

The Use of Simulation-Based Learning in Cardiology Education: A Systematic Review

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Abstract

The use of simulation in medical education is now a well-established practice. Many articles currently explore various simulation methods and the impacts reported by students. In cardiology, this is no exception; however, reviews on the topic do not focus on a specific area.

The objective of this study was to evaluate the existing evidence on the use of simulation in medical education, with a specific focus on cardiology.

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and searched the Ovid MEDLINE, Literatura Latino-Americana e do Caribe em Ciências da Saúde (LILACS), CINAHL, and CENTRAL databases. Clinical trials reporting the use of realistic simulation for teaching cardiology were included. Two independent reviewers assessed the studies for eligibility. The simulation methods and topics, along with their evaluations, were analyzed.

A total of 435 articles were initially identified based on the search criteria. Seven articles were selected for detailed analysis. Three of these studies reported an improvement in cardiac auscultation skills through simulation. One study showed improved ability to recognize coronary anatomy; another demonstrated enhanced performance during catheterization, and one highlighted better outcomes during angioplasty. Only one study showed a slight improvement in the diagnosis of acute myocardial infarction. In addition to these clinical improvements, there was also a noted increase in student engagement and satisfaction.

Realistic simulation, when integrated as a complement to existing curricula, enhances the performance of cardiology students.

Keywords

Simulation Training; Medicine; Cardiology; Medical Education

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Introduction

Teaching and learning technologies are increasingly sought after and promoted in higher education. Among the innovative options is simulation.¹ Simulation provides students with the opportunity to engage in complex clinical scenarios in a safe and controlled setting. Additionally, it facilitates the development of technical and communication skills, as well as the practice of clinical decision-making and teamwork.^{1,2} By offering a realistic learning environment, simulation complements traditional clinical practice and enhances the training of future doctors.³

Through simulation, students can acquire and improve technical skills, such as clinical procedures, handling medical equipment, and surgical skills.^{4,5} In addition, they have the opportunity to practice effective communication with patients and their families, developing essential skills for medical practice.⁶ Some studies indicate that, within cardiology, the use of simulation increases student adherence and satisfaction, which are key indicators of engagement and acceptance of educational methods in this field. This evidence can lead to improvements in students' skills and competence, both in undergraduate and postgraduate courses.^{7,8}

By practicing procedures and making clinical decisions in a simulated environment, students can make mistakes and learn from them without putting patients at risk.⁹ In addition to the educational advantages, simulation also offers benefits for patient safety. Despite these advantages, the use of simulation requires qualified instructors and time for planning and conducting the sessions, which can be an obstacle.^{10,11} However, these challenges can be overcome with proper planning and investment in infrastructure.¹² In cardiology, for example, there are specific simulators for cardiac auscultation, coronary anatomy, and performing invasive procedures. Therefore, the aim of this study was to evaluate the available evidence on the use of simulation in medical education in comparison to traditional teaching methods, specifically within the context of cardiology education.

Methods

Type of study and registration

This systematic review was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).¹³ It is registered with the International Prospective Register of Systematic Reviews (PROSPERO) under registration number CRD42023423174.

Central Illustration: The Use of Simulation-Based Learning in Cardiology Education: A Systematic Review**Technical skills**

- ↑ Cardiac auscultation skills
- ↑ Recognition of coronary anatomy
- ↑ Performance in catheterization and angioplasty

Student engagement

- ↑ Student adherence to activities
- ↑ Satisfaction with the learning process

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*Evidence on simulation in medical education.***Eligibility criteria**

To conduct this systematic review, the PICOS¹⁴ strategy was applied. The population studied consisted of medical students, and the intervention involved simulation-based teaching, compared to other teaching-learning methods. The outcomes assessed were cardiac auscultation ability, recognition of coronary anatomy, skills during catheterization and angioplasty, diagnosis of acute myocardial infarction, as well as student adherence and satisfaction. Randomized clinical trials were included, with no restrictions on language or publication year. Randomized clinical trials focusing on the use of simulation-based learning were eligible for inclusion. For a study to be eligible, it had to involve medical students using simulation for teaching and learning. Studies with adults (18 years or older), regardless of gender, were also considered. Simulation-based learning is an educational approach that utilizes simulations to facilitate the acquisition of knowledge, skills, and attitudes within a controlled and safe environment that mimics real-life situations. This methodology allows learners to practice and apply their knowledge in simulated scenarios, where they can make mistakes without serious consequences, thus promoting active learning and reflection on practice.¹⁵ Exclusion criteria included studies with insufficient data and pilot studies.

Sources of information

We conducted a search in the Literatura Latino-Americana e do Caribe em Ciências da Saúde (LILACS)

through the Regional Portal of the Virtual Health Library, the Cumulative Index to Nursing and Allied Health (CINAHL) via the Portal de Periódicos da Capes, MEDLINE/PubMed, and the Cochrane Central Register of Systematic Reviews on July 22, 2023. Additionally, we searched the reference lists of previous systematic reviews and eligible clinical trials for inclusion in this review. The search for articles was concluded in December 2023.

Search

The search was conducted using the previously described PICOS strategy and Boolean operators AND and OR. The descriptors used for the population included: Enrollment, School, Enrollments, School Enrollment, School Enrollments, Student, Students, Medical, Physicians, Physician, Cardiovascular Disease Specialty, Disease Specialty, Cardiovascular, Specialty, Cardiovascular Disease, and Cardiology. For the intervention, we used the following terms: Malingering, Simulation Exercise, Feint, Simulacrum, Simulation (Technique), Simulation Training, Interactive Learning, Learning, Interactive, and Training. We focused on the following outcomes: cardiac auscultation ability, recognition of coronary anatomy, skills during catheterization and angioplasty, diagnosis of acute myocardial infarction, as well as student adherence and satisfaction. Descriptors for the study design included randomized clinical trials, clinical trials, and controlled trials.

Study selection

The studies were initially grouped and organized using the Intelligent Systematic Review (Rayyan) application, which facilitated the import and categorization of references according to specific criteria of relevance and study type. Duplicate removal was performed automatically by Rayyan, which identified and eliminated duplicate records to ensure the inclusion of unique studies. The search was conducted in the previously mentioned databases using specific search strategies. The selected studies underwent a comprehensive screening process, and data were extracted independently by two reviewers, with any discrepancies resolved through consensus.

The extraction process involved three stages: first, titles were reviewed; second, abstracts were assessed; and third, full texts were read. Afterward, an exploratory reading of the selected studies was performed, followed by a more selective and analytical reading. The data extracted from the articles were summarized, including details such as the authors, journal, year of publication, title, and key conclusions, to gather relevant information for the study.

Data collection process

The collected data included information on study characteristics, interventions, outcomes, and methodological quality, enabling a thorough and robust analysis of the results. The methodological quality of the studies was assessed by two independent reviewers. In cases of disagreement, the article was reviewed in its entirety for reassessment. If the disagreement persisted, a third reviewer was involved to assess the study and make the final decision.

Quality of each study

The risk of bias for the clinical trials was assessed using the modified Cochrane ROB 2 tool for clinical trials. We evaluated each trial across the following domains: randomization sequence generation, allocation concealment, blinding, incomplete data, selective reporting, and other biases. For each domain, the risk was classified as "high," "probably high," "probably low," or "low."

The overall certainty of the "evidence" for each outcome was determined using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach.

Results

Figure 1 shows the PRISMA flowchart of the search and selection process. A total of 435 studies were identified through the database search. After removing duplicates, the abstracts of 412 studies were assessed and included if deemed appropriate. The full text of 40 articles was evaluated for eligibility, and 7 articles were ultimately included for qualitative synthesis.

The assessment of the risk of bias is presented in Figures 2 and 3, where detailed analyses have been conducted. These figures clearly illustrate the criteria used to determine the reliability of the data and the quality of the

included studies, allowing for a deeper understanding of the potential impacts on the final results (Figures 2 and 3).

Table 1 provides a summary of the 7 studies ultimately included, which involved 823 medical students from their third to final year. The studies were conducted in 4 different countries, with the number of participants per study varying from 18 to 219.

Impact on cardiology teaching

The use of realistic simulation in cardiology education has demonstrated significant improvements in students' skills, particularly in cardiac auscultation. Data shows that simulation led to a notable increase in the accuracy of mitral regurgitation recognition, with 89.7% of students in the intervention group correctly identifying the condition compared to 71.4% in the control group, with a p value of 0.02. Furthermore, the simulation group exhibited superior performance in correctly diagnosing all cardiac conditions compared to the control group. These advancements highlight the effectiveness of simulation in practicing the skills necessary for accurate cardiac diagnoses, whereas lung auscultation skills did not show significant differences between groups.

Improvements in student performance were also evident in post-test scores, with an average change of 4.6 ± 4.0 points. Participants in the simulation training arm achieved a higher delta score compared to the control group (5.4 ± 4.2 versus 3.8 ± 3.7 , $p = 0.04$). Residents in particular showed a more pronounced effect, with an average improvement of 6.6 ± 4.0 points in the simulation group versus 3.5 ± 3.4 points in the control group ($p = 0.02$). These results demonstrate that simulation is especially beneficial for residents, reflecting a significant impact on developing complex diagnostic skills.

Students who engaged in realistic simulation also showed a significant increase in overall skills scores, with an average gain of 5.8 ± 6.1 points compared to a decrease of 6.7 ± 8.4 points in the control group ($p = 0.003$). Performance in physical examination and diagnosis was significantly better in the simulation group compared to the didactics and control groups ($p < 0.001$ and $p < 0.02$, respectively). Additionally, student satisfaction was higher in the simulation group, with 98% reporting satisfaction compared to 75% in the control group ($p < 0.001$). These findings underscore not only the effectiveness of simulation-based training in enhancing practical and diagnostic skills but also the increased satisfaction and confidence of students in their clinical competencies.

Discussion

The studies included in this review found an improvement in the ability to auscultate the heart, to recognize coronary anatomy, and to perform catheterization and angioplasty. In addition, there was also an increase in student adherence and satisfaction (Central Illustration).

Performing auscultation in the traditional way can reduce students' ability to recognize alterations. In general, one student tends to auscultate the other; as there are no alterations, the

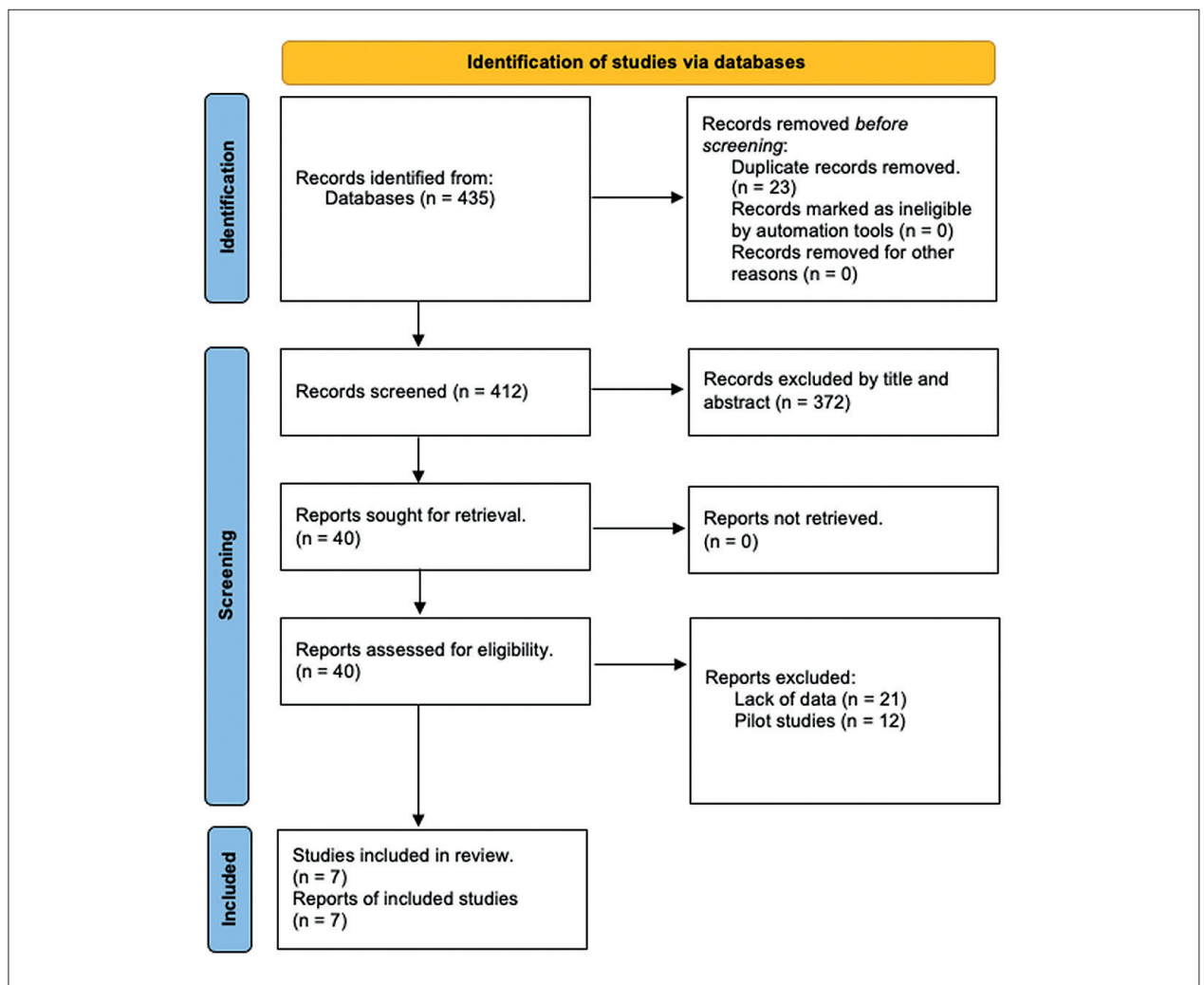


Figure 1 – Flowchart of the research strategy.

		Risk of bias domains					
		D1	D2	D3	D4	D5	Overall
Study	Bernardi et al. (2019)						
	Lee et al. (2022)						
	Voelker et al. (2016)						
	DeWaay et al. (2014)						
	Kern et al. (2011)						
	Fischer et al. (2018)						
	Rüllmann et al. (2022)						
		Domains: D1: Bias arising from the randomization process. D2: Bias due to deviations from intended intervention. D3: Bias due to missing outcome data. D4: Bias in measurement of the outcome. D5: Bias in selection of the reported result.					Judgement High Some concerns Low

Figure 2 – Traffic light plot.

Review Article



Figure 3 – Summary plot.

student ends up recognizing the normal sound, and it is not possible to distinguish the type of impairment when examining patients. Authors such as Bernardi et al.,¹⁵ Kern et al.,¹⁹ and Rüllmann et al.²¹ have shown that the use of simulation increased the ability to recognize sounds at the end of the training period. A meta-analysis published by McKinney et al.²² concluded that simulation-based learning is an effective educational strategy for teaching cardiac auscultation.

Similar results have been seen in the teaching of medicine as well as nursing.²³ These results reinforce the fact that simulation-based learning is capable of increasing competences and skills and is not associated with a specific course. The playfulness and closeness to reality favor the teaching-learning process, creating a favorable environment conducive to teaching.

The study by Lee et al.¹⁶ highlights the importance of innovative teaching methods, such as simulation-based learning, in coronary anatomy education. This approach is consistent with previous research highlighting the benefits of simulation in medical education. For example, in a study conducted by Johnson et al.,²⁴ the authors demonstrated that simulation increased student engagement and improved retention of anatomical knowledge compared to traditional teaching methods.

In addition, the study by Lee et al.¹⁶ highlights the importance of a practical and contextualized approach to teaching coronary anatomy. Authors such as Smith et al.²⁵ emphasize the need for students to understand the clinical relevance of anatomy to medical practice. Simulation offers students the opportunity to apply their anatomical knowledge in simulated clinical scenarios, better preparing them for clinical practice.

Another relevant point is simulation's ability to provide a safe environment for practice and error. Authors such as Estai et al.²⁶ have shown that simulation allows students to experience different clinical scenarios and develop practical skills without the risk of harming real patients. This promotes more active and exploratory learning, contributing to a better understanding of coronary anatomy and its clinical application.

The use of simulation-based learning has proven effective in optimizing the angioplasty procedure. In the present study, participants reported increased confidence in performing technical procedures and greater ability to identify signs and symptoms of acute myocardial infarction after the simulation

sessions. These findings are consistent with previous studies, such as those by Islam et al.²⁷ and Khokhar et al.,²⁸ which highlight that simulation provides a safe and controlled environment for practicing technical skills and complex procedures, such as coronary angioplasty. Similarly, Rourke et al.²⁹ demonstrated that simulation-based learning was effective in improving the recognition and management of acute myocardial infarction, especially by offering opportunities for practice in realistic contexts with immediate feedback. In addition, research such as that by Farina et al.³⁰ has shown that simulation provides a realistic opportunity for learners to apply theoretical knowledge in practice, enabling a better understanding of the pathophysiology of acute myocardial infarction and improving their decision-making skills in cardiovascular emergency situations.

The use of simulation not only generates technical improvements during learning; it also makes students want to use the material provided and increases their engagement during classes. Several studies included in this review found improved student satisfaction and adherence. This result corroborates the research by Kagaya et al.³¹ and Birdane et al.³² In both studies, the level of satisfaction was higher in the group that used realistic simulation. Traditional teaching is being widely criticized.³³ Students in a more technological age prefer activities that involve skills that will be put into practice in the real world.

Students who demonstrate higher levels of engagement tend to be more participative and are better equipped to develop the competencies and skills expected of them.^{34,35} Additionally, incorporating "real-world" elements into scenario construction enhances the validity of the simulation. For example, Zhang et al.³⁶ simulated cardiac emergencies using real patients recovering from a previous cardiac event, integrating intermittent interruptions to mimic a real-life "on-call scenario." This approach reflects the multitasking, time management, and composure required of doctors who often need to manage multiple tasks under pressure.

The correlation of the observed outcomes in the included studies reveals a significant diversity in methodological approaches, reflecting different contexts and target populations. This heterogeneity in simulation and evaluation methods is crucial for the interpretation of the results, since variations in experimental protocols can directly influence the observed outcomes. For example, some studies adopted simulations based

Table 1 – Data extracted from the articles included in the systematic review

Study (author/ year)	Country	Sample	Design	Inclusion criteria	Interventions		Relevant details	Measurements	Results
					Intervention	Control			
Bernardi et al. (2019) ¹⁵	Italy	107	Randomized clinical trial	Fifth-year medical students	The study included fifth-year medical students who practiced individually with the patient simulator for an hour before taking their medical semiotics exam.	The study included fifth-year medical students who had no prior experience training with the patient simulator before participating in this research.	Manikin with programmable heart sounds + visual feedback (phonocardiogram). Students interacted individually for 1 hour.	Cardiac and pulmonary auscultation skills	Exposure to the simulator led to a significant improvement in cardiac auscultation skills, with 89.7% of IG students correctly identifying mitral regurgitation, compared to 71.4% of CG students (p = 0.02). Additionally, a significantly higher percentage of IG students accurately diagnosed all cardiac conditions compared to CG students. However, no differences were observed between the groups in lung auscultation skills.
Lee et al. (2022) ¹⁶	USA	105	Randomized clinical trial	University of Arizona students, residents, and fellows	Participants received simulation-based training in addition to traditional didactic instruction.	They received only didactic instruction.	Virtual fluoroscopy-based coronary angiography simulator (high-fidelity 2D/3D)	Pre-test Coronary Angiography Training Study	The participants showed an improvement in their post-test scores, with an average increase of 4.6 ± 4.0 points. Those in the simulation training group had a higher delta score compared to the control group (5.4 ± 4.2 versus 3.8 ± 3.7, p = 0.04). The impact was more pronounced for residents (6.6 ± 4.0 versus 3.5 ± 3.4), with a significant interaction between the training arm and level of training (p = 0.02).

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The “skills score” increased by 5.8 ± 6.1 points in the VR simulation group, while it decreased by 6.7 ± 8.4 points in the control group ($p = 0.003$) from the simple stenosis in the pre-assessment to the more complex lesion in the post-assessment, highlighting the effectiveness of simulation-based training.

To assess the level of individual performance, a “competency score” was determined, consisting of 14 performance characteristics (5-level Likert scale, maximum score of 70 points).

Coronary angiography simulator with catheterization. Included repeated practice in a safe environment and immediate feedback. Used for initial technical training.

The simulation group underwent 7.5 hours of VR simulation training.

The control group participated in 4.5 hours of lectures.

Fellowship cardiologists

Stratified randomized study

18

Germany

Voelker et al. (2016)¹⁷

There was a significant improvement in overall performance with simulation compared to didactic instruction and the control group ($p < 0.001$). Performance in the physical examination component was significantly better in the simulation group compared to both the didactic and control groups, as was performance in diagnosis ($p < 0.02$ for all comparisons).

Assessment of clinical performance during the first trimester of the final year of the medical program at the institution.

Small-group simulation-based curriculum with debriefing and lectures. Focused on diagnosis, physical exam, and therapeutic decisions during a clinical performance exam.

This group of students was the “didactic” group, whose specific curriculum included 2 hours of classes titled “The Approach to the Unstable Patient” during their internship.

They participated in small simulation training groups, alongside the specific didactic curriculum.

Fourth-year medical students

Randomized clinical trial

291

USA

DeWaay et al. (2014)¹⁸

They received training in cardiopulmonary examination skills, along with cardiac examination skills, using Harvey, the Cardiopulmonary Patient Simulator, a validated cardiac simulator.

Third-year medical students

Quasi-experimental study

124

USA

Kern et al. (2011)¹⁹

Students trained with cardiac simulation performed significantly better than the control group in all 5 cardiac skills. The number of students who correctly performed all 5 cardiac examination skills increased significantly ($p = 0.004$). There was no change in the lung examination skills.

They were assessed using a multi-station OSCE test at the end of the internship, 5 weeks after the learning exercise.

Use of simulation manikins with heart sounds + standardized patient scenarios. Aimed at assessing clinical skills in cardiovascular examination.

They received skills training for cardiopulmonary examination using only a single standardized patient.

Fischer et al. (2018) ²⁰	France	118	Randomized clinical trial	Third to sixth year medical students	Participants received a simulator-based course that covered the same content as the control group.	They received a PowerPoint-based course.	Coronary angiography simulator (Mentice VIST-Lab)	All students were assessed using 40 multiple-choice questions (with a maximum score of 100 points), covering topics such as coronary anatomy (part 1), angiographic projections (part 2), and the interpretation of real coronary angiograms (part 3). Student satisfaction was also evaluated through a simple questionnaire.	IG students achieved higher overall scores than CG students, regardless of their year of study (59.5 [SD 10.8] points versus 43.7 [SD 11.3] points, $p < 0.001$). The same trend was observed in each section of the test: 36.9 (SD 6.6) points versus 29.6 (SD 6.9) points ($p < 0.001$) for part 1; 5.9 (SD 3.0) points versus 3.1 (SD 2.8) points ($p < 0.001$) for part 2; and 16.8 (SD 6.9) points versus 10.9 (SD 6.5) points ($p < 0.001$) for part 3. Student satisfaction was significantly higher in the IG compared to the CG (98% versus 75%, $p < 0.001$).
Rüllmann et al. (2022) ²¹	Germany	60	Cross-over prospective randomized controlled trial	Third-year medical students	They attended 3 courses lasting 90 minutes each, held one week apart, in a different sequence: a virtual case-based auscultation course conducted via video chat, self-study of the literature, and a face-to-face course using an auscultation simulator.	They did not receive the intervention for a certain period.	Virtual auscultation via video chat (case-based + pre-recorded audio)	The performance of both groups on the simulator was evaluated after they participated in either the virtual auscultation course or self-study of the literature. To assess their auscultation skills, the students underwent 5 assessments, each involving the same 6 pathologies.	Compared to self-study of the literature, participation in the virtual auscultation course resulted in a significantly better description of heart murmurs in the auscultation simulator, particularly in identifying low- and high-pitched sounds. However, there was no significant difference between the groups in terms of diagnostic accuracy or identification of the point of maximum intensity. After the virtual course, students reported higher satisfaction rates and a greater increase in self-assessed competence compared to those who engaged in self-study of the literature.

CG: control group; IG: intervention group; OSCE: objective structured clinical examination; SD: standard deviation; VR: virtual reality.

Review Article

on computational models, whereas others used controlled clinical experiments. These discrepancies not only make direct comparison of results difficult, but also highlight the inherent limitations in generalizing the findings. Therefore, it is essential to recognize that differences in the methods used can contribute to variability in results, which should be carefully considered when discussing the implications and conclusions of the analyzed studies.

This review has some limitations, such as the heterogeneity of simulation and evaluation methods. This limitation made it impossible to carry out a more robust analysis or meta-analysis.

Conclusion

This systematic review provides robust evidence that simulation is an effective method for teaching cardiology to medical students, yielding significant positive outcomes compared to other teaching approaches, even with relatively short simulation sessions.

Author Contributions

Conception and design of the research and writing of the manuscript: Jesus WLA, Veltri T, Pimenta R, Silva RP, Cordeiro ALL; acquisition of data and analysis and interpretation of the data: Cordeiro ALL; critical revision of the manuscript for intellectual content: Jesus WLA, Veltri T, Pimenta R, Silva RP.

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Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

This study is not associated with any thesis or dissertation work.

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Availability of Research Data

The datasets generated and analyzed during the current study are not publicly available due to patient confidentiality but are available from the corresponding author upon reasonable request.

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