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Review article

Electrocardiography teaching methods

Métodos de enseñanza en electrocardiografía

Raimundo Carmona Puerta[1,2*] https://orcid.org/0000-0003-2246-1089

Elizabeth Lorenzo Martínez[1,3] https://orcid.org/0000-0001-8293-5392

[1]Universidad Católica del Cibao. La Vega, República Dominicana.

[2]Vicerrectoría de Investigación y Asuntos Académicos de Posgrado. La Vega, República Dominicana.

[3]Escuela de Medicina, Facultad de Ciencias de la Salud. La Vega, República Dominicana.

[*]Autor para la correspondencia: endotelio1975@gmail.com

ABSTRACT

Introduction: For decades, medical schools have been teaching the electrocardiogram, yet, low competency in this subject persists. The effectiveness of new teaching methods compared to traditional ones in addressing this gap remains a topic of study and debate.

Objective: The aim of this review is to discuss the methods used in the electrocardiogram teaching.

Methods: A comprehensive search of citations published in MEDLINE, Scopus, Web of Science, SciELO, ScienceDirect, and the Cochrane Library was conducted from August 2024 to November 2024. The search terms included: electrocardiography teaching; electrocardiography learning; competence; face-to-face lectures; digital learning; and flipped classroom. A total of 345 articles were identified, with 63 included in the review based on the quality of results and relevance to the topic.

Results: There is no gold standard for electrocardiogram teaching; thus, a variety of traditional and innovative methods are used, either in combination or as standalone approaches. Notable methods include traditional lectures, internet-based education, flipped classrooms, computer-assisted programs for electrocardiogram interpretation, mobile applications, and near-peer teaching. While all methods facilitate learning, no specific method is considered the best. However, self-directed learning correlates with lower interpretation competence. Evidence from randomized controlled trials suggests that summative assessment contributes more to electrocardiogram learning than formative assessment and reduces discrepancies between teaching methods.

Conclusions: A diverse range of methods exists for electrocardiogram teaching. Combining various approaches appears to be the most effective strategy, with summative assessment having a greater impact on learning outcomes.

Keywords: competence; digital learning; electrocardiography learning; electrocardiography teaching; face-to-face lectures; flipped classroom.

RESUMEN

Introducción: Durante décadas, las escuelas de medicina han enseñado el electrocardiograma, pero persiste la baja competencia en esta materia. La efectividad de los nuevos métodos de enseñanza en comparación con los tradicionales continúa siendo tema de estudio y debate.

Objetivo: Discutir los métodos utilizados en la enseñanza del electrocardiograma.

Métodos: Se realizó una búsqueda exhaustiva de citas publicadas en MEDLINE, Scopus, Web of Science, SciELO, ScienceDirect y la Biblioteca Cochrane desde agosto de 2024 hasta noviembre de 2024. Los términos de búsqueda incluyeron: enseñanza de la electrocardiografía, aprendizaje de la electrocardiografía, competencia, clases presenciales, aprendizaje digital y aula invertida. Se identificaron 345 artículos; solo 63 se incluyeron en la revisión por su calidad y relevancia.

Resultados: No existe un estándar de oro para la enseñanza del electrocardiograma; se utilizan una variedad de métodos tradicionales y nuevos, ya sea en combinación o como estrategias independientes. Incluyen conferencias tradicionales, educación basada en internet, aulas invertidas, programas asistidos por computadora para la interpretación del electrocardiograma, aplicaciones móviles y enseñanza entre pares. Si bien todos los métodos facilitan el aprendizaje, no se considera que alguno sea el mejor. Sin embargo, el aprendizaje autodirigido se correlaciona con menor competencia en la interpretación. Estudios aleatorizados sugieren que la evaluación sumativa contribuye más al aprendizaje del electrocardiograma que la formativa y reduce las discrepancias entre métodos.

Conclusiones: Existe una amplia gama de métodos para la enseñanza del electrocardiograma. Combinarlos parece ser la estrategia más efectiva, con la evaluación sumativa teniendo un mayor impacto en los resultados del aprendizaje.

Palabras clave: aprendizaje de la electrocardiografía; aprendizaje digital; aula invertida; clases presenciales; competencia; enseñanza de la electrocardiografía.

Recibido:

Aceptado:

Introduction

The electrocardiogram (ECG) is the simplest and the least expensive technique for evaluating cardiovascular patients. The information it provides is vast, as is the complexity of learning it. Several studies reveal that the deficit of skills in interpreting ECG is a worldwide problem that affects healthcare professionals of all academic levels.[1] Although almost all medical schools curricula include teaching electrocardiography, newly graduated doctors lack the necessary competence in this subject. Despite being aware in courses that this technique is widely available and that patients often approach young doctors for a diagnosis, the difficulty of learning it is seen in day-to-day practice. Among many, motivation is not high as the topic is complex no matter how simplified it is taught. The experience and pedagogical mastery of the teacher also contribute to this. The aim of this review is to discuss the methods used in the ECG teaching.

Methods

A search of citations published in MEDLINE, Scopus, Web of Science, SciELO, ScienceDirect, and the Cochrane Library was conducted from August 2024 to November 2024. The search terms included: electrocardiography teaching;

electrocardiography learning; competence; face-to-face lectures; digital learning; and flipped classroom.

The search encompassed original studies, narrative reviews, and systematic reviews with and without meta-analysis in English or Spanish. Additionally, the reference lists of the retrieved articles were manually examined to gather all potentially relevant studies. Duplicate citations were removed. The analysed articles spanned from 1965 to 2024. A total of 345 articles were identified, of which 63 were included in the review based on the quality of the results and their relevance to the topic. Priority was given to experimental studies with pre-tests and post-tests, as well as systematic reviews. Narrative reviews were only utilized to theoretically support certain sections of the document.

Results

Basic Concepts

To standardize the reading of this article, we adopted the definitions of key terms according to previous works by Viljoen *et al.*[2]

ECG analysis: refers to the detailed examination of an ECG tracing, which requires the measurement of intervals and the evaluation of the rhythm and each waveform.

ECG interpretation: refers to the conclusion reached after careful ECG analysis, that is, making a diagnosis of an arrhythmia, ischaemia and so on.

ECG competence: refers to the ability to accurately analyse and interpret the ECG.

Traditional methods

The face-to-face lecture is still one of the most important methods in ECG teaching, so many universities retain this modality as a unique or hybrid option. It is indisputable that direct student-teacher contact reaches its climax with this form of teaching. However, some authors see as a weakness of lecture-based learning that students remain passive and have little opportunity to develop independent thinking and problem-solving skills.[3,4]

The results obtained in lecture-based teaching can be improved when higher quality and updated teaching materials are provided to the students. Comparison of two groups of medical interns were educated via lecture and teaching rounds, resulting in higher final scores for the group that studied with a novel supplemental material containing a new algorithm for identifying arrhythmias.[5] In the experiment conducted by Hatala *et al.*,[6] involving two equivalently instructed groups utilizing the traditional category-based format for ECG diagnosis, the implementation of a contrastive session during the practical phase –where examples from various categories are intermingled– resulted in a significant learning gain compared to non-contrastive practice, where all examples are practiced within a single category block.

An experimental study in undergraduate nursing students comparing the influence of simulation-based and traditional teaching programs on critical thinking and self-confidence in ECG interpretation found that both achieved improvement, but no significant differences between methods.[7] The post-test scores after the application of several three-week interactive teaching sessions (physical/hybrid mode) on ECG rhythm identification, interpretation, management in COVID-19 patients, improved significantly [pre-test: 9.29/15 (61.9%) vs. post-test: 11.63/15 (77.5%); $p < 0.001$] in 682 healthcare workers involved in COVID-19 patient care and management (faculty, senior residents, junior residents, and interns).[8] In a survey of 88 teachers in a third-year internal medicine clerkship, lectures (75.0 %) and teaching rounds (44.0 %) were the most cited methods of instruction.[9]

The ladder diagram

The ladder or trapezoidal diagram is a very useful graphical aid in the teaching of electrocardiography. It was first used in 1885 for the purpose of temporally analysing venous and arterial pulsations or waveform tracings.[10] Its creation is attributed to Engelmann or Chaveau but its popularity came from the books by Wenckebach and Mackenzie.[11] The consecration of the method occurred in 1920 when Sir Thomas Lewis applied it to ECG analysis, which is why it has also been called Lewis diagram for decades.

The ladder diagram allows analysis of the mechanisms of arrhythmias at the same time as the ECG is displayed. In its most simplified form, three bands are drawn to represent the atria, the atrioventricular junction and the ventricles.[12,13] Additional bands can be used when, in order to explain the mechanism of a particular arrhythmia, it is necessary to represent certain anatomical areas in greater detail. Examples are the sinoatrial junction, the division of the atrioventricular junction into the AH and HV zones and the expansion of the ventricular zone with the representation of the left and right bundle branch.[14] It allows graphing normal, slow, accelerated, hidden conduction, the bidirectional character that it may have in some circumstances, the relationship between consecutive beats and temporal synchronization. The Lewis diagram can even be used to predict arrhythmia production mechanisms, as Pick and Langendorf did in 1950. Another property of these graphs is their intuitive character that allows the student to develop logical thinking that complements the memorization of images and systematic analysis.

Unfortunately, most of the ECG training currently taught does not even mention this powerful teaching method. Because many programs are short, many teachers were never educated in this method, and what is required a good background in electrophysiology, the Lewis diagram is hardly used today. An ECG course should never do without the ladder diagram.

The vectocardiogram

This tool has been lost in the teaching of the ECG. For many, it is an old technique that has been totally overtaken by the scalar ECG, but it is the ideal way to visualize the spatial component of the ECG. For Hurst(15) ECG interpretation has fallen to an unacceptable level and he attributes part of this deterioration to an insufficient understanding of spatial electrocardiography. A good ECG instructor should always incorporate vectorial principles when teaching electrocardiography.

Digital learning

Learning remotely is here to stay,(16) the newest consumers of post-secondary education, the so-called 'digital natives', have come to expect education to be delivered in a way that offers increased usability and convenience.(17) The method has spread universally with good acceptance by teachers and students. Its scope is greater than that of face-to-face teaching, although technological availability constitutes a limitation that must be considered for its implementation. In a meta-analysis encompassing 13 studies, no differences were found in acquired ECG competence between computer-assisted instruction and face-to-face teaching. However, a subanalysis indicated that computer-assisted instruction in a blended learning environment was more effective than face-to-face teaching alone, especially when trainees had unrestricted access to educational resources and/or participated in deliberate practice with feedback.(18) The ECG instruction, based on lectures and supplemented by a web application, was superior to lectures alone (immediate post-intervention test scores: 75.27 ± 16.22% vs. 50.27 ± 17.10%, $p <$

0.001; Cohen's d = 1.58) in a cohort study involving fourth-year medical students.[19] Six months after receiving ECG instruction, attrition of ECG competence was lower in the blended learning group compared to the conventional teaching group (57.7 ± 18.5% vs 31.0% ± 13.2%, p < 0.001).

The integration of a low resource JavaScript based ECG training interface (CrowdLabel) and a standardized curriculum for self-guided tuition in ECG interpretation was evaluated in a recent work. After a 6 week training period, a significant improvement was observed in the ECG interpretation scores compared to the results during the training period (median accuracy scores during the training period: 33.9% vs. median accuracy scores during the test: 37.5%; p < 0.05).[20] The use of perceptual adaptive learning modules incorporated into the physician assistant students curriculum after lecture-based ECG learning improved ECG interpretation accuracy and fluency, which supports the supplementary use of this learning technique.[21] A pre- and post-test design study enrolling medical students from the University of Copenhagen examined the effect of a standalone web-based ECG tutorial on the acquisition of ECG interpretation skills.[22] The post-test score improved significantly (possible score range: 0 – 100; pre-test: 52.7 ± 16.8 vs. post-test: 68.4 ± 12.3; p < 0.001) demonstrating the benefit of the method.

The application of a web-based ECG competition strategy in improving ECG interpretation was successful in Haiti when applied to internal medicine and emergency medicine residents.[23] In the systematic review by Ardekani *et al.*[24] the use of these methods led to better or at least identical outcomes relative to the control groups in the included studies. The use of web-based, self-directed learning resources substantially improves ECG learning according to an international, prospective, randomized controlled trial that enrolled 863 healthcare professionals and medical students.[25] The trial showed benefits in any of the three methods investigated (online question-bank, online lectures and online, question-bank and lectures [hybrid]).

An interventional study conducted in Polish fifth-year medical students that compared two ECG e-learning strategies concluded that collaborative e-learning of ECG reading is superior to self-e-learning strategy.[26] Web-based peer or individual learning were shown to be equally effective in improving learning flow, interpretation skills, and self-confidence in a study conducted at two colleges of nursing in the Republic of Korea.[27] New results suggest that ECG learning supported by self-generation of diagnoses during online practice is better than answering multiple-choice questions.[28] The reinforcement of traditional lectures with web applications enhances competency and confidence among medical students.[19] The use of social networks such as Facebook and X are also being explored as possible educational tools for teaching ECG, but definitive data are not yet available.(29)

Computer-based programs on ECG interpretation have been used for years with good results.(30) Since the pioneering study by Owen *et al*.(31) it was seen that the use of computers would be promising in the teaching of ECG. With the technology advancement, these programs have been transformed into mobile applications.

Ramos-Garzón(32) developed a mobile application aimed primarily at nursing students that has already been expanded to nursing and medical professionals. After validation by experts, it achieved a content validity coefficient of 0.91 for clarity, 0.95 for precision and 0.97 for relevance. The application consists of four learning modules and a heart rhythm simulator. It is currently used in more than 40 countries. The University of California School of Medicine introduced the use of the AliveCor KardiaMobile (medical-grade ECG) mobile application in the first year of the career to enhance the hands-on learning experience and interpretation of cardiovascular physiology.(33) Students were divided into groups of eight to ten and worked for 50 minutes with four active learning assignments. To assess students' perceptions of the use of mobile ECG applications, they were asked to complete an online survey at the completion of their academic year. 67% (n = 39) agreed or strongly agreed that the AliveCor KardiaMobile device was a valuable addition to electrocardiography instruction, 51% (n = 39) stated that the activity improved their understanding of the ECG, 92% (n = 39) stated agreement or strong agreement that the use of mobile medical devices will help them improve their medical education. 92% of students (n = 38) agreed or strongly agreed that knowing about mobile medical devices will be important in their future practice as physicians. In a study, the benefits of utilizing mobile learning were observed exclusively among undergraduate medical trainees, but not among residents, specifically in the process of revising and correcting an erroneous initial ECG diagnosis.(34) The authors suggest that the observed differences may be attributed to residents' tendency to maintain their initial diagnoses without considering alternative possibilities, a phenomenon that has been previously described ("premature closure") and is often encountered in physicians who rely more on pattern recognition than on systematic analysis.(34,35,36,37,38)

New teaching methods in electrocardiography

Derganc y Gomiščček(39) developed an experimental method for teaching basic ECG principles. The experimental setup has a model representing the human body, a direct current power supply, two digital multimeters, and a simple single-lead electrocardiograph. Students perform four experimental tasks consisting of 1) learning the concept of the electrical dipole of the heart, 2) becoming familiar with the meaning and shape of equipotential lines, 3) measuring the voltages between points representing the right arm, left arm and left leg to recreate a simplified ECG of the three standard leads, plus making changes in the orientation of the dipole by gradually modifying the connector pairs in the model, and 4) performing their own ECG to correlate what they learned in the simple model with a real ECG signal. In the experience of the authors more discussion of electrocardiography is often generated after the last task. The innovative pedagogical method HEART (heart rate/rhythm, electrical conduction, axis, R-wave progression, tall/small voltages, and ST/T changes) put into practice through a workshop showed favourable results in medical students and junior emergency medicine residents from the University of Toronto.(40) The method was enhanced with other teaching strategies such as flipped classroom and near-peer teaching. In a post-HEARTS ECG workshop survey, residents and students agreed or strongly agreed that the workshop improved their perceived ability y confidence in interpreting ECG. Among the strengths of the workshop are the ease of remembering and applying the HEARTS mnemonic, and the iterative application of the approach. A promising strategy based on having students draw ECG traces based on a given diagnosis was preliminarily tested in a small controlled trial.(41) The developers stated that the new method improves student engagement and suggests better performance, while providing more precise feedback to teachers.

Flipped classroom is a relatively new learning methodology. Instead of following the traditional order of delivering content in the classroom and then doing homework at home, the student studies the planned content outside the classroom and takes advantage of class time to do hands-on activities supervised by the teacher. A meta-analysis of 28 studies showed an overall significant effect in favor of flipped classrooms over traditional classrooms for health professions education.(42) A randomized controlled trial for ECG learning (experimental group: flipped classroom; control group: lecture-based learning) which involved 181 junior-year medical undergraduates, found higher scores in the experimental group than in the controls and a positive attitude toward the flipped classroom method that was similar to that found in the control group.(43) Another experimental study that explored the effects of the Cardiac Rhythm Identification for Simple People method in 120 nurses using the flipped classroom approach or lecture-based learning showed superiority in the former.(44) Parameters such as ECG test scores, ECG test scores six months later, self-learning enthusiasm, understanding of teaching content, satisfaction of teaching mode, satisfaction of teaching effectiveness, and interest in learning ECG were significantly better in the group in which it was applied the flipped classroom. Attending classes improves outcomes in the ability to interpret ECG and related content when a flipped classroom format is used in undergraduate medical students, but appears to offer no advantage when content is delivered by lecture.[45] The flipped classroom combined with workshops outperformed the traditional face-to-face lecture method in a recent multicenter study conducted among fourth-year French medical students after completing their cardiology internships.[46]

A new graphical method was created by Chen[47] with the aim of facilitating the teaching of the ECG. It has three properties that aid in memorization and interpretation, 1) symmetry, 2) difference and 3) regionality, that allude to the spatial arrangement of the leads, the magnitudes of the deflections and the topography. Some aspects of the ECG are usually taught by algorithms, this is the case of arrhythmias. Because the diagnostic possibilities are large and the theoretical foundations are complex, the basic courses taught at the undergraduate level implement this resource. The application of a new algorithm used as supplementary material to lectures and teaching rounds proved to be superior to the same teaching method without algorithm in medical interns.[5]

Other methods

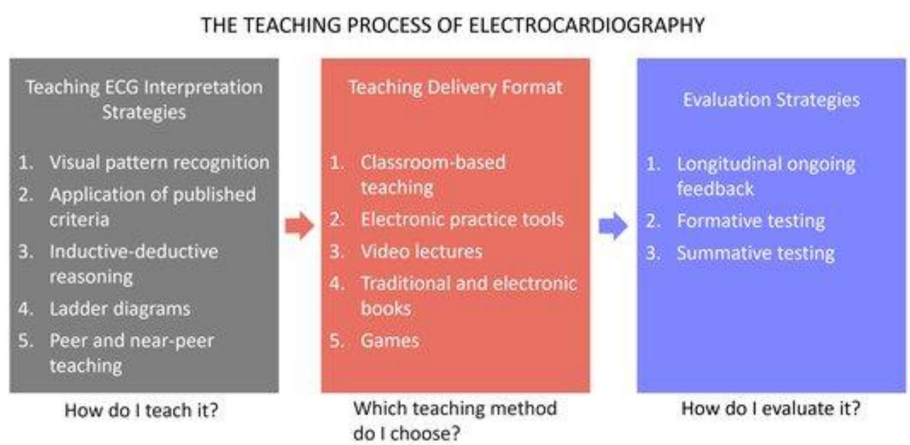
The realization of an interactive national ECG workshop for medical students in the United Kingdom resulted in a net gain of knowledge.[48] It was structured in six one-hour sessions where tutorials covering all major ECG topics were provided. The researchers considered that the benefit was obtained from activity-based teaching. In 68 house officers at Pakistan Naval Ship Shifa Hospital, Karachi Pakistan, the realization of a goal-directed ECG workshop improved the competence and confidence in ECG interpretation.[49]

Several universities have enthusiastically adopted the teaching model known as near-peer teaching, wherein a senior student assumes the role of an instructor and imparts knowledge to one or more peers. In the context of ECG education, near-peer teaching demonstrated superiority over the e-learning approach in second-year medical students who were randomly assigned to one of the two methods.[50]

A quasi-experiment involving 230 nurses concluded that gamification is an effective way to enhance the acquisition of basic electrocardiography knowledge compared to the traditional method.[51] ECG training through team-based learning proved more effective in improving ECG reading proficiency than the traditional lecture method, according to an experimental study conducted with 64 nurses.[52] Monteiro *et al.*[53] studied the effect of massed and distributed instruction and blocked and interleaved practice on ECG learning, in medical students. The study revealed that distributed instruction was superior to massed instruction, but no clear advantage was found with interleaved practice.

The best method to teach and learn ECG

A recent meta-analysis that selected 23 studies on methods of teaching ECG to medical students concluded that selecting the most suitable strategy depends on the culture and facilities of the medical schools and the primary intent of teaching and assessment.(24) There is no single method or format that can be labeled as the best for teaching or learning to interpret the ECG, but self-directed learning appears to be associated with poorer interpretation competence.(54) A combination of methods and exposure to numerous ECG traces is recommended. Antiperovitch *et al.*(55) discussed the foundational aspects of ECG teaching in their insightful article. These aspects are succinctly summarized in as an authentic process (fig.).



Note: The figure shows the three sequential questions that a teacher should ask when preparing an electrocardiography course and the main options available.

Abbreviations: ECG = Electrocardiogram.

Fig. - Teaching process of electrocardiography.

The assessment format matters

The way in which the content will be evaluated is also important since there are two main methods, formative and summative assessment. In a medical students group randomized to receive traditional ECG training or near-peer teaching summative rather than formative assessment enhanced (two times) the performance and decreased any difference between teaching methods.[56] A randomized controlled trial to see the effects of formative or summative assessment in 534 medical students who received three methods of teaching (self-directed learning, lecture-based training, or small-group peer teaching) found that in comparison with formative assessments, summative assessments enhanced the probability of authentically recognizing at least 3/5 ECG diagnoses.[57] The authors concluded that summative assessments impact learning outcomes much higher. Inaba *et al*.[58] have been the first to communicate the development of an assessment tool for the competence of ECG interpretation using expert panel consensus and multidimensional item response theory. A survey of 88 faculty members involved in internal medicine clerkships revealed that the most commonly employed assessment methods were written examinations (40%) and objective structured clinical assessments (23%).[9]

Possible targets where to reinforce ECG teaching

After surveying 325 preclinical and clinical medical students, Ohn *et al*.[59] identified five key points in ECG learning. 18.2% reported lack of recall, 28.4% lack of understanding, 3.6% difficulty in application, 15.1% difficulty in analysis and 17.8% difficulty in interpretation. A univariate analysis based on survey data obtained from Hebrew medical students showed that the sources of knowledge that are significantly associated with competence are: attendance in regular ECG classes (OR: 0.51 [95% CI: 0.30–0.85]; $p<0.010$), ECG teaching during clinical clerkships (OR: 2.75 [95% CI: 1.65–4.60]; $p<0.0001$) and work experience in medicine (OR: 7.78 [95% CI: 4.28–14.14]; <0.0001).[60] In that investigation, self-study was not associated with the development of competence in ECG interpretation. In multivariate analysis only previous medical experience was associated with competence (OR: 7.97 [95% CI: 4.03-15.77]; $p < 0.0001$). Data from surveys of two cohorts of first-year students from two medical schools revealed that total cases practiced and time spent practicing were correlated with their performance during practice and on an exam.[61] From a mathematical model, the study also identified that students would need to spend 112 minutes and complete 34 practice cases to achieve 75% on an ECG rhythm strip exam. Following the adoption of a new curriculum design at Ain Shams University, Cairo, Egypt, which included the introduction of a new method of teaching ECG to second-year students, the most important factors that facilitated learning were identified and recommendations were made based on student perceptions.[62] 91.9% (n = 62) of the students stated that the integrated clinical lectures, visiting patients, and relating ECGs to their clinical conditions were the most important facilitating factors in their learning during the new approach. Among the suggestions they made to improve the approach were: an integrated forum containing lectures and presentation of ECGs, more practice, creation of an integrated study guide similar to an ECG booklet with links to relevant videos and clinical vignettes, utilization of gaming platforms, and holding national and international competitions. Based on their experiences Stacey and Manthey[63] recommend increasing the number of ECGs that students work with, achieving immediate feedback and having a single facilitator who guarantees that all students receive the same information and have similar experiences. If small group work is preferred, they suggest preparing separate facilitators to ensure each group receives similar information and covers the same material. The excess of information in ECG courses also conspires in the development of ECG interpretation skills. Several authors believe that undergraduate ECG courses should avoid excessive content and should be as close as possible to what young physicians will encounter in clinical practice.[64]

Conclusions

There are several ECG teaching methods such as traditional lecture, internet-based education, flipped classroom, computer-based programs on ECG interpretation, mobile applications, near-peer teaching, among others. Most methods positively impact learning. Rather than using only one of them, it is recommended to integrate several methods. The method associated with the poorest outcomes in acquiring ECG competency appears to be self-directed learning. The evaluation system employed influences ECG learning. Evidence supports the use of summative assessment over formative assessment.

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Conflicts of interest

The authors declare no conflicts of interest.