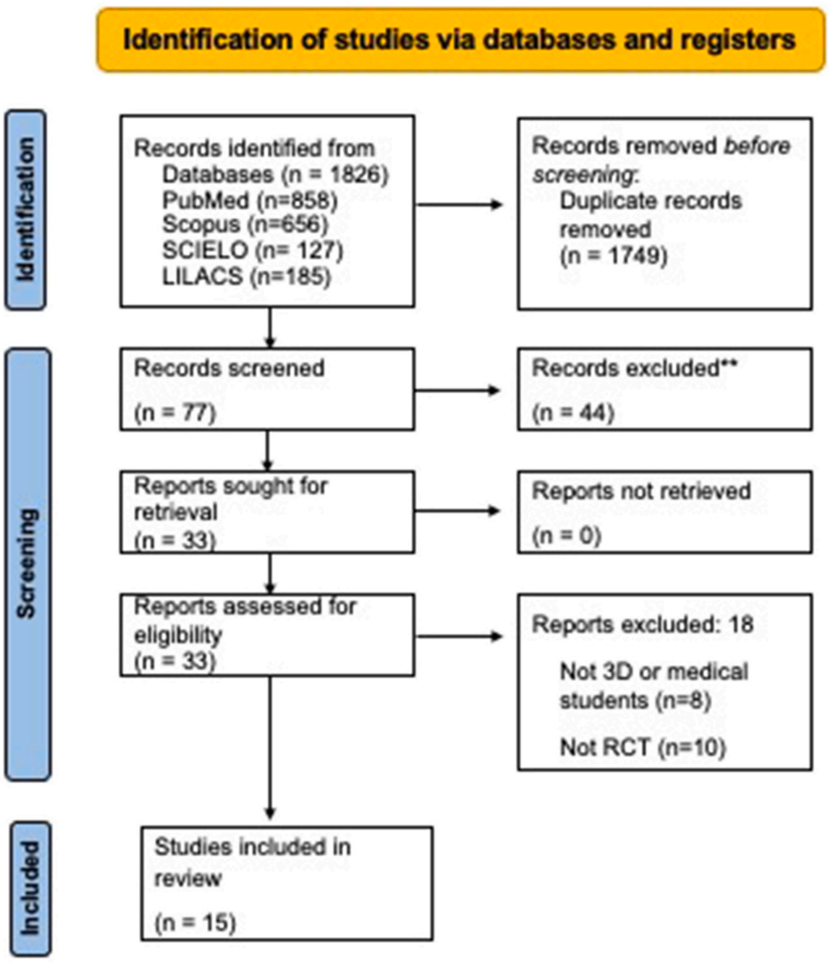

Fig. 1. Flowchart of the RCTs selection procedure.

Table 1
Descriptions of the RCTs valued.

Authors publication date	Students	Mean age	Female/ male	Intervention control	Main outcomes	Time spent	Students perceptions
Wu et al. [47]	92	25 years	56/36	A 3D eye model was used. Group A (model-assisted training group) and group B (traditional training group).	43 students in group A (93.48%) effectively saw the fundus, while 21 in group B (45.65%) accomplished ($p < 0.0001$)	Group A was significantly faster than group B ($p < 0.0001$).	The 3D-printed eye model significantly improved the students' study interest
Nicot et al. [34]	431	NR	NR	This randomized controlled trial was designed to compare the understanding of facial fractures with three-dimensionally–printed models versus classic virtual three-dimensional reconstructions displayed in two-dimensions	The 3D model was a better teaching material compared with two-dimensional support ($p = 0.008$). Moreover, three-dimensionally-printed models provide a better understanding ($p = 0.015$).	NR	NR
Karsenty et al. [35]	347	22 years	247/ 100	Students were randomized into printing groups (3D printed models in congenital heart defects lectures) or control groups. All students received the same 20 min lecture with projected digital 2D images. The printing groups also manipulated 3D-printed models during the lecture.	Objective knowledge improved after the lecture and was higher in the printing group compared to the control group ($p < 0.0001$).	NR	Students' opinion of their understanding of congenital heart defects was higher in the printing group compared to the control group ($p < 0.0001$).
Yi et al. [36]	60	19 years	37/23	To evaluate the educational effect of 3-dimensional (3D) printed models (3DPMs), 3D images, and 2-dimensional images (2DI) in the anatomy education of the ventricular system	The students in the 3DPM and 3DI groups performed significantly better than those in the 2DI group in terms of the practice test score (3DPM group vs. 2DI group, $p < 0.001$; 3DPM group vs. 2DI group, $p = 0.009$).	NR	The 3DPM group performed better than the 3DI group for "enjoyment" and "attitude" ($p = 0.039$ and $p = 0.025$, respectively).
Sheu et al. [37]	49	NR	NR	Students were randomized to a 3-dimensional printed ultrasound-compatible vascular model (3DPVAM) or a commercial model (CM) simulation experience (SE) for ultrasound (US) guided femoral artery (FA) access.	In both groups, training increased student confidence. The confidence increase in 3DPVAM trainees was non-inferior to that in CM trainees.	NR	The majority of 3DPVAM and CM trainees agreed that the model was easy to use and useful for practice
Hojo et al. [38]	34	NR	22/12	Participants were randomly assigned to the 3D Printed pelvic model for the lateral pelvic lymph node dissection model group or the textbook group.	The scores of the 3D model group were significantly higher than those of the textbook group students ($p < 0.05$).	NR	Most students felt satisfied with the use of the 3D model.
Bettega et al. [39]	49	24 years	30/19	A 3D printer, to create a human chest cavity simulator that allows the reproduction of the closed chest drainage technique (CCD), comparing its effectiveness with that of the animal model.	A higher score was observed in the simulator model group for use as didactic material and learning of the CCD when compared to the animal model group ($p < 0.05$).	NR	There was a preference for the simulator model as didactic material.
Wu et al. [40]	90	NR	34/56	The use of 3D printed models versus radiographic images as a technique for the education of medical students about bone spatial anatomy and fractures was investigated.	No significant differences were found in the upper limb or lower limb test scores between the 3D printed model group and the traditional radiographic image group; however, the scores on the pelvis and spine test for the	No significant differences were found in the test-taking times for the upper limb or lower limb ($p = 0.603$ and $p = 0.746$, respectively) between the two groups; however,	The visual analog scale of satisfaction mean score was 7.49 ± 1.38 for the 3D printed model group and 5.80 ± 1.30 for the traditional radiographic image

(continued on next page)

Table 1 (*continued*)

Authors publication date	Students	Mean age	Female/ male	Intervention control	Main outcomes	Time spent	Students perceptions
					traditional radiographic image group were significantly lower than the scores for the 3D printed model group ($p = 0.000$).	the test-taking times for the pelvis and spine in the traditional radiographic image group were significantly longer than those of the 3D printed model group ($p = 0.000$ and $p = 0.002$, respectively).	group, with $p < 0.001$.
Su et al. [41]	63	21 years	33/30	Two groups participated in a seminar with or without a 3D heart model with ventricular septal defect lesions.	With these 3D models, feedback shown in the questionnaires from students in the experimental group was significantly more positive than their classmates in the control. And the test results also showed a significant difference in structural conceptualization in favor of the experimental group.	NR	3D printing technology for congenital heart disease education stimulates students' interest in congenital heart disease.
Chen et al. [24]	79	20 years	45/34	Colored skull models were produced by 3D printing technology. A randomized controlled trial was conducted to compare the learning efficiency of 3D printed skulls with that of cadaveric skulls and atlas.	The 3D group was better than the other two groups in total score (structure recognition), and scores on a lab test. Scores involving the theory tests, however, showed no difference between the three groups.	NR	No differences were found in the enjoyment of learning between the groups.
Alali et al. [42]	67	21 years	36/31	This study investigates the use of 3D-printed models in educational seminars on cleft lip and palate, by comparing integrated "hands-on" student seminars, with 2D presentation seminar methods.	The addition of the 3D-printed model resulted in a significant improvement in the mean percentage of knowledge gained (44.65% test group; 32.16%; control group; $p = 0.038$).	NR	The students felt the 3D-printed model significantly improved the learning experience ($p = 0.005$) and their visualization ($p = 0.001$).
Lim et al. [43]	52	19 years	27/25	To assess effectiveness against cadaveric materials for learning external cardiac anatomy. Three groups underwent self-directed learning sessions using either cadaveric materials, 3D prints, or a combination of cadaveric materials/3D prints (combined materials).	Post-test scores were significantly higher for the 3D prints group compared to the cadaveric materials or combined materials groups ($p = 0.012$).	NR	NR
Kong et al., 2016 [24]	92	NR	NR	After 3D reconstruction, three types of 3D computer models of hepatic structures were designed and 3D printed as models of hepatic segments without parenchyma (type 1) and with transparent parenchyma (type 2), and hepatic ducts with segmental partitions (type 3) versus traditional anatomical atlas (TAA).	The type 3 model was better than the type 1 and 2 models in anatomical condition, and type 2 and 3 models were better than the type 1 model in tactility. The teaching effect of the type 1 model was significantly better than the type 2 model and TAA, while the type 3 model was significantly better than the type 2 and	NR	The type 3 model was better than the type 1 model in overall satisfaction ($p = 0.05$).

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Table 1 (*continued*)

Authors publication date	Students	Mean age	Female/ male	Intervention control	Main outcomes	Time spent	Students perceptions
					TAA in the first quiz ($p > 0.05$).		
Wang et al. [45]	34	22 years	17/17	A 3D printing cardiac model versus a traditional model.	The 3D model was not significantly superior to a traditional model in teaching cardiac diseases.	The students in the 3D group were slightly quicker to answer all questions when compared with the traditional group, but without statistical significance.	The students' satisfaction was similar for both groups.
Li et al. [46]	120	22 years	65/55	Two spinal fracture simulation models were generated by 3D printing (3Dp). The students were randomized into three teaching module groups [two-dimensional computed tomography images (CT), 3D, or 3Dp]	Students in the 3Dp or 3D group performed significantly better than those in the CT group.	Students in the 3Dp group were the first to answer all questions.	Pleasure, assistance, effect, and confidence were more predominant in students in the 3Dp group than in those in the 3D and CT groups.

NR = Not reported.

the titles and abstracts 44 investigations were also excluded. Regarding the full text occasioned the exclusion of 18 additional experiments. Lastly, 15 RCTs [24,34–47] were entered in this study (Fig. 1).

The features of the incorporated trials are depicted in Table 1. These RCTs were issued between 2015 and 2022. These experiments studied 1659 undergraduates with a minimum sample of 34 students [38,45] and a maximum of 431 [34]. These trials valued 3D models for undergraduate education in different areas of medicine. Five RCTs studied heart models [35,36,41,43,45], 3 RCTs explored facial [34], spinal [45], and bone [40] fractures, and the rest of the trials investigated arterial [47], pelvic [38]; hepatic [44], chest [39], skull [24], cleft lip and palate [42], and eye [47] models.

Regarding the efficacy of 3D models, in terms of learning skills and knowledge gained by medical students, most RCTs presented higher scores (Table 1) [24,34–36,38–44,46,47]. However, Sheu et al. [37] compared 3D-printed ultrasound-compatible vascular models, with a commercial model simulation experience for ultrasound-guided femoral artery access, and showed that in both groups, training increased student confidence [37]. Similarly, Wang et al. [45] indicated that the 3D model was not significantly superior to a traditional model in teaching cardiac diseases.

Seeing the test-taking times, four RCTs showed variable outcomes [40,45–47]. Li et al. [46] reported that the students in the 3Dp group were the first to answer all questions. Similarly, it was indicated that the 3D group was significantly faster than the control group [47]. On the other hand, Wu et al. [40] indicated that no significant dissimilarities were observed in the test-taking times for the lower limb or upper limb ($p = 0.746$ and $p = 0.603$, respectively) between the two groups; however, the test-taking times for the pelvis and spine in the conventional radiographic image group were significantly longer than those of the 3D printed model group ($p = 0.000$ and $p = 0.002$, respectively). Wang et al. [45] presented that the students in the 3D group were slightly quicker to answer all questions when compared with the traditional group, but without statistical significance. The other 11 experiments did not present results concerning test-taking times.

Table 2
Quality of the selected RCTs.

RCT	Randomization	Double blinding	Withdraw	Proper randomization	Proper double blinding	Score
Wu et al. [47]	1	0	1	0	0	2
Nicot et al. [34]	1	0	1	1	0	3
Karsenty et al. [35]	1	0	1	0	0	2
Yi et al. [36]	1	0	1	1	0	3
Sheu et al. [37]	1	0	1	0	0	2
Hojo et al. [38]	1	0	1	1	0	3
Bettega et al. [39]	1	0	1	0	0	2
Wu et al. [40]	1	0	1	0	0	2
Su et al. [41]	1	0	1	1	0	3
Chent et al. [24]	1	0	1	1	0	3
Alali et al. [42]	1	0	1	0	0	2
Lim et al. [43]	1	1	1	1	1	5
Kong et al. [44]	1	0	1	1	0	3
Wang et al. [45]	1	0	1	0	0	2
Li et al. [66]	1	0	1	1	0	3

Regarding the third question, it was observed that most of the students in the RCTs selected, indicated satisfaction, enjoyment, and interest in utilizing the 3D systems, and recognized that their abilities were enhanced (Table 1). However, Wang et al. [45] described that the students' satisfaction was similar for 3D and conventional groups. The RCTs of Nicot et al. [34] and Lim et al. [43] did not present information about student perceptions.

Seven reports presented an elevated risk of bias [35,37,39,40,42,45,47] whereas 7 of the studied experiments offered a moderate risk [24,34,36,38,41,44,46]. Only one RCT [43] presented a low risk of bias (Table 2). The RCTs studied in this systematic scoping review had ample heterogeneity in their designs, replicated predominantly in the anatomical sites studied, the outcome variables explored, and the valuation exams considered. These features preclude a statistical exploration.

4. Discussion

This systematic scoping review compares for the first time the efficacy of 3D models for medical education. Regarding that 3D tools suggest innovations linked to clinical procedures implemented in medicine, an aspect that can innovate curricula in medical schools, it is indispensable to estimate their usefulness with the best accessible scientific evidence. Considering this condition, responses were assumed to each of the three planned interrogations of this study.

The 3D studies have been commonly designed as education support, simulation, social communication, and game settings [16]. Therefore, the fact that 3D environments permit game-based learning actions is significant for education [48]. Other investigations have concluded that 3D technologies are convenient for collaborative learning [49,50]. Moreover, it has been proposed that undergraduates may involve in performance, cooperative, experiential, diagnostic, constructivist, role-playing, problem-based, and ability development actions in 3D [16].

Regarding the efficacy of 3D models, in terms of learning skills and knowledge gained by medical students, most RCTs presented higher scores [24,34–36,38–44,46,47]. These RCTs described that 3D models generally improve spatial knowledge, understanding, and appreciation of anatomical structures in comparison with conventional approaches, involving images presented in two dimensions such as schoolbook and computer-based learning [24,34–36,38–44,46,47]. Furthermore, Snow et al. [51] indicated that memory for physical items is appreciably superior to their two-dimensional complements. Additional benefits of 3D technology include the opportunity to contextualize the learning activity by selecting the wanted target [14], and a 3D model also may be created from a saved file of an attractive case experienced in a clinical course or based on the adaptation of a real case [52].

While several aspects of touching learning by applying 3D have been recognized, it is necessary to evaluate the effect of these elements while utilizing 3D models [53]. It has been suggested that these factors be grouped into three groups. First, factors associated with the 3D model included the intention of the prototype, the obtainability of visual and auditory material concurrently, and directions created by the software [54]. Second, aspects correlated to the learner features [55]. Third, elements linked to the curriculum and the learning setting [56]. These considerations must be contemplated by creators of novel 3D models and course formulators, as well as the training team [53].

In this review, considering the test-taking times, four RCTs showed variable results [40,45–47]. Two RCTs showed less time for the 3D group [40,47], another RCT indicated variable results in the response times of the test depending on the anatomical zone evaluated [46], while another described that the students in the 3D group were slightly quicker to answer all questions when compared with the traditional group, but without statistical significance [45]. In this regard, it was informed that the undergraduates who presented lower test-taking times showed superior results, which established that the undergraduates in the 3D model group profited from better knowledge of different topics [40].

Herein, it was found that most of the students in the RCTs selected, indicated satisfaction, enjoyment, and interest in utilizing the 3D systems, and recognized that their abilities were enhanced. In this regard, it has been informed that students read less and be more attracted to new technologies [57]. Currently, the utilization of video games and smartphones is generating apprentices with a novel profile of intellectual abilities [58]. Therefore, different programs have incorporated these technologies into their curricula [59,60].

Although none of the experiments reviewed here had as its main objective to evaluate the cost-effectiveness of 3D systems, in the RCT of Bettega et al. [39] was reported that the definitive cost for manufacturing the 3D model was minor than that of a commercial simulator, establishes the possibility of implementing 3D in education and clinical practice. Moreover, it has been reported that the price and volume of 3D systems have diminished quickly over the previous years, and it has converted ease of approach to digital data implemented to construct 3D models that have democratized their practice in education and clinical procedures [61].

Assumed the rising relevance in 3D models as demonstrated by the cumulative amount of available investigation in this field, there is a demand for multi-institutional reports that assess concepts behind education by implementing 3D technologies and influence of learning by 3D prototypes on the improvement of knowledge, understanding, clinical abilities, integration, and utilization [53].

The principal weakness of this review is connected to the considerable risk of bias in 7 RCTs explored [35,37,39,40,42,45,47]. These biases were mainly associated to double blinding. It was indicated that blinding the procedures is problematic when new technology systems are used [62]. Nevertheless, a superior amount of RCTs with a low risk of bias are needed to permit more decisive outcomes.

5. Conclusions

Higher efficacy, in terms of learning skills and knowledge gained, was perceived when the 3D systems were used by medical students. Undergraduates also expressed great satisfaction with the use of these technologies. Regarding the test-taking times, the results favored the 3D group.

Ethics approval and consent to participate

Not applicable.

Author contribution statement

Carlos M. Ardila: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Daniel González-Arroyave: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Mateo Zuluaga-Gómez: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

The datasets used and/or analyzed during the present study are available from the corresponding author upon reasonable request.

Patient consent for publication

Not applicable.

Declaration of interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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