International Journal of Healthcare Simulation Vol.1, Issue no.3

ORIGINAL RESEARCH

Effectiveness of high- and low-fidelity simulation-based medical education in teaching cardiac auscultation: a systematic review and meta-analysis

Craig Osborne[1], Craig Brown[2], Alyaa Mostafa[2]

[1]*Emergency Department, Queen Elizabeth University Hospital, NHS Greater Glasgow & Clyde, Glasgow, UK*
[2]*School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, Aberdeen, UK*

Corresponding author: Alyaa Mostafa, a.mostafa@abdn.ac.uk

https://ijohs.com/article/doi/10.54531/NZWS5167

ABSTRACT

Introduction

Simulation-based medical education (SBME) is an evolving method of teaching cardiac examination skills to healthcare learners. It has been deliberated how effective this teaching modality is and whether high-fidelity methods are more effective than low-fidelity methods. This systematic review aimed to assess the effectiveness of high-fidelity SBME in teaching cardiac auscultation compared with no intervention or another active teaching intervention (low-fidelity SBME) using evidence from randomized controlled trials (RCTs).

Methods

Literature searches were performed on Medline, Embase, PsychInfo and Cinahl. RCTs that compared the effectiveness of high-fidelity simulation against no intervention or high-fidelity simulation against low-fidelity simulation in teaching cardiac auscultation to healthcare learners were included. Outcomes were knowledge, skills and satisfaction relating to cardiac auscultation education. Data were analyzed using Review Manager 5.3 software.

Results

Seventeen RCTs (n = 1055) were included. Twelve RCTs (n = 692) compared high-fidelity simulation with no intervention. The pooled effect sizes for knowledge and skills were 1.39 (95% confidence interval [CI], 0.39–2.38; $p = 0.006$; $I^2 = 92\%$) and −0.28 (95% CI, −1.49 to 0.93; $p = 0.65$; $I^2 = 94\%$), respectively. Five RCTs (n = 363) compared high-fidelity simulation with low-fidelity simulation. The pooled effect sizes for knowledge and skills were −0.73 (95% CI, −1.99 to 0.53; $p = 0.26$; $I^2 = 86\%$) and 0.32 (95%CI −0.75 to 1.39; $p = 0.56$; $I^2 = 89\%$), respectively.

Conclusions

This review's findings suggest that high-fidelity SBME is an effective teaching method for cardiac auscultation education. Interestingly, there was no significant difference in knowledge or skills among learners when comparing high-fidelity simulation with low-fidelity simulation. Further research is needed to establish the effectiveness of different forms of SBME as educational interventions.

What this study adds

What is already known on this topic

- Numerous studies have suggested that simulation-based medical education (SBME) is significantly more effective than bedside or lecture-based teaching in improving healthcare learners' knowledge, skills and satisfaction relating to cardiac auscultation teaching.
- With the impact Covid-19 has had on experiential learning, the opportunity for SBME to be used in student's learning is greater than ever.
- However, there is not a systematic review of the existing randomized controlled trials to provide the highest level of evidence in this field.
- Studies have also disagreed over whether high-fidelity SBME is more effective than low-fidelity SBME.

What this study adds

- Our results provide the highest level of evidence in this area, suggesting that high-fidelity SBME may not be significantly more effective than other active low-fidelity SBME teaching interventions, despite being more expensive.

Introduction

Cardiac auscultation is a key clinical skill for the diagnosis of patients with various heart diseases and is both reliable and cost-efficient [1,2]. Therefore, poor cardiac auscultation may lead to the dismissal of important pathology (false negatives) or over diagnosis (false positives) which has further implications on unnecessary referrals and investigations [3]. Although cardiac auscultation is clearly important, several studies have reported on skill incompetence within healthcare learners in cardiac auscultation [4,5]. The Covid-19 pandemic has affected this further, with fewer clinical learning experiences being available to students. Clinicians and departments are under unprecedented pressure, and time to teach students has been compromised, with timetabled teaching being periodically suspended.

Simulation-based medical education (SBME) was introduced in medical schools to improve learners' competence and clinical experiences [6–9]. Simulation refers to the artificial representation of a real-world process allowing the trainer to control the learning environment to achieve educational goals [10]. Several studies show that the use of SBME in health professional education has a positive impact on the learners' satisfaction and self-confidence [11–15]. SBME can also facilitate different planned exposure scenarios and auscultator abnormalities for various cardiac pathologies which are difficult for students to obtain in clinical placements [16].

There has been progression from low-fidelity SBME [17], such as using recorded audio files or multimedia CD-ROMs, to the development of high-fidelity SBME [18] with computerized manikins. These are more realistic and give learners a controlled, safe learning environment to make and correct mistakes without affecting patients' safety [19]. High-fidelity (authentic) learning theory also explains the rationale of using SBME by increasing learners' motivation to learn various clinical experiences [20].

Two systematic reviews [21,22] favour high-fidelity SBME in medical education compared with traditional teaching or no intervention. However, these reviews were relatively low levels of evidence (being limited to cohort and single-group studies). Thus, the effectiveness of SBME in cardiac auscultation training remains controversial. Several studies have also shown no significant differences in the effectiveness of high-fidelity SBME versus low-fidelity SBME [23,24].

This systematic review aims to address the gap in the literature regarding the effectiveness of SBME in cardiac auscultation training for health professional education within randomized control trials.

Methods

This systematic review and meta-analysis were performed as per the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement guidance [25]. *The objective* was to synthesize the highest level of available evidence regarding the effectiveness of SBME in cardiac auscultation within healthcare education. *The research questions* were: Does the use of high-fidelity SBME for training healthcare professionals improve learners' knowledge, skill performance, attitudes and satisfaction in cardiac auscultation training? And, if so, how does this compare to other active low-fidelity SBME teaching interventions?

Study eligibility

Inclusion criteria were randomized controlled trials (RCTs) investigating the use of high-fidelity SBME modalities within cardiac auscultation, defined as humanoid simulators able to generate a heart sound, to teach health professionals at any stage of their training, in comparison to either a low-fidelity modality, defined as any form of simulation excluding the use of the humanoid simulators able to generate a heart sound alone such as set of headphones using recorded audio files or multimedia CD-ROMs), or no intervention, defined as a form of teaching not utilizing SBME. Learning outcomes included learners' knowledge acquisition (written test scores, identification of murmurs), skills acquisition (examination skills, Observed Structured Clinical Examination [OSCE] performance) and satisfaction [26] (subjective self-reported attitude towards teaching technique).

Table 1 describes the inclusion and exclusion criteria using a Participants, Intervention, Comparisons and Outcomes format.

Study identification

MEDLINE, EMBASE, CINAHL, Scopus, Web of Science and PsychINFO were searched independently by two authors (CO and AM) with no starting date. The last date of the search was 25 February 2022. Terms used for learners

Table 1: Details of inclusion and exclusion criteria [27]

	Inclusion Criteria	Exclusion Criteria
Study design	Randomized controlled trials	All other study types
Participants	All healthcare students and professionals in the training of cardiac auscultation All healthcare students learning cardiac auscultation	Healthcare students or professionals in training and learning about other cardiology topics such as cardiopulmonary resuscitation or interventional cardiology
Intervention	A high-fidelity cardiopulmonary simulator able to generate a heart sound (e.g. Harvey®, SAM® and Nasco®)	Other forms of teaching interventions
Comparisons	No Intervention (e.g. continued usual teaching, no change to curriculum) Low-fidelity SBME comparison (e.g. computer-generated sounds only)	
Outcomes	Knowledge acquisition (written test scores, identification of murmurs) Skills acquisition (examination skills, OSCE performance) Satisfaction (subjective self-reported attitude towards teaching technique)	

OSCE = Observed Structured Clinical Examination

included 'education medical', 'education nursing', 'physician associates', 'medical students' and 'nursing students'. Terms used for intervention included: 'simulator', 'manikins', 'Harvey' and 'simulation'. Topics included 'cardiac auscultation' 'heart sounds', 'heart murmurs' and 'cardiac examination'. Terms for outcomes included 'skills', 'satisfaction' and 'knowledge'. These were decided with advice from an experienced research librarian.

No language restriction was applied. Search criteria were limited to humans. Furthermore, a manual search of bibliographies of the primary articles and reference lists of all included studies were searched and reviewed for additional relevant studies. A manual search of the abstract databases of international conferences was performed, including Association for Medical Education, Scottish National Medical Education, Association for Simulation Practice in Healthcare (ASPIH), Developing Excellence in Medical Education and International Association for Medical Education conferences.

Study selection

All identified studies' titles, abstracts and full texts were screened independently by two authors (CO and AM) for eligibility, and studies that met the inclusion criteria were included, in accordance with the Cochrane Handbook for Systematic Reviews of Interventions [27].

Data extraction

Data were extracted independently by two authors (CO and AM) followed by crosschecking and clarification of any differences, and if there were discrepancies, further discussion and decision were done including the senior author (CB). There were no non-English articles that required translation. Data entered into an excel sheet included the number and level of participants training, detailed randomization methods, purpose and aim of the study, area of clinical topic, details for intervention and comparison groups allocation, measurement of outcomes methods and the results.

Data synthesis

In this review, studies were classified into two groups: High-Fidelity SBME versus No Intervention comparison (two groups randomized where one group uses SBME and the other has usual or traditional teaching) or High-Fidelity SBME versus Low-Fidelity SBME (two or more groups randomized where each group is using a different form of SBME).

Corresponding authors were contacted if data were missing. Data were analyzed using Review Manager Version 5.3 (Cochrane Collaboration, Oxford, UK). Results were expressed as standardized mean difference (SMD) and standard deviations (SD). For continuous outcomes, SMD was chosen due to the fact that knowledge and skills were being measured on differing scales in the RCTs. A p-value < 0.05 (95% confidence interval [CI]) was considered to be statistically significant. Heterogeneity was measured using the I^2 score. A random-effects model was used throughout to allow meta-analysis.

Assessment of risk of bias and study quality

Th risk of bias was assessed using the Cochrane 'Risk of Bias' tool [27]. The methodological quality of each study was assessed using the Medical Education Research Study Quality Instrument (MERSQI), with low-quality studies scoring (MERSQI < 12) [28].

Results

Overview of studies identified

The literature search demonstrated by the PRISMA diagram (Figure 1) initially generated n = 1025 studies, with full article review performed for n = 44 studies and n = 17 met inclusion criteria and were included in this review. Table 2 presents the summary of the included studies.

Twelve RCTs compared high-fidelity SBME with no intervention and five RCTs compared high-fidelity SBME with low-fidelity SBME.

High-fidelity SBME interventions studied

Several different high-fidelity simulators were used in these studies. The most commonly used simulator interventions were:

- Four RCTs used Harvey® (Laerdal Medical, Miami, FL, USA) [23,29–31]
- Three RCTs used Nasco auscultation technology™ [32–34]

The following simulators were all used in one RCT each:

- CardioSIM® Auscultation System [24]
- CPS 'K' [35]
- Heart Sim II® [Atlantic Medical Systems Inc.] [36]
- Infant Baby SIM and Child PediaSIM [Medical Education Technologies Inc.] [37]
- MedSim® Eagle SIM [38]
- SAM® [Cardionics Inc., Texas, United States] [39]
- VitalSIMKelly [40]

Three RCTs did not specify which specific heart sound simulator they used [41–43].

Findings of this review

High-fidelity SBME versus no intervention

a) Knowledge

Six RCTs assessed knowledge outcomes [33,37–40,42] in 307 learners (n = 157 in SBME vs. n = 150 in no intervention group). Meta-analysis produced a statistically significant difference in knowledge acquisition favouring the high-fidelity SBME group, with pooled effect size of 1.39 (95% CI, 0.39–2.38; p = 0.006; I^2 = 92%; Figure 2).

b) Skills

Five RCTs assessed skills outcomes [24,30,35,36,41] in 236 learners (n = 125 in SBME vs. n = 111 in no intervention group) and were included in the meta-analysis. There was no statistical difference between the groups (−0.28; 95%CI, −1.49 to 0.93; p = 0.65; I^2 = 94%; Figure 2).

Four RCTs [31,32,41,43] were not included in the meta-analysis as they did not report standard deviations or they reported outcomes as a number and percentage. Birdane *et al.* [32] reported that learners who underwent SBME demonstrated significantly greater accuracy in identifying a range of important clinical murmurs than learners who did not. Oddone *et al.* [31] reported that SBME was effective in improving learners' ability to diagnose mitral stenosis compared with no supplemental teaching (15% improvement vs. 0% improvement). Penta and Kofman [41] reported that time spent with

Figure 1: PRISMA trial flow.

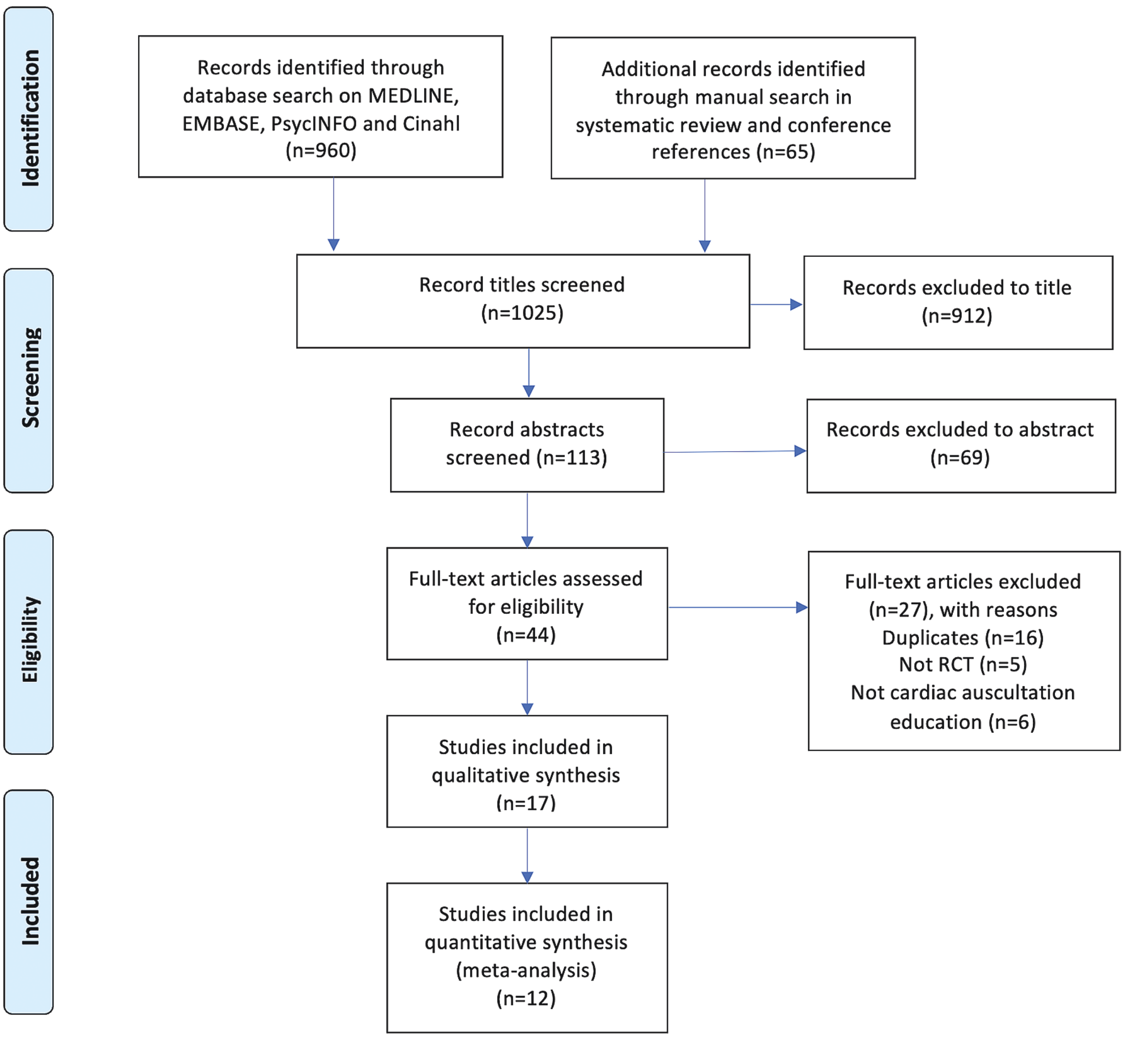


Table 2: Included RCTs

Study (Author, year)	Participants	Intervention vs. Comparison	Outcomes and Assessment	MS*
No Intervention comparison RCTs (12)				
Birdane 2012	130 Year-5 medical students	Nasco auscultation trainer and smartscope™) (2 h) vs. routine theoretical and practical internship training	Knowledge Diagnosing real patients' heart sounds on the ward, including MR, MS, PS, AR and VSD	11.5
Catumbela 2017	117 Year-3 medical students	Nasco auscultation trainer and smartscope™ (6 h) vs. traditional ward-based teaching	Knowledge Identifying murmurs in real patients in cardiology ward	11.5
Gauthier 2017	32 Year-1 medical students	Harvey® CPS (1 h) vs. standardized patient teaching	Skills + Satisfaction OSCE performance on ability to perform cardiac examination + Satisfaction questionnaire	11.5
Kronschnabl 2021	70 Year-3 medical students	CPS 'K' (75 m) vs. no supplemental teaching	Skills Cardiac examination of volunteer	14.5
Martinez 2012	32 Year-5 medical students + 18 medical residents	SAM® CPS (2 h) vs. routine training	Knowledge Identifying 8 simulated heart sounds	11.5
Oddone 1993	56 Medical residents	Harvey® CPS (8 h) incorporated into curriculum vs. no supplemental teaching	Skills Cardiac examination of 3 real patients	12.5
Penta 1973	30 Medical students	CPS (4.5 h) incorporated into curriculum vs. no supplemental teaching	Skills Cardiac examination of 6 simulated scenarios	11.5
Scherer 2007	23 Nurse practitioner students	MedSim® Eagle SM (0.5 h) vs. Seminar and case study teaching	Knowledge Short Answer Question Test	11.5
Sverdrup 2010	49 Year-3 medical students	CardioSim® Auscultation System (4 h) vs. bedside teaching	Skills OSCE Performance	11.5
Tiffen 2011	29 Nursing students	VitalSIMKelly CPS (1 h) incorporated into curriculum vs. no supplemental teaching	Knowledge + Satisfaction Written knowledge test + Satisfaction questionnaire	14.5
Tuzer 2016	52 Year-4 nursing students	High-fidelity simulator vs. standardized patient teaching	Knowledge + Skills Knowledge test + OSCE performance	12.5
Vural Dogru 2020	72 Year-1 nursing students	High-fidelity simulator vs. 'traditional teaching method'	Knowledge + Skills Written knowledge test + OSCE performance	14.5
SBME comparison RCTs (5)				
Champagne 1989	37 Nurse practitioners	Heart Sim II [Atlantic Medical Systems Inc.] (0.5 h) with and without palpation	Knowledge Identifying 20 heart sounds	15.5
Chen 2015	60 Nursing students	Infant BabySIM + Child PediaSIM, Medical Education Technologies Inc. (0.5 h) vs. Heart sounds only	Knowledge + Skills Identifying 20 heart sounds + Likert scale	11.5
De Giovanni 2009	37 Year-3 medical students	Harvey® CPS (3 h) vs. CD of recorded sounds	Skills Cardiac examination in 5 real patients	14.5
Fraser 2011	86 Year-1 medical students	Harvey® CPS (2 h) MR teaching vs. SBME without murmur teaching	Skills Cardiac examination in MR patients	11.5
Friederichs 2014	143 Pre-clinical medical students	(Life/form Auscultation Trainer and Smartscope, Nasco) (0.5 h) vs. hybrid models	Satisfaction Satisfaction questionnaire	11

*MS = MERSQI Score [28]
AR – aortic regurgitation, MR – mitral regurgitation, OSCE – Observed Structured Clinical Examination, PS – pulmonary stenosis, VSD – ventricular septal defect

a high-fidelity SBME modality positively correlated with greater skills acquisition amongst learners. Vural Dogru and Zengin Aydin [43] found that median scores for students' knowledge (p = 0.001) and skills (p < 0.001) were significantly better when taught by a high-fidelity simulator method than with the traditional teaching method.

c) Satisfaction

Two RCTs [30,40] assessed satisfaction outcomes in 61 learners (n = 31 in SBME vs. n = 30 in no intervention group). Both RCTs found that satisfaction relating to SBME for cardiac auscultation was positive and better in the SBME group compared with the no intervention group. There were no standard deviations reported so meta-analyses could not be performed.

High-fidelity SBME versus low-fidelity SBME

a) Knowledge

Two RCTs [36,37] compared the effects of high-fidelity SBME versus low-fidelity SBME in a total of 81 learners (n = 38 in high-fidelity SBME vs. n = 43 in low-fidelity SBME group). Meta-analysis showed no significant difference between the two groups and was in favour of low-fidelity SBME (−0.73; 95% CI, −1.99 to 0.53; p = 0.26; I^2 = 86%; Figure 3).

b) Skills

Three RCTs assessed skills outcomes [23,29,37] in 135 learners (n = 64 in high-fidelity SBME vs. n = 71 in another active teaching intervention using SBME group). There was no significant difference between the two groups (0.32, 95% CI −0.75 to 1.39; p = 0.56; I^2 = 89%; Figure 3).

c) Satisfaction

One RCT compared two forms of SBME with satisfaction as an outcome. Friederichs *et al.* [34] compared hybrid SBME (hybrid models involve a human being that was electronically outfitted to produce pathological heart sounds with hardware and software chips) versus use of mannequins only. Learners reported a better satisfaction with the simulator in the hybrid SBME group when compared with the high-fidelity SBME only group (83% vs. 64%). The reported overall benefit scores on a student questionnaire were not significantly different (88% vs. 87%). As only one RCT reported a satisfactory outcome for this comparison, meta-analysis was not possible.

Heterogeneity

No studies were excluded on the basis of methodological heterogeneity. There was high degree (I^2 > 75%) of statistical heterogeneity in both assessed outcomes (knowledge and skills). Therefore, a random-effects model was used.

Risk of bias

The risk of bias was assessed using the Cochrane Collaboration's RoB tool [27]. Most RCTs had good blinding of the assessor collecting the outcome and in reporting selection bias. However, reporting of random sequence generation, allocation concealment and blinding of participants were generally poor (Figure 4a and b).

Discussion

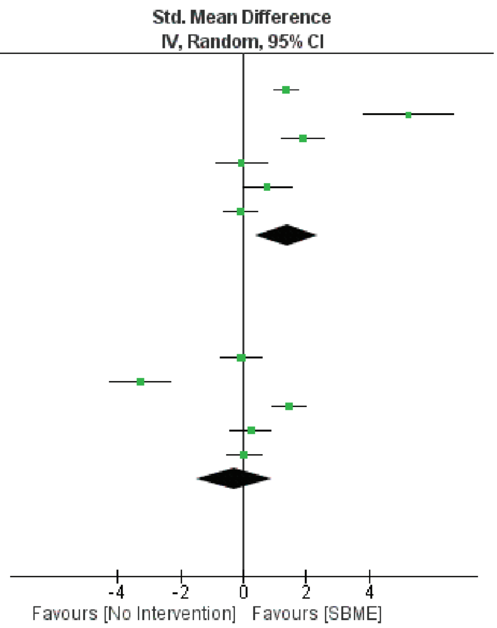
The results of this review provide evidence to support high-fidelity SBME as an effective instructional approach to cardiac auscultation teaching compared with no intervention. However, the effectiveness is comparable with low-fidelity SBME.

High-fidelity SBME versus no intervention

Knowledge acquisition amongst learners was significantly better with high-fidelity SBME compared with no

Figure 2: Knowledge and skill outcomes comparing high fidelity SBME and no intervention.

	High-fidelity SBME			No Intervention				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.1.1 Knowledge								
Catambela 2017	3.16	0.62	58	2.15	0.84	59	18.1%	1.36 [0.95, 1.76]
Chen 2015	46.79	2.55	21	32.5	2.77	16	13.5%	5.28 [3.85, 6.71]
Martinez 2012	5.84	1.28	25	3.32	1.35	25	17.2%	1.89 [1.21, 2.56]
Scherer 2007	12.79	1.5	13	12.9	2.1	10	16.6%	-0.06 [-0.88, 0.77]
Tiffen 2011	7.36	1.15	14	6.21	1.72	14	16.8%	0.76 [-0.01, 1.53]
Tuzer 2016	72.79	9.13	26	73.8	11.28	26	17.7%	-0.10 [-0.64, 0.45]
Subtotal (95% CI)			**157**			**150**	**100.0%**	**1.39 [0.39, 2.38]**
Heterogeneity: Tau² = 1.39; Chi² = 66.34, df = 5 (P < 0.00001); I² = 92%								
Test for overall effect: Z = 2.72 (P = 0.006)								
1.1.2 Skills								
Chen 2015	3.4	0.29	21	3.42	0.31	16	20.1%	-0.07 [-0.72, 0.59]
Gauthier 2017	57.2	1.51	20	62.2	1.46	20	18.7%	-3.30 [-4.28, -2.32]
Kronschnabl 2021	17.03	3.01	37	11.82	4.04	33	20.5%	1.46 [0.93, 1.99]
Sverdrup 2010	11.4	5.1	21	10.3	3.6	16	20.1%	0.24 [-0.41, 0.89]
Tuzer 2016	90.23	9.02	26	90.08	8.63	26	20.5%	0.02 [-0.53, 0.56]
Subtotal (95% CI)			**125**			**111**	**100.0%**	**-0.28 [-1.49, 0.93]**
Heterogeneity: Tau² = 1.79; Chi² = 71.43, df = 4 (P < 0.00001); I² = 94%								
Test for overall effect: Z = 0.45 (P = 0.65)								



intervention or usual teaching. These results agree with two other systematic reviews which suggest that SBME training increases clinical knowledge [21,22].

Butter *et al.* [44] compared third-year students who had been trained with high-fidelity SBME against untrained fourth-year students. The high-fidelity SBME-trained group demonstrated significantly greater knowledge of simulated heart sounds (93% vs. 73.9%; $p < 0.001$) and heart sounds in real patients (81.8% vs. 75.1%, $p = 0.003$). In a single-group study, Perlini *et al.* [45] compared final-year medical students before and after SBME-based training. Their work found significant improvement in the students' knowledge after SBME-based training (72% vs. 11% baseline; $p < 0.001$).

There was insufficient evidence to support SBME over no intervention in skills acquisition, which also agrees with McKinney *et al.* [46], possibly because of the low number of RCTs in this field. Skill improvement may also require more time to reach a significant difference [41]. RCTs in this review measured skills with OSCE performance, whereas knowledge was tested with written test scores. Skills required to do well in an OSCE setting are more complex than simply knowledge of heart sounds. Learners need to be trained to interact with a patient, communicate and show respectful professionalism while examining the correct anatomical areas and identifying any heart sounds. Time spent with the simulators ranged from 0.5 to 4.5 hours. More practice may be required in order to show a difference between SBME and usual teaching for skills transfer. In contrast, a test score only requires knowledge of the murmur. This is a huge advantage for SBME over usual teaching. Once learners hear a murmur on a high-fidelity simulator, they are more likely to retain knowledge regarding it, especially if they have not had the opportunity to hear this in opportunistic bedside teaching [10,16].

Kern *et al.* [47] found that there was a significant improvement in cardiac auscultation technique (85% vs. 71%; $p = 0.003$) within an academic year where students had SBME teaching compared with previous academic years where SBME was not taught. Interestingly, the students only had 50 minutes of contact with the simulator. However, these cohort studies have the added advantage that they assess students in summative examinations contributing to their overall degree. Therefore, the students' exam performance may be more reliable as they have a greater motivation to demonstrate the full potential of their learning [48]. RCT designs cannot ethically test students in a summative examination as they are not being treated equally. Therefore, RCTs often recruit their students on a voluntary basis, and the outcome measurements (OSCEs/tests) are formative.

In this review, participants' satisfaction was assessed in few RCTs but suggested that learners are highly satisfied with high-fidelity SBME compared with standard methods or no intervention. Participant-orientated satisfaction is an important aspect of any educational interventional process as learner engagement is key to achieving curricular outcomes through different educational approaches. Satisfaction can come from the novelty factor if students have not used a simulator before. By the same token, increased enjoyability can improve learning [26].

Gauthier *et al.* [30] reported students' feedback was that SBME offered superior clinical findings compared with the use of standardized patients. It was noteworthy that 68.8% of students who had SBME training requested that they had a combination of SBME and standardized patients in future learning. Several studies remind the reader that SBME should act to supplement clinical teaching with real or volunteer patients rather than aim to replace it.

Scherer *et al.* [39] reported students' feedback was that SBME allowed them to problem solve in a critical scenario without the stress of treating a real patient. Many stated that the experience helped them to gain more confidence in decision making in clinical practice.

High-fidelity SBME versus low-fidelity SBME

Our review shows no significant difference between the effectiveness of high-fidelity SBME and low-fidelity SBME. This could be crucial information for health education directors, as high-fidelity SBME being a more expensive teaching method compared with low-fidelity SBME.

Investigating this further could help training institutions save money by choosing the cheaper option of low-fidelity SBME in order to achieve similar learning outcomes. An

Figure 3: Knowledge and skill outcomes comparing high and low fidelity SBME.

	High-fidelity SBME			Low-fidelity SBME				Std. Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI
1.2.1 Knowledge								
Champagne 1989	42.4	6	17	43	7.4	20	50.2%	-0.09 [-0.73, 0.56]
Chen 2015	42.86	5.22	21	51.19	6.56	23	49.8%	-1.37 [-2.04, -0.71]
Subtotal (95% CI)			**38**			**43**	**100.0%**	**-0.73 [-1.99, 0.53]**
Heterogeneity: Tau² = 0.72; Chi² = 7.40, df = 1 (P = 0.007); I² = 86%								
Test for overall effect: Z = 1.13 (P = 0.26)								
1.2.2 Skills								
Chen 2015	3.4	0.29	21	3.6	0.26	23	33.4%	-0.72 [-1.33, -0.10]
De Giovanni 2009	3.11	0.9	18	2.47	1.12	19	32.8%	0.61 [-0.05, 1.28]
Fraser 2011	74	36.4	25	36.8	33.1	29	33.8%	1.06 [0.48, 1.63]
Subtotal (95% CI)			**64**			**71**	**100.0%**	**0.32 [-0.75, 1.39]**
Heterogeneity: Tau² = 0.79; Chi² = 18.09, df = 2 (P = 0.0001); I² = 89%								
Test for overall effect: Z = 0.59 (P = 0.56)								

38

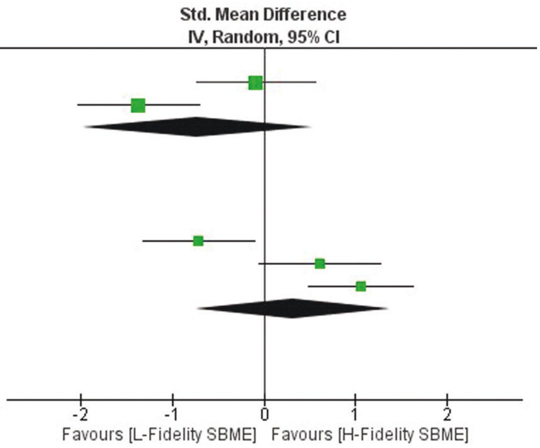


Figure 4: Risk of bias tables for all included studies.

Low risk of bias (+)
Unclear risk of bias (?)
High risk of bias (−)

	Birdane 2012	Catambela 2017	Champagne 1989	Chen 2015	De Giovanni 2009	Fraser 2011	Friederichs 2014	Gauthier 2017	Kronschnabl 2021	Martinez 2012	Oddone 1993	Penta 1973	Scherer 2007	Sverdrup 2010	Tiffen 2011	Tuzer 2016	Vural Dogru 2020
Random sequence generation (selection bias)	+	?	?	?	?	+	?	?	+	?	?	?	?	?	?	?	?
Allocation concealment (selection bias)	?	?	?	?	?	+	−	?	+	?	+	−	?	−	?	−	+
Blinding of participants and personnel (performance bias)	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
Blinding of outcome assessment (detection bias)	+	?	+	+	+	+	−	?	+	+	?	+	+	+	+	?	?
Incomplete outcome data (attrition bias)	+	?	+	+	+	+	+	?	+	+	+	−	+	+	+	+	+
Selective reporting (reporting bias)	+	?	+	+	+	+	+	?	+	+	+	−	+	+	+	+	+
Similarity of baseline characteristics	?	?	+	?	+	+	?	+	+	+	?	−	?	?	+	?	+

additional financial benefit from SBME may be the costs avoided through students making fewer errors in clinical practice. Benefits like these can be monetized and, therefore, included in a cost-effectiveness analysis. More difficult benefits to summate would include higher patient-centred care, increased empathy and an increased knowledge of relevant skills in the clinical environment [49].

The available data we have suggest that there is no significant advantage with high-fidelity SBME. Due to cost and staff availability issues, using SBME strategically is important to undergraduate and postgraduate health professional course directors.

The analyzed data for this review provide practical suggestions for educators. Firstly, integration may not be essential, converse to conclusions of existing literature [4]. In addition, time spent with simulators may be important in the transfer of the skills learnt.

Friederichs *et al.* [34] reported that feedback from tutors, simulated patients and students was all positive with hybrid simulation, i.e. SBME and volunteer patient combined. Students reported a higher level of attention and seriousness during the class that was taught with the hybrid model than in the group taught with auscultation manikins. The standardized patients also responded positively and 'felt accepted and respected'. This positive verbal feedback was reflected by satisfaction questionnaires.

Low-fidelity SBME versus no intervention

Although it would be useful to compare the effectiveness of low-fidelity SBME against no intervention, there is a gap in the literature regarding this comparison. The only one RCT included to compare these modalities was Chen *et al.* [37] who found that low-fidelity SBME significantly improved knowledge compared with no intervention, but not the improvement skills in cardiac auscultation. However, this included a small number of participants.

Recommendations for future research

There are evidently a small number of high-quality RCTs looking into the effectiveness of SBME in cardiac auscultation teaching – a topic that should be of high interest to healthcare educators and learners. This has been highlighted by the Covid-19 pandemic, which resulted in increased pressure on senior clinicians and reduced elective presentations for students to seek exposure to. SBME is an effective modality in teaching students' clinical skills including cardiac auscultation that will not take precedence in medical emergencies such as respiratory failure and cardiac arrest [50]. Ideally, future RCTs would be multi-institutional, have large sample sizes and allow more powerful statistical analysis.

Future studies should focus on comparing key instructional design features either between simulations or comparing different types of SBME to another educational modality, using rigorous and reproducible outcome measures. Assessing diagnostic skills in real clinical practice is the desired outcome to elucidate the best practices for this expensive resource.

Strengths and limitations

This systematic review and meta-analysis assimilate the available literature regarding the effectiveness of high-fidelity SBME in cardiac auscultation training for healthcare professionals within RCTs. The highest level of evidence (Level 1) is obtained from a systematic review of RCTs because it allows comparison of an intervention group with a non-intervention group, which represents the population under investigation [27]. It also avoids inevitable bias in observational and non-randomized clinical trials. This review was conducted in accordance with PRISMA guidelines [25]. The search strategy was comprehensive and thorough, including various databases and manual searches within relevant conferences. In addition, there was no language restriction, allowing the inclusion of all available trials worldwide. Studies reviewed were conducted in different countries (Angola, Canada, Chile, Germany, Norway, Turkey, United Kingdom and the United States); therefore, findings could be extrapolated. Authors of all included studies were contacted for any missing data. Data were methodically extracted using a custom-designed form, and meta-analysis was only undertaken where appropriate to generate summaries. The risk of bias was assessed using the standard Cochrane Collaboration's risk of bias assessment tool, which helped to facilitate the estimation of the true effectiveness of the interventions [27].

This review is primarily limited by the low number of published RCTs. In addition, RCTs that were found had small sample sizes. Therefore, the statistical power of our meta-analyses was limited. To overcome this, all available conference abstracts/unpublished RCTs were included. In the case of missing data, authors were contacted to obtain the required data. Heterogeneity between studies was high as they examined different populations, so a random-effects model was used.

Conclusions

This systematic review and meta-analysis showed that high-fidelity SBME is an effective teaching method for cardiac auscultation education. SBME significantly increases learners' knowledge and obtains better skills and satisfaction relating to cardiac auscultation education than no intervention. Interestingly, there was no significant difference in knowledge or skills among learners when comparing high-fidelity simulation to low-fidelity simulation. Further high-quality research is needed to establish the effectiveness of different forms of SBME as educational interventions to enhance the teaching of cardiac examination for different healthcare learners.

Declarations

Authors' contributions

Dr Craig Osborne – development of the idea, literature search, study screening, data collection, data analysis, quality of study assessment, writing–up and submission.
Dr Craig Brown – discuss the project idea, review and edit the manuscript.
Dr Alyaa Mostafa – create and developed the idea of the project, double check the literature search and data collection, review the analysis, edit and final approval of the manuscript.

Funding

None.

Availability of data and materials

None.

Ethics approval and consent to participate

None declared.

Competing interests

None declared.

References

1. Dolara A. The decline of cardiac auscultation. The ball of the match point is poised on the net. Journal of Cardiovascular Medicine. 2008 Nov 1;9(11):1173–1174.
2. Shaver J. Cardiac auscultation: a cost-effective diagnostic skill. Current Problems in Cardiology. 1995 Jul 1;20(7):441–530.
3. Ramani S, Ring B, Lowe, R, Hunter D. A pilot study assessing knowledge of clinical signs and physical examination skills in incoming medicine residents. Journal of Graduate Medical Education. 2010 Jul 1;2(2):232–235.
4. Issenberg S, McGaghie W, Petrusa E, Lee G, Scalese R. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. Medical Teacher. 2005 Feb 1;27(1):10–28.
5. McGaghie W, Issenberg S, Petrusa E, Scalese R. A critical review of simulation-based medical education research: 2003–2009. Medical Education. 2010 Jan 1;44(1):50–63.
6. Crofts J, Ellis D, Draycott T, Winter C, Hunt L, Akande V. Change in knowledge of midwives and obstetricians following obstetric emergencies: a randomised controlled trial of local hospital, simulation centre and teamwork training. BJOG. 2008 Sep 1;114(12):1534–1541.
7. Hinde T, Gale T, Anderson I, Roberts M, Sice P. A study to assess the influence of Interprofessional point of care simulation training on safety culture in the operating theatre environment of a university teaching hospital. Journal of Interprofessional Care. 2016 Feb 6;30(2):251–253.
8. Miller D, Crandall C, Washington C, McLaughlin S. Improving teamwork and communication in trauma care through in situ simulations. Academic Emergency Medicine. 2012 May 1;19(5):608–612.
9. Beaubein J, Baker D. The use of simulation for training teamwork skills in health care: how low can you go? Quality and Safety in Healthcare. 2004 Oct 1;13(1):51–56.
10. Al-Elq A. Simulation-based medical teaching and learning. Journal of Family and Community Medicine. 2010 Jan 1;17(1):35–40.
11. Weaver A. High-fidelity patient simulation in nursing education: an integrative review. Nurse Education Perspectives. 2011 Jan 1;32(1):37–40.
12. Bambini D, Washburn J, Perkins R. Outcomes of clinical simulation for novice nursing students: communication, confidence, clinical judgment. Nurse Education Perspectives. 2009 Mar 1;30(2):79–82.
13. Blum C, Borglund S, Parcells D. High-fidelity nursing simulation: impact on student self-confidence and clinical competence. International Journal of Nursing Education Scholarship. 2010 Jan 1;7:Article 18.
14. Fountain R, Alfred D. Student satisfaction with high-fidelity simulation: does it correlate with learning styles? Nurse Education Perspectives. 2009 Mar 1;30(2):96–98.
15. Nehring W. U.S. boards of nursing and the use of high-fidelity patient simulators in nursing education. Journal of Professional Nursing. 2008 Mar 1;24(2):109–117.
16. Gordon M, Ewy G, Felner J, Forker A, Gessner I, McGuire C. Teaching bedside cardiologic examination skills using 'Harvey', the cardiology patient simulator. Medical Clinics of North America. 1980 Mar 1;64(2):305–313.
17. Buck G. Development of simulators in medical education. Gesnerus. 1991 Jan 1;48(1):7–28.
18. Cooper J, Taqueti V. A brief history of the development of mannequin simulators for clinical education and training. Quality and Safety in Healthcare. 2004 Oct 1;13(1):11–18.
19. Lewis R, Strachan A, McKenzie SM. Is high fidelity simulation the most effective method for the development of non-technical skills in nursing? A review of the current evidence. Open Nursing Journal. 2012 Jul 27;6(1):82–89.
20. Zapko K, Ferranto M, Blasiman R, Shelestak D. Evaluating best educational practices, student satisfaction and self-satisfaction in simulation: a descriptive study. Nurse Education Today. 2018 Jan 1;60(1):28–34.
21. Cook D, Brydges R, Zendejas B, Hamstra S, Hatala R. Technology-enhanced simulation to assess health professionals: a systematic review of validity evidence, research methods, and reporting quality. Academic Medicine. 2013 Jun 1;88(6):872–883.

22. McGaghie W, Issenberg B, Cohen E, Barsuk J, Wayne D. Does simulation-based medical education with deliberate practice yield better results than traditional clinical education? A meta-analytic comparative review of the evidence. Academic Medicine. 2011 Jun 1;86(6):706–711.
23. De Giovanni D, Roberts T, Norman G. Relative effectiveness of high- versus low-fidelity simulation in learning heart sounds. Medical Education. 2009 Jul 1;43(7):661–668.
24. Sverdrup Ø, Jensen T, Solheim S, Gjesdal K. Training auscultatory skills: computer simulated heart sounds or additional bedside training? A randomized trial on third-year medical students. BMC Medical Education. 2010 Jan 18;10:3.
25. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. British Medical Journal. 2009 Jul 21;339(1):2535.
26. Sockalingam N. The relation between student satisfaction and student performance in blended learning curricula. International Journal of Learning. 2012 Jan 1;18(12):121–134.
27. Higgins J, Green S. Cochrane handbook for systematic reviews of interventions. The Cochrane Collaboration and John Wiley & Sons Ltd. Available from: https://www.radioterapiaitalia.it/wpcontent/uploads/2017/01/cochrane-handbook-for-systematic-reviews-of-interventions.pdf [Accessed 14 February 2019.]
28. Reed D, Beckman T, Wright S, et al. Predictive validity evidence for medical education research study quality instrument scores: quality of submissions to JGIM's medical education special issue. Journal of General Internal Medicine. 2008 Jul 10;23(7):903–907.
29. Fraser K, Wright B, Girard L, Tworek J, Paget M, Welikovich L. Simulation training improves diagnostic performance on a real patient with similar clinical findings. Chest. 2011 Feb 1;139(2):376–381.
30. Gauthier N, Johnson C, Keenan M, et al. Does cardiac physical exam teaching using a cardiac simulator improve medical students' diagnostic skills? Canadian Journal of Cardiology. 2017 Oct 1;33(10):44–45.
31. Oddone E, Waugh R, Samsa G, Corey R, Feussner J. Teaching cardiovascular examination skills: results from a randomized controlled trial. American Journal of Medicine. 1993 Oct 1;95(4):389–396.
32. Birdane A, Yazici H, Aydar Y, et al. Effectiveness of cardiac simulator on the acquirement of cardiac auscultatory skills of medical students. Advances in Clinical and Experimental Medicine. 2012 Nov 1;21(6):791–798.
33. Catumbela E, Nunes R, Napato A, et al. Evaluation of the efficacy of training in cardiac auscultation in medical students at the Agostinho Neto University. SESAM Conference, Bilbao, 2018. Available from: https://advancesinsimulation.biomedcentral.com/articles/10.1186/s41077-018-0066-5 [Accessed 17 January 2019.]
34. Friederichs H, Weissenstein A, Ligges S, Möller D, Becker J, Marschall B. Combining simulated patients and simulators: pilot study of hybrid simulation in teaching cardiac auscultation. Advanced Physiology Education. 2014 Dec 1;38(1):343–347.
35. Kronschnabl D, Baerwald C, Rotzoll D. Evaluating the effectiveness of a structured, simulator-assisted, peer-led training on cardiovascular physical examination in third-year medical students: a prospective, randomized, controlled trial. GMS Journal For Medical Education. 2021 Sep 15;38(6)Doc108.
36. Champagne M, Harrell J, Friedman B. Use of a heart sound simulator in teaching cardiac auscultation. Focus on Critical Care. 1989 Dec 1;6(6):448–456.
37. Chen R, Grierson L, Norman G. Evaluating the impact of high- and low-fidelity instruction in the development of auscultation skills. Medical Education. 2015 Feb 18;49:276–285.
38. Scherer Y, Bruce S, Runkawatt V. A comparison of clinical simulation and case study presentation on nurse practitioner students' knowledge and confidence in managing a cardiac event. International Journal of Nursing Education Scholarship. 2007 Nov 21;4(1).
39. Martínez G, Guarda E, Baeza R, Garayar B, Chamorro G, Casanegra P. A heart sound simulator as an effective aid in teaching cardiac auscultation to medical students and internal medicine residents. Revista Española de Cardiología. 2012 Dec 1;65(12):1135–1136.
40. Tiffen J, Corbridge S, Robinson P. Patient simulator for teaching heart and lung assessment skills to advanced practice nursing students. Clinical Simulation in Nursing. 2011 May 1;7(3):91–97.
41. Penta F, Kofman S. The effectiveness of simulation devices in teaching selected skills of physical diagnosis. Medical Education. 1973 May 1;48(5):442–445.
42. Tuzer H, Dinc L, Elcin M. The effects of using high-fidelity simulators and standardized patients on the thorax, lung, and cardiac examination skills of undergraduate nursing students. Nurse Education Today. 2016 Oct 1;45:120–125.
43. Vural Dogru B, Zengin Aydin L. The effects of training with simulation on knowledge, skill and anxiety levels of the nursing students in terms of cardiac auscultation: a randomized controlled study. Nurse Education Today. 2020 Jan 1;84(1):104216.
44. Butter J, McGaghie W, Cohen E, Kaye M, Wayne D. Simulation-based mastery learning improves cardiac auscultation skills in medical students. Journal of General Internal Medicine. 2010 Mar 26;25(8):780–785.
45. Perlini S, Salinaro F, Santalucia P, Musca F. Simulation-guided cardiac auscultation improves medical students' clinical skills: the Pavia pilot experience. Internal and Emergency Medicine. 2014 Mar 1;9(2):165–172.
46. McKinney J, Cook D, Wood D, Hatala R. Simulation-based training for cardiac auscultation skills: systematic review and meta-analysis. Journal of Internal Medicine. 2013 Feb 1;28(2):283–291.
47. Kern D, Mainous A, Carey M, et al. Simulation-based teaching to improve cardiovascular exam skills performance among third-year medical students. Teaching and Learning in Medicine. 2011 Feb 12;23(1):15–20.
48. Cilliers F, Schuwirth L, Adendorff H, Herman N, Van Der Vleuten C. The mechanism of impact of summative assessment on medical students' learning. Advances in Health Science Education. 2010 May 9;15(5):695–715.
49. Maloney S, Haines T. Issues of cost-benefit and cost-effectiveness for simulation in health professions education. Advances in Simulation. 2016 May 17;1(13).
50. Pandey P. Pandemic highlighted the need for simulation-based medical education. Education Times. Posted on 15 February 2021. Available from: educationtimes.com [Accessed 20 February 2021.]