Review Article

Access this article online
Quick Response Code:

Website: www.jehp.net
DOI: 10.4103/jehp.jehp_780_22

Surfing the clinical trials of ECG teaching to medical students: A systematic review

Ali Ardekani[1,2], Ahmad M. Hider[3], AmirAli Rastegar Kazerooni[2], Seyed Ali Hosseini[1], Amirhossein Roshanshad[2], Mitra Amini[4], Javad Kojuri[4]

Abstract:

Interpreting an electrocardiogram (ECG) is crucial for every physician. The physician's competency in ECG interpretation needs to be improved at any stage of medical education. The aim of the present study was to review the currently published clinical trials of ECG teaching to medical students and provide suggestions for future works. On May 1, 2022, PubMed, Scopus, Web of Science, Google Scholar, and ERIC were searched to retrieve relevant articles on clinical trials of ECG teaching to medical students. The quality of the included studies was assessed utilizing the Buckley *et al*. criteria. The screening, data extraction, and quality appraisal processes were duplicated independently. In case of disagreements, consultation with a third author was put forth. In total, 861 citations were found in the databases. After screening abstracts and full texts, 23 studies were deemed eligible. The majority of the studies were of good quality. Peer teaching (7 studies), self-directed learning (6 studies), web-based learning (10 studies), and various assessment modalities (3 studies) comprised the key themes of the studies. Various methods of ECG teaching were encountered in the reviewed studies. Future studies in ECG training should focus on novel and creative teaching methods, the extent to which self-directed learning can be effective, the utility of peer teaching, and the implications of computer-assisted ECG interpretation (e.g., artificial intelligence) for medical students. Long-term knowledge retention assessment studies based on different approaches integrated with clinical outcomes could be beneficial in determining the most efficient modalities.

Keywords:

Cardiac arrhythmias, clinical clerkship, electrocardiography, medical education, medical students

[1]School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran, [2]Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran, [3]University of Michigan Medical School, Ann Arbor, MI, USA, [4]Clinical Education Research Center, Shiraz University of Medical Sciences, Shiraz, Iran

Address for correspondence:
Dr. Mitra Amini, Clinical Education Research Center, Shiraz University of Medical Sciences, Shiraz, Iran.
E-mail: mitraamini51@yahoo.com

Received: 06-06-2022
Accepted: 12-07-2022
Published: 31-03-2023

Introduction

The electrocardiogram (ECG) is a fundamental, cost-efficient test to assess a wide range of cardiac abnormalities.[1] A crucial part of any medical education curriculum is teaching ECG interpretation to students.[2,3] Although new technologies and artificial intelligence (AI) have interpreted ECG more straightforward in recent years, it should be borne in mind that due to the infancy of the studies, implications regarding the extent to which AI can supersede human interpretation of the ECG are yet to be known.[4] Therefore, all physicians must acquire the ability of ECG interpretation.

A recent meta-analysis reported that the accuracy of ECG interpretation was 42%, 58%, and 74.9% for medical students, residents, and cardiologists, respectively, which is considerably low.[5] A variety of pedagogical strategies have been used to teach ECG interpretation, such as self-directed learning (SDL), internet-based, lecture-based, workshop-based, contrastive and non-contrastive, and clinically integrated methods.[6] Each of these educational strategies has its advantages and disadvantages, and it is up to the

How to cite this article: Ardekani A, Hider AM, Rastegar Kazerooni A, Hosseini SA, Roshanshad A, Amini M, *et al*. Surfing the clinical trials of ECG teaching to medical students: A systematic review. J Edu Health Promot 2023;12:107.

institutions to utilize the best possible one considering their facilities and culture. Randomized controlled trials, as one of the most reliable types of studies in the hierarchy of evidence, are the best way of comparing educational interventions. Although, blinding may not be applicable to the educational interventions as both teachers and students will find out the method of teaching. Several studies in recent years compared the above-mentioned educational strategies for ECG teaching to medical students,[7-14] however, the knowledge is still expanding and to date, there has been no review study that comprehensively evaluated these methods.

Given the immense significance yet low competency of ECG interpretation in medical students, we aimed to systematically and qualitatively review the current literature regarding ECG teaching clinical trials in undergraduate medical education (UME).

Materials and Methods

This study was conducted in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement[15] and Cook *et al*.'s[16] approach to conducting systematic reviews in medical education.

Search strategy

To find suitable keywords and MeSH terms, a preliminary search was done at the end of April 2022. The leading search was conducted on the 1st of May 2022 in PubMed, Scopus, Web of Science, Cochrane Library, ERIC, and Google Scholar with relevant keywords [Supplementary Table 1]. In addition, the reference lists of the obtained articles were manually searched to retrieve all possibly relevant studies. All retrieved citations were imported to the Rayan web application,[17] and duplicates were removed.

Eligibility criteria and screening

Two independent reviewers screened the titles and abstracts of the citations against the eligibility criteria. Randomized controlled trials on ECG training for undergraduate medical students published after 2000 were included. No exclusion was made due to language or country of publication. Opinion pieces, editorials, and other reports without actual interventions were excluded. After the first screening, two authors reviewed the full text of the remaining studies separately for possible inclusion. In the screening process, consultation with the most expert authors was the proxy by which we reached consensus in cases of disagreement.

Data extraction and quality appraisal

Two authors reviewed the eligible studies and extracted their data. The first author's name, country of origin, year of publication, intervention description, and outcomes were inserted into a pre-designed Excel spreadsheet. Two authors assessed the quality of the included studies utilizing the Buckley *et al*. criteria.[18] This instrument assesses the quality of educational interventions across 11 domains [Supplementary Table 2]. A study was deemed high-quality if it passed seven of the 11 criteria. In the process of data extraction and quality appraisal, consultation with a third author was put forth when there was a discrepancy.

Results

Searching in the databases, 861 titles and abstracts were retrieved. After removing the duplicates and screening the remaining studies, 23 articles[7-14,19-33] were included in the present study [Figure 1]. One study[7] was the follow-up assessment of previously published data. The quality of the studies was evaluated by the checklist provided by Buckley *et al*.[18] All studies except one[23] met at least seven out of eleven checklist items and were considered high-quality interventions.

In terms of global distribution, 6, 10, and 7 studies were from Asia,[9,11,12,21,25,33] Europe,[7,10,20,22,27-32] and North America,[8,13,14,19,23,24,26] respectively. An overview of the studies is available in Table 1. Most of the studies (22/23) were conducted after 2010.[7-14,19-28,30-33] Also, 19 studies' populations were solely undergraduate medical students,[7-13,19-21,24-26,28-33] while four were mixed among different educational levels.[14,22,23,27] Peer teaching was used in seven studies,[7,10,12,20,24,30,31] revealing its benefits for both trainers and trainees.[24] Self-directed learning (SDL) was evaluated in six studies,[7,10,12,26,27,30] deeming it inferior to the other methods unless accompanied by a summative assessment. Ten studies used internet-based platforms for teaching.[9,10,12-14,20,23,25,28,32] The primary focus of the remaining three studies was the assessment method and its effect on the overall score of the students.[7,30,31] These studies found summative assessments to be superior to formative assessments in terms of meeting the learning outcomes, with students achieving higher scores in the former.

Discussion

In the present study, following a standard protocol 23 studies were found eligible to be reviewed. As mentioned in a recent meta-analysis,[5] ECG interpretation skills need improvement across every training level in medical education. This underlines the importance of adopting various methods to teach and maintain students' knowledge. Of note, in recent years, the use of artificial intelligence (AI) in the interpretation of ECGs has been of paramount significance.[4] Although this should not affect the dedication to teaching ECG interpretation to

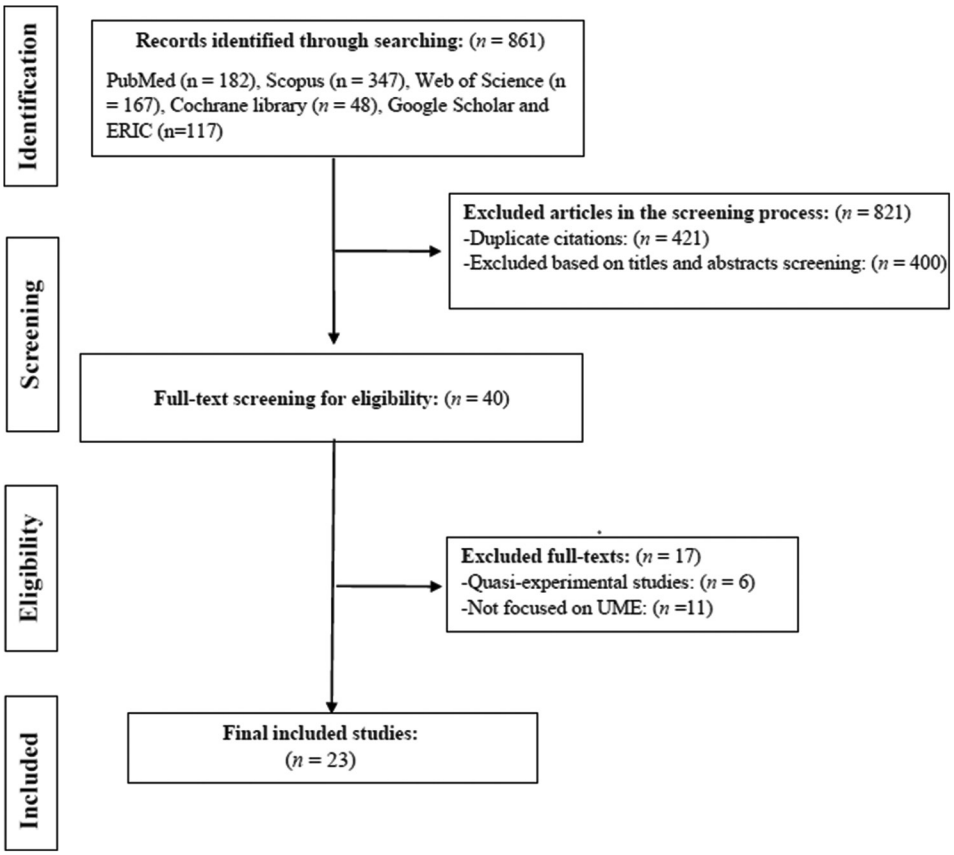

Figure 1: The flow-diagram of the screening process

medical students, it should be borne in mind that AI may take the lead in ECG interpretation in future years.

Internet-based education, a substitute for in-person strategies

Unsurprisingly, internet-based methods have been blended with every educational strategy in recent years. Utilization of these methods led to better or at least identical outcomes relative to the control groups in the included studies. This shows the receptiveness of the faculties and students to teach and learn via the internet, underlining the significance of providing the required infrastructure in less developed countries. The extent to which online ECG education can substitute in-person strategies is yet to be robustly understood.

Summative or formative assessment, which one is superior?

"Assessment drives learning".[34] It has been shown in previous investigations that whether the assessment is summative or formative makes a difference in educational outcomes. The primary concern of summative evaluation is to make decisions about a student's performance, whereas learning is the main purpose of formative evaluation. The studies conducted by Raupach *et al*.[7,30,31] hinted at the superiority of summative assessments, leading to better outcomes in ECG training. Since the learning outcome might differ depending on the assessment method, it is important to choose the proper assessment method to achieve the best possible results. Based on the studies, the combined use of summative and formative assessments may lead to better outcomes.

To what extent can self-directed learning (SDL) supersede didactic methods?

There is still a lively debate on how SDL can take the lead in medical education. In the included studies,[7,10,12,26,27,30] when these methods were not associated with a summative assessment, they were less effective than other methods. It seems that if SDL is being utilized, the use of a summative evaluation is necessary to ensure the proper usage of SDL materials. Of course, these methods can be used as supplementary educational materials along with other strategies.

Peer teaching strategies: A win-win situation

Teaching in small groups of students can be beneficial for both parties. It has been shown by Gregory *et al*.[24] that those peer teachers who prepared first and taught afterward achieved better outcomes than those who prepared but did not teach afterward. However, it is

Table 1: An overview of the included articles

Author, year	Description of the intervention (*n*)	Results	Suggestions or conclusions
Antiperovitch *et al*.,[14] 2021	Participants were randomly assigned to two ECG interpretation teaching methods: multiple-choice or self-generation (They typed their diagnosis with the help of an auto-complete function.). The teaching section included 30 ECGs. After that, the students were assessed by an immediate test and 3-4 weeks later (*n*=48)	Participants assigned to the self-generation method had higher score on the immediate post-test than those who were assigned to multiple-choice method.	Learner-generated diagnoses may provide better results rather than multiple-choice questions.
Blissett *et al*.,[19] 2015	Learner and expert -generated schemas for understanding ECG rhythm interpretation were used to compare knowledge acquisition, diagnostic accuracy, and cognitive load. Participants were randomly assigned to two experiments. Experiment 1 was the comparison of expert-generated schemas with traditional teaching frameworks. Utilizing the same methodology, experiment 2 was the comparison of expert-generated versus learner-generated schemas (*n*=57)	Experiment 1: Participants who Learned from expert-generated schemas had higher accuracy of diagnosing on immediate testing, lower cognitive load, and higher discriminating knowledge. The performance of both groups was similar on delayed testing. Experiment 2: Participants who learned from learner-generated schemas had a decreased accuracy of diagnosing during the training section, with similar performance during the immediate and delayed testing sections. Increased cognitive load was observed in learner-generated schema generation. Expert-generated schema resulted in better learning of ECG rhythm interpretation, in comparison to traditional frameworks.	In comparison to traditional frameworks, expert-generated schema improved ECG learning.
Davies *et al*.,[20] 2016	The participants were randomized into two groups: e-learning and near-peer tutorial (*n*=39)	The near-peer group showed significantly better performance in the final assessment than the e-learning group.	Both e-Learning and near-peer teaching enhance the confidence in ECG interpretation.
Dong *et al*.,[21] 2015	The participants were randomly assigned to the concept map and traditional teaching groups (*n*=126)	A significant superiority of concept maps was noted in ECG interpretation. Between the groups, the average ECG features completion index had no significant difference.	Concept maps may be a valuable strategy for teaching ECG to medical students.
Fent *et al*.,[22] 2016	Medical students and junior doctors were randomly assigned into two groups: traditional teaching (lecture) or a computer simulator program (*n*=168)	No difference was observed in the immediate and delayed (three months after teaching) ECG interpretation test scores between the groups.	Simulator-based teaching may be an appropriate teaching method. However, more evidence is needed.
Gayle *et al*.,[23] 2020	Thirty-three case-based ECG quizzes were sent to the participants via email. Then, they were assigned to either receive the same quizzes via the QuizTime application or merely receive the initial material (*n*=66)	Post-test results in the two groups did not differ significantly.	Utilizing QuizTime application did not show different results but may be an appropriate strategy to evaluate their knowledge.
Gregory *et al*.,[24] 2011	3rd-year students were arranged to educate 2nd-year students on "Advanced Cardiac Life Support algorithms" and ECG interpretation. Just before teaching, the tutors were assigned not to teach, to teach ECG, or to teach the algorithms (*n*=17)	In comparison with baseline, peer teachers' examination scores showed the most significant gains for subjects they prepared for and then taught, with gains persisting for two months. Less dramatic gains were evident for the content they prepared but did not teach, but they too persisted for 60 days.	Actively teaching and preparing to teach may positively impact peer teacher learning outcomes.
Kewcharoen *et al*.,[12] 2020	Participants who were fourth and fifth-year medical students were randomized either to self-study or peer-assisted learning groups (*n*=80)	The mean difference score of peer-assisted learning group was higher than the fourth-year self-study group. However, the mean post-test and difference score in the fifth-year group did not significantly differ.	Peer-assisted learning and conventional self-study showed comparable results.

Contd...

Table 1: Contd...

Author, year	Description of the intervention (*n*)	Results	Suggestions or conclusions
Kopeć *et al*.,[10] 2018	Participants were randomized to collaborativeeLearning (C-eL) and SelfeLearning (S-eL) groups. 15 ECGs were sent to the students in the SeL group with a thorough description via email (one every second day), while ECGs were emailed to CeL students without descriptions. In subgroups, CeL students analyzed ECGs together and submitted their interpretation within two days. After that, a description of each ECG was sent to them (*n*=60)	According to the final test results, CeL of ECG among participants was superior to SeL.	C-eL of ECG was superior to self e-learning.
Li *et al*.,[25] 2019	Participants were randomly assigned to classically displayed ECGs of limb leads, or orderly displayed ECGs of limb leads (*n*=147)	The orderly displaying can efficiently increase the accuracy of diagnosing axis in comparison with the classical displaying. However, both methods enhance the diagnostic accuracy compared to the baseline.	Showing limb lead ECGs may increase diagnostic accuracy when determining QRS axis.
Mahler *et al*.,[26] 2011	Participants were randomized to receive ECG interpretation education utilizing: workshop, lecture, or SDL (*n*=234)	The test scores in lecture- and workshop-based methods were almost identical. SDL resulted in lower scores compared to workshop and lecture methods.	The results of this study suggest that stand-alone SDL formats are less effective.
McAloon *et al*.,[27] 2014	Participants were randomized to either a focused teaching program (FTP) or SDL (*n*=62)	The undergraduates' FTP group demonstrated significantly higher performance in interpreting "ventricular tachycardia" and "narrow complex tachycardia" in comparison with the SDL group. The confidence of the participants, enhanced in both learning methods, though to a greater extent in the FTP group.	A well-designed teaching strategy can enhance the competence in ECG interpretation.
Montassier *et al*.,[28] 2016	Participants were randomized to either an e-learning group or a lecture-based group (*n*=98)	The e-learning group was non-inferior in comparison with the lecture-based group. E-learning can be an efficient tool for medical students to acquire ECG interpretation skills.	An interactive e-learning strategy comprising quizzes, and feedback, may provide an appropriate method for teaching.
Monteiro *et al*.,[8] 2017	A study was conducted with two levels ofmassed and distributed instruction, and two levels of interleaved and blocked practice. They assigned the participants to one of the four instruction-practice conditions (*n*=80)	The mean scores demonstrated the superiority of distributed instruction over massed instruction; however, no interplay was observed between teaching and practice strategies. The superiority for blocked over mixed practice and distributed over massed instruction was noted in the delayed final test scores.	These strategies have various effects.
Mueller *et al*.,[29] 2005	Participants were assigned to either a simulator or control group. After an introduction on antiarrhythmic drugs, those in the simulator group were presented with arrhythmias utilizing an advanced life support manikin. The students were told to prescribe a drug or defibrillate, showing the outcome on the monitor. ECG charts without a simulator was the mean by which they assessed students in the control group (*n*=234)	Students in the simulator group considered the simulator helpful. Simulator group students indicated that they could better link the theory to real practice.	Manikin based teaching may be an efficient strategy.
Nag *et al*.,[11] 2018	Participants were randomized into two groups; algorithm based approach in one group and traditional PowerPoint presentation in the other group (*n*=70)	The taken time to identify the correct rhythm was almost identical between the two groups. After two months, students in the algorithm group could recognize correct rhythm significantly better than those who were taught by power point-based approach. Also the taken time to verbalize the appropriate treatment was also identical in both groups.	Algorithm-based teaching may be an efficient strategy.

Contd...

Table 1: Contd...

Author, year	Description of the intervention (*n*)	Results	Suggestions or conclusions
Raupach *et al*.,[31] 2010	Medical students were randomized to receive traditional ECG training or near-peer teaching. Summative or formative assessments were done for subgroups. A retention exam (unannounced) was taken eight weeks after the course ended (*n*=335)	Near-peer teaching was superior to the lectures only in the formative assessment group, while both teaching methods were identically effective in the summative assessment group. A summative rather than formative assessment enhanced (two times) the performance increase, and decreased any difference between teaching methods. A significant decrease in student performance was observed eight weeks after the course in both groups.	The assessment format will impact the outcome of teaching.
Raupach *et al*.,[30] 2013	Medical students received three methods of teaching: SDL, lecture-based training, or small-group peer teaching (all in two parallel groups). One of the two groups was assessed formatively, while the other was subjected to a summative examination (*n*=534)	In comparison with formative assessments, summative assessments enhanced the probability of authentically recognizing at least 3/5 ECG diagnoses, spending at least two additional hours per week on ECG self-study, and using additional sources for learning. Lecture-based training and peer teaching were only linked to higher efforts for learning but did not boost the scores.	Summative assessments impact learning outcomes much higher.
Raupach *et al*.,[7] 2016	Medical students took part in a follow-up study of Raupach *et al*. A retention test two months after the first study was done to assess learning outcomes (*n*=493)	Summative assessments predicted retention test scores. The type of teaching was not associated with test scores. Motivation and overall performance levels were not associated with performance decrease or skills retention. Regardless of the educational method, summative assessments increased the medium-term ECG interpretation skills retention.	Summative assessments have a significant impact on medium-term retention of ECG interpretation skills.
Rolskov Bojsen *et al*.,[32] 2015	The initial ECG tutorial had three parts: a theory module (basic information), training module (15 different ECGs with feedback), and an encyclopedia. Then, students were randomized to complete a retention test after 2-4, 10-12, or 18-20 weeks follow-up (*n*=203)	The scores of junior and senior students were significantly different at baseline but showed comparable score gains. A reduction in test score between post-test and retention-test was observed in all three follow-up groups; however, between groups mean retention-test scores did not significantly differ. A decline in test scores at follow-up was observed in both senior and junior group. Also, comparing the pre-test to retention-test, junior students had higher scores than senior students.	Web-based ECG teaching may be an efficient strategy for teaching ECG interpretation skills to medical students.
Rui *et al*.,[9] 2017	Participants were randomized to a flipped classroom, or Lecture-Based Learning as a control group (*n*=181)	The score of the students on ECG interpretation in the intervention group was significantly higher than the control group. Most students in the experiment group had positive attitudes toward the flipped classroom strategy and supported the lecture-based method. Before class, the students spent significantly more time in the flipped class group than those in the control group, while, after class, the time spent by the two groups did not differ.	Medical students' self-learning abilities and their interest in learning may be increased by adopting a flipped classroom strategy.
Thach *et al*.,[13] 2020	Participants were randomized to learn worked examples of "bradycardias with salient features" first and "tachycardias with discriminatory features" second or vice versa. A questionnaire on the attitudes of the participants towards the difficulty, clarity, and perceived learning was filled at the end (*n*=65)	The levels of diagnostic accuracy were similar in both groups. Participants in both groups had higher diagnostic accuracy compared to historical controls. Salient rather than discriminatory features was associated with greater intrinsic load in students' perspective.	The use of discriminatory features in worked examples in training medical students in ECG interpretation is supported by this study.
Zeng *et al*.,[33] 2015	Participants were randomly assigned to traditional and innovative teaching groups. The tutors in the traditional teaching method used the traditional outline, while the tutors utilized the graphics-sequence memory method in the innovative group (*n*=200)	The new method (graphics-sequence memory) was observed to be a more efficient method for ECG education (43% vs. 77% accuracy).	A variety of teaching methods to improve the teaching ability should be used by the tutors.

worth noting that for this type of teaching the instructors should be trained beforehand.

Integration with previous reviews

Several reviews have been conducted in the field of ECG training in medical education.[5,6,35,36] A recent meta-analysis by Cook *et al*.[5] provided a robust quantitative interpretation of physicians' ECG interpretation skills, though their primary concern was not to qualitatively synthesize teaching methods in undergraduate medical education (UME). In another meta-analysis by Viljoen *et al*.,[35] it was found that blending computer-assisted and lecture-based learning provides a better outcome than lecture-based alone, supporting our findings. Overall, the present study is the first to systematically review ECG interpretation clinical trials in UME.

Using a standard protocol, we reviewed clinical trials in UME regarding ECG training. However, this study was not free of limitations. There may be unreported university-based interventions to which we did not have access. Also, blinding participants to educational methods was not possible due to the inherent nature of educational interventions, representing a potential source of bias. In addition, we focused on UME, while there could be interventions at other levels of education.

Conclusion

In recent years, various methods have been utilized to transfer ECG interpretation skills to medical students. However, selecting the most suitable strategy depends on the culture and facilities of the medical schools and the primary intent of teaching and assessment. Future studies in ECG training should focus on novel and creative teaching methods, the extent to which self-directed learning can be effective, the utility of peer teaching, and the implications of computer-assisted ECG interpretation (e.g., artificial intelligence) for medical students. Also, long-term knowledge retention assessment studies based on different methods integrated with clinical outcomes could be beneficial to determine the most efficient methods.

Abbreviations

Electrocardiogram: ECG, AI: Artificial Intelligence, Self-Directed Learning: SDL, Undergraduate Medical Education: UME.

Authors contribution

Ali Ardekani, Mitra Amini and Javad Kojuri: Study conceptualization and design. Ali Ardekani, Ahmad Hider, AmirAli Rastegar Kazerooni, Seyed Ali Hosseini, and Amirhossein Roshanshad: Data collection and analysis. All authors contributed to writing the paper and reading as well as approving the final manuscript.

Data availability statement

The data that support the findings of this study are presented within the manuscript.

Acknowledgments

The present study was obtained from a part of the thesis that was done by Ali Ardekani for obtaining MD/MSc degree (Project No. 24047).

Financial support and sponsorship

Shiraz University of Medical Sciences supported this project financially.

Conflicts of interest

There are no conflicts of interest.

References

1. Salerno SM, Alguire PC, Waxman HS. Training and competency evaluation for interpretation of 12-lead electrocardiograms: Recommendations from the American College of Physicians. Ann Intern Med 2003;138:747-50.
2. Viljoen CA, Millar RS, Manning K, Burch VC. Determining electrocardiography training priorities for medical students using a modified Delphi method. BMC Med Educ 2020;20:431. doi: 10.1186/s12909-020-02354-4.
3. Ardekani A, Rahimian Z, Feili A, Amini M, Tabari P, Moosavi M. Competencies required for medical students to confront the COVID-19 pandemic: A needs assessment study. J Educ Health Promot 2021;10:326. doi: 10.4103/jehp.jehp_1358_20.
4. Siontis KC, Noseworthy PA, Attia ZI, Friedman PA. Artificial intelligence-enhanced electrocardiography in cardiovascular disease management. Nat Rev Cardiol 2021;18:465-78.
5. Cook DA, Oh SY, Pusic MV. Accuracy of Physicians' Electrocardiogram Interpretations: A systematic review and meta-analysis. JAMA Intern Med 2020;180:1461-71.
6. Fent G, Gosai J, Purva M. Teaching the interpretation of electrocardiograms: Which method is best? J Electrocardiol 2015;48:190-3.
7. Raupach T, Harendza S, Anders S, Schuelper N, Brown J. How can we improve teaching of ECG interpretation skills? Findings from a prospective randomised trial. J Electrocardiol 2016;49:7-12.
8. Monteiro S, Melvin L, Manolakos J, Patel A, Norman G. Evaluating the effect of instruction and practice schedule on the acquisition of ECG interpretation skills. Perspect Med Educ 2017;6:237-45.
9. Rui Z, Lian-Rui X, Rong-Zheng Y, Jing Z, Xue-Hong W, Chuan Z. Friend or foe? Flipped classroom for undergraduate electrocardiogram learning: A randomized controlled study. BMC Med Educ 2017;17:53. doi: 10.1186/s12909-017-0881-8.
10. Kopeć G, Waligóra M, Pacia M, Chmielak W, Stępień A, Janiec S, *et al*. Electrocardiogram reading: A randomized study comparing 2 e-learning methods for medical students. Polish Arch Intern Med 2018;128:98-104.
11. Nag K, Rani P, Kumar YRH, Monickam A, Singh DR, Sivashanmugam T. Effectiveness of algorithm based teaching on recognition and management of periarrest bradyarrhythmias among interns - a randomized control study. Anaesth Pain Intensive Care 2018;22:81-6.
12. Kewcharoen J, Charoenpoonsiri N, Thangjui S, Panthong S, Hongkan W. A comparison between peer-assisted learning and

self-study for electrocardiography interpretation in Thai medical students. J Adv Med Educ Prof 2020;8:18-24.
13. Thach TH, Blissett S, Sibbald M. Worked examples for teaching electrocardiogram interpretation: Salient or discriminatory features? Med Educ 2020;54:720-6.
14. Antiperovitch P, Gula L, Blissett S. Improving ECG interpretation through self-generation of diagnoses during practice: A randomized study. Can J Cardiol 2021;37:1644-7.
15. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. BMJ 2009;339:b2535. doi: 10.1136/bmj.b2535.
16. Cook DA, West CP. Conducting systematic reviews in medical education: A stepwise approach. Med Educ 2012;46:943-52.
17. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev 2016;5:210. doi: 10.1186/s13643-016-0384-4.
18. Buckley S, Coleman J, Davison I, Khan KS, Zamora J, Malick S, *et al*. The educational effects of portfolios on undergraduate student learning: Abest evidence medical education (BEME) systematic review. BEME Guide No. 11. Med Teach 2009;31:282-98.
19. Blissett S, Cavalcanti R, Sibbald M. ECG rhythm analysis with expert and learner-generated schemas in novice learners. Adv Health Sci Educ 2015;20:915-33.
20. Davies A, Macleod R, Bennett-Britton I, McElnay P, Bakhbakhi D, Sansom J. E-learning and near-peer teaching in electrocardiogram education: A randomised trial. Clin Teach 2016;13:227-30.
21. Dong R, Yang X, Xing B, Zou Z, Zheng Z, Xie X, *et al*. Use of concept maps to promote electrocardiogram diagnosis learning in undergraduate medical students. Int J Clin Exp Med 2015;8:7794-801.
22. Fent G, Gosai J, Purva M. A randomized control trial comparing use of a novel electrocardiogram simulator with traditional teaching in the acquisition of electrocardiogram interpretation skill. J Electrocardiol 2016;49:112-6.
23. Gayle KA, Mendes LA, Damp JB, Murray KT, Richardson TD. Use of text message based education to supplement ecg education: A randomized controlled trial. J Am Coll Cardiol 2020;75:3516. doi: 10.1016/S0735-1097(20)34143-7.
24. Gregory A, Walker I, McLaughlin K, Peets AD. Both preparing to teach and teaching positively impact learning outcomes for peer teachers. Med Teach 2011;33:e417-22.
25. Li G, Banarsee K, Laukkanen JA, Hao L. Orderly display of limb lead ECGs raises Chinese intern's diagnostic accuracy when determining frontal plane QRS axis. Med Educ Online 2019;24:1549923. doi: 10.1080/10872981.2018.1549923.
26. Mahler SA, Wolcott CJ, Swoboda TK, Wang H, Arnold TC. Techniques for teaching electrocardiogram interpretation: Self-directed learning is less effective than a workshop or lecture. Med Educ 2011;45:347-53.
27. McAloon C, Leach H, Gill S, Aluwalia A, Trevelyan J. Improving ECG competence in medical trainees in a UK district general hospital. Cardiol Res 2014;5:51-7.
28. Montassier E, Hardouin JB, Segard J, Batard E, Potel G, Planchon B, *et al*. E-Learning versus lecture-based courses in ECG interpretation for undergraduate medical students: A randomized noninferiority study. Eur J Emerg Med 2016;23:108-13.
29. Mueller MP, Christ T, Dobrev D, Nitsche I, Stehr SN, Ravens U, *et al*. Teaching antiarrhythmic therapy and ECG in simulator-based interdisciplinary undergraduate medical education. Br J Anaesth 2005;95:300-4.
30. Raupach T, Brown J, Anders S, Hasenfuss G, Harendza S. Summative assessments are more powerful drivers of student learning than resource intensive teaching formats. BMC Med 2013;11:61. doi: 10.1186/1741-7015-11-61.
31. Raupach T, Hanneforth N, Anders S, Pukrop T, Th J Ten Cate O, Harendza S. Impact of teaching and assessment format on electrocardiogram interpretation skills. Med Educ 2010;44:731-40.
32. Rolskov Bojsen S, Räder SBEW, Holst AG, Kayser L, Ringsted C, Hastrup Svendsen J, *et al*. The acquisition and retention of ECG interpretation skills after a standardized web-based ECG tutorial-a randomised study Approaches to teaching and learning. BMC Med Educ 2015;15:36. doi: 10.1186/s12909-015-0319-0.
33. Zeng R, Yue RZ, Tan CY, Wang Q, Kuang P, Tian PW, *et al*. New ideas for teaching electrocardiogram interpretation and improving classroom teaching content. AdvMed Educ Pract 2015;6:99-104.
34. Wormald BW, Schoeman S, Somasunderam A, Penn M. Assessment drives learning: An unavoidable truth? Anat Sci Educ 2009;2:199-204.
35. Viljoen CA, Scott Millar R, Engel ME, Shelton M, Burch V. Is computer-assisted instruction more effective than other educational methods in achieving ECG competence amongst medical students and residents? A systematic review and meta-analysis. BMJ Open 2019;9:e028800. doi: 10.1136/bmjopen-2018-028800.
36. Cook DA, Oh S-Y, Pusic MV. Assessments of physicians' electrocardiogram interpretation skill: A systematic review. Acad Med 2022;97:603-15.

Supplementary Table 1: Search strategies

Database	Strategy
Pubmed	((Electrocardiography[MeSH Terms]) OR (Electrocardiogra*[Title/Abstract]) OR (ECG[Title/Abstract]) OR (EKG[Title/Abstract])) AND ((medical student*[Title/Abstract]) OR (Clinical Clerkship[MeSH Terms]) OR ("Clinical Clerkship*"[Title/Abstract]) OR (medical students[MeSH Terms]))
Web of Science	(TS=("medical student*" OR "clinical clerkship*")) AND (TS=(electrocardio* OR ECG OR EKG))
Scopus	(INDEXTERMS (electrocardio*) OR TITLE-ABS (electrocardio* OR ecg OR ekg)) AND (INDEXTERMS ("medical student*" OR "clinical clerkship*") OR TITLE-ABS ("medical student*" OR "clinical clerkship*"))
Cochrane	(("medical student*"):ti, ab, kw OR (MeSH descriptor: [Students, Medical] explode all trees) OR (MeSH descriptor: [Clinical Clerkship] explode all trees) OR (("clinical clerkship*"):ti, ab, kw)) AND (((electrocardiogram):ti, ab, kw) OR ((electrocardiograph*):ti, ab, kw) OR (MeSH descriptor: [Electrocardiography] explode all trees) OR ((ecg):ti, ab, kw) OR ((ekg):ti, ab, kw))

Supplementary Table 2: Quality appraisal tool

Indicator	Description
Research question	Is the research question (s) or hypothesis clearlystated?
Study subjects	Is the subject group appropriate for the study being carried out (number, characteristics, selection, and homogeneity)?
Data collection methods	Are the methods used (qualitative or quantitative) reliable and valid for the research question and context?
Completeness of data	Have subjects dropped out? Is the attrition rate less than 50%? For questionnaire based studies, is the response rate acceptable (60% or above)?
Control for confounding	Have multiple factors/variables been removed or accounted for where possible?
Analysis of results	Are the statistical or other methods of results analysis used appropriate?
Conclusions	Is it clear that the data justify the conclusions drawn?
Reproducibility	Could the study be repeated by other researchers?
Prospective	Does the study look forwards in time (prospective) rather than backwards (retrospective)?
Ethical issues	Were all relevant ethical issues addressed?
Triangulation	Were results supported by data from more than one source?

Buckley S, Coleman J, Davison I, Khan KS, Zamora J, Malick S, Morley D, Pollard D, Ashcroft T, Popovic C, Sayers J. The educational effects of portfolios on undergraduate student learning: A Best Evidence Medical Education (BEME) systematic review. BEME Guide No. 11. Med Teach. 2009 Apr; 31(4):282-98. doi: 10.1080/01421590902889897. PMID: 19404891