



Web-Based ECG Learning Applications and Their Potential Contribution to Basic Trauma and Cardiac Life Support Competencies: A Scoping Review

Nur Halimah¹, Inca Buntari Agustini², Ni Made Dewi Wahyunadi³, I Wayan Edi Sanjana⁴

^{1,2,3,4}Faculty of Health, Institute of Technology and Health, Bali, Jl. Tukad Balian No.180, Renon, Kecamatan Denpasar Selatan, Kota Denpasar, Bali, Indonesia
Corresponding E-mail: incaagustini@gmail.com

ABSTRACT

Introduction: Electrocardiogram (ECG) interpretation is essential for recognising shockable rhythms, life-threatening arrhythmias, and ischemia in basic trauma and cardiac life support (BT&CLS). Although digital ECG learning tools are increasingly implemented, their contribution to BT&CLS-related competencies has not been comprehensively mapped, particularly in low- and middle-income countries (LMICs). **Objective:** To map and synthesise evidence on web-based ECG learning applications used to improve competencies relevant to BT&CLS, including knowledge, interpretation accuracy, confidence, usability, and resuscitation-related performance. **Methods:** This scoping review followed the PRISMA-ScR guideline. Searches were conducted in PubMed, ScienceDirect, and Google Scholar for peer-reviewed studies published in English or Indonesian between January 2019 and December 2024. Eligibility was guided by the Population–Concept–Context framework and included healthcare learners and professionals using web-based, mobile, or digital ECG learning tools in emergency, cardiovascular, or life-support education. Two reviewers independently performed study selection, data extraction, and quality appraisal using RoB 2 and Joanna Briggs Institute tools. Findings were synthesised narratively through thematic analysis. **Results:** Of 1,243 records identified, 18 studies were included. Study designs comprised randomised controlled trials, quasi-experimental, mixed-methods, observational, and usability studies across diverse settings. Web-based ECG applications consistently improved ECG knowledge and interpretation accuracy, with several interventions outperforming traditional lectures. Participants also reported increased confidence, engagement, and positive user experience. Methodological quality was generally moderate to good, although limited long-term follow-up and direct BT&CLS outcome assessment were noted. **Conclusion:** Web-based ECG learning applications enhance ECG-related competencies and are feasible across settings, including LMICs. Future studies should integrate ECG learning into BT&CLS simulations and evaluate effects on real-world resuscitation performance.

ARTICLE INFO

Article History:

Received: December 03rd, 2025

Revised: June 28th, 2026

Accepted: June 30th, 2026

First Available Online:

June 30th, 2026

Published: June 30th, 2026

Keywords:

Education, Distance¹,
Electrocardiography²,
Basic Life Support³,
Education, Nursing⁴,
Emergency Nursing⁵,
Scoping Review⁶.

1. INTRODUCTION

Cardiovascular diseases (CVDs) remain the leading cause of global mortality, contributing to approximately 18.6 million deaths annually and disproportionately affecting low- and middle-income countries (LMICs) (Roth et al., 2020). A substantial proportion of these deaths are attributed to acute coronary syndromes, malignant arrhythmias, and sudden cardiac arrest events requiring rapid assessment and timely intervention to prevent irreversible outcomes. Survival from out-of-hospital cardiac arrest (OHCA) remains low, frequently below 10%, despite advancements in emergency medical systems (Kiguchi et al., 2020). As emphasised in international resuscitation guidelines, early recognition of cardiac arrest, rapid initiation of high-quality basic life support (BLS), effective defibrillation, and informed advanced cardiac life support (ACLS) remain essential determinants of survival (Panchal et al., 2020).

Electrocardiography (ECG) represents an important educational and clinical component within cardiac and trauma life support. Effective ECG interpretation provides foundational information that supports recognition of shockable rhythms, detection of life-threatening arrhythmias, identification of myocardial ischemia, guidance for defibrillation decisions, and monitoring of peri-arrest deterioration; however, these competencies operate alongside broader clinical reasoning, team coordination, and procedural skills required during emergency care and resuscitation (Panchal et al., 2020). Nevertheless, persistent global evidence shows that ECG interpretation competency remains suboptimal among medical students, nurses, and even experienced clinicians. Studies have documented frequent misinterpretation of common arrhythmias, ST-elevation myocardial infarction (STEMI), and conduction abnormalities, with significant implications for patient safety (Amini et al., 2022; Kashou et al., 2020). These gaps pose particular concerns for high-acuity settings such as emergency departments, trauma units, and intensive care units where rapid ECG-informed decision-making is critical.

Traditional ECG training relies heavily on lectures, printed tracings, and workshop-based activities embedded in BLS or ACLS courses. While valuable, these approaches often provide limited repetitive practice, insufficient case variety, and minimal personalised feedback—factors that restrict long-term retention and expert-level pattern recognition. Recent educational literature emphasises the importance of spaced repetition, exposure to diverse ECG patterns, real-time feedback, and interactive learning mechanisms that may overcome the limitations of conventional classroom formats (Bazrgar et al., 2023; Nilsson et al., 2019).

The rise of digital learning has enabled scalable, flexible, and interactive ECG learning through web-based applications, online modules, mobile apps, and microlearning platforms. Systematic evidence suggests that digital ECG learning tools improve interpretation accuracy, theoretical knowledge, and learner confidence compared with traditional teaching methods (Maia et al., 2021). Their advantages include 24/7 accessibility, unlimited opportunities for practice, multimedia explanations, automated scoring, and the ability to customise difficulty levels.

Web-based ECG platforms have been implemented across diverse populations. Nilsson et al. (2019) reported that medical students' engagement with an online ECG platform depended strongly on perceived usefulness and alignment with assessment demands. Gumilang et al. (2021) demonstrated significant improvement in ECG interpretation competency using a mobile web-based application in Indonesia. Similarly, Gharini et al. (2023) found that a Massive Open Online Course (MOOC) enhanced general practitioners' ECG knowledge while identifying challenges related to learner completion. More advanced innovations, including blended-learning ECG programs (Bazrgar et al., 2023), structured webpage-based instruction for nurses (Lee et al., 2024), and asynchronous microlearning ECG cases for residents (Capustin et al., 2025), suggest that frequent, clinically relevant, and learner-centred exposure may support ECG competency development. Collectively, these studies demonstrate that web-based ECG learning applications can provide pedagogically strong and scalable learning environments; however, the extent to which these educational gains contribute to competencies required in trauma and cardiac life support remains uncertain.

Parallel to developments in ECG education, resuscitation training itself has increasingly adopted digital and blended modalities. A systematic review by Chong et al. (2023) concluded that online-only and blended BLS training can achieve learning outcomes comparable to or better than

conventional in-person approaches. Han et al. (2023) also demonstrated that remote and online BLS education improves essential life-support competencies among laypersons. Despite this progress, few digital resuscitation interventions explicitly integrate structured ECG learning within trauma and cardiac life support pathways.

Importantly, improved ECG interpretation should not be assumed to directly translate into improved resuscitation performance. Competency-based education frameworks distinguish cognitive competence (knowledge acquisition and interpretation) from performance competence (application of knowledge in real clinical situations). Within emergency and resuscitation settings, ECG interpretation must be integrated with situational awareness, rapid decision-making, communication, and procedural execution under time pressure. Simulation-based learning theory further suggests that competency transfer occurs more effectively when learners apply knowledge within realistic and context-rich scenarios rather than through isolated skill acquisition. Therefore, digital ECG learning may serve as a foundational component supporting preparedness for BT&CLS, but additional integration with simulation and emergency decision-making activities is likely required before measurable improvements in resuscitation performance can occur (Chong et al., 2023; Han et al., 2023; Panchal et al., 2020).

Despite growing interest in digital learning, several critical gaps remain in the current body of knowledge. First, there is persistent fragmentation between ECG learning and resuscitation training. Most ECG-focused digital tools are developed and evaluated as stand-alone educational resources and rarely align their instructional design with competencies required for trauma and cardiac life support (Amini et al., 2022; Lee et al., 2024). Second, synthesis of web-based ECG applications explicitly connected to trauma and cardiac life support contexts remains limited. Previous reviews of ECG education (Maia et al., 2021) and digital BLS or ACLS training (Chong et al., 2023) have examined these domains separately. Third, evidence from LMICs remains limited despite the high burden of cardiac emergencies and the potential of digital approaches to expand equitable access to training (Gumilang et al., 2021; Gharini et al., 2023).

To address these gaps, this scoping review aims to systematically map, evaluate, and synthesise web-based ECG learning applications and examine their potential contribution to competencies relevant to basic trauma and cardiac life support. Specifically, this review seeks to describe the characteristics of web-based ECG learning applications used in medical, nursing, and emergency care education; evaluate reported learning outcomes including knowledge, technical skills, confidence, retention, and selected performance indicators; and identify pedagogical, technological, and contextual gaps that may inform future development of integrated ECG and life-support digital training models.

2. METHODS

Study Design

This review adopted a scoping review design to systematically map the breadth and nature of existing evidence on the use of web-based electrocardiogram (ECG) learning applications to enhance competency in Basic Trauma and Cardiac Life Support (BT&CLS). A scoping methodology was chosen to accommodate the diversity of study designs, educational contexts, and digital learning modalities observed in the literature, and to enable exploration of emerging concepts that may not yet be suitable for a full systematic review or meta-analysis. The review process was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR), ensuring methodological transparency, comprehensive coverage, and structured reporting across all stages of evidence identification, selection, and analysis (Tricco et al., 2018). This approach supported a broad examination of how digital ECG learning innovations are implemented, the competencies they target, and the extent to which they intersect with emergency care education, clinical decision-making, and technology-enhanced instructional strategies.

Search Strategy

A comprehensive search strategy was implemented to identify relevant literature published between 1 January 2019 and 31 December 2024. The review period was intentionally restricted to

this timeframe because web-based and mobile ECG educational technologies have evolved rapidly in recent years, particularly following increased adoption of digital and remote learning approaches after the COVID-19 pandemic. Limiting inclusion to studies published from 2019 onward was intended to ensure relevance to contemporary educational technologies and current implementation contexts.

Electronic searches were conducted in PubMed, ScienceDirect, and Google Scholar because these databases provide broad coverage of medical, nursing, health professions education, and educational technology literature. Searches were completed in January 2025.

Search terms were developed iteratively using combinations of Medical Subject Headings (MeSH) and free-text terms related to electrocardiography, digital learning, web-based education, and life-support education. Boolean operators (AND, OR), phrase searching, and truncation were applied where supported by each database.

The following search strings were applied:

PubMed

("Electrocardiography"[MeSH] OR ECG OR electrocardiogram OR electrocardiography)

AND ("Education"[MeSH] OR learning OR training OR teaching)

AND (web-based OR online OR digital OR mobile OR e-learning OR application OR MOOC OR simulation OR virtual reality)

AND ("Basic Life Support" OR "Cardiac Life Support" OR emergency OR trauma OR resuscitation)

Filters:

Publication dates: January 2019–December 2024

Language: English OR Indonesian

Article type: journal articles

ScienceDirect

TITLE-ABSTR-KEY

(electrocardiogram OR ECG)

AND

(web-based OR online OR digital OR mobile learning OR e-learning OR simulation)

AND

(training OR education OR competency OR interpretation)

Filters:

Research articles

Publication years: 2019–2024

English or Indonesian

Google Scholar

("electrocardiogram" OR ECG)

AND

("web-based learning" OR "online learning" OR "digital education")

AND

(training OR competency OR interpretation)

Google Scholar retrieval followed a structured procedure to improve reproducibility. Searches were conducted using quotation marks and Boolean combinations where supported. Results were sorted by relevance, and screening was limited to the first 200 records (first 20 pages) because relevance decreases substantially beyond this threshold. Duplicate records and clearly irrelevant titles were excluded during screening. Forward and backward citation tracking was additionally conducted for included studies to identify potentially eligible publications not captured through database searching.

To minimise publication bias, citation searching and limited gray literature screening were also undertaken, including institutional repositories and conference materials when sufficient methodological information was available.

Eligibility Criteria

The eligibility criteria were structured using the Population–Concept–Context (PCC) framework to ensure a systematic and coherent approach to study selection. The Population included healthcare learners and professionals such as medical students, nursing students, nurses, physicians, emergency care providers, and other clinical trainees involved in ECG education or basic trauma and cardiac life support (BT&CLS) training. The Concept focused on web-based, mobile, or digital ECG learning applications designed to enhance competencies related to ECG interpretation, rhythm recognition, decision-making in trauma or cardiac emergencies, knowledge acquisition, confidence, or user satisfaction. The Context encompassed educational or clinical training environments where digital or online ECG learning tools were implemented as part of resuscitation, emergency care, or cardiovascular education.

Studies were eligible if they reported empirical findings quantitative, qualitative, or mixed-methods published in peer-reviewed journals between 2019 and 2024 and written in English or Indonesian. Studies were excluded if they involved non-healthcare populations, did not address ECG-related learning within trauma or cardiac life support contexts, focused solely on traditional face-to-face or printed teaching methods without any digital component, or were published prior to 2019. Applying the PCC framework ensured that the review synthesized recent, relevant, and contextually appropriate evidence aligned with evolving digital learning technologies and methodological guidance for scoping and comprehensive reviews (Tricco et al., 2018).

Study Selection Process

Following the database search, all retrieved articles were imported into a reference management program to remove duplicates. Titles and abstracts were screened independently by two reviewers who applied the predefined eligibility criteria. Articles deemed potentially relevant were subjected to full-text review. Any discrepancies between reviewers were resolved through discussion or consultation with a third reviewer to maintain methodological rigor. This multi-step screening approach ensured that only studies meeting the predetermined standards were included in the final synthesis and reduced the potential for reviewer bias (Pollock et al., 2021).

Data Extraction

Data extraction was conducted using a structured approach based on guidance from the Cochrane Handbook for Systematic Reviews of Interventions. A standardized extraction matrix was developed to collect information systematically from each included study. The extracted data encompassed details such as authorship, publication year, geographical context, study design, sample characteristics, type and features of the web-based ECG learning platform, comparator conditions when applicable, assessment tools employed to measure outcomes, key findings, effect measures, and limitations identified by the original researchers. Two reviewers independently performed the extraction process to minimize human error and ensure accuracy. Any differences were reviewed collaboratively until consensus was reached. This process helped ensure that data were captured consistently and comprehensively across all included studies (Higgins et al., 2022).

Quality Assessment

Quality appraisal was performed to evaluate the methodological soundness of the included studies. Randomized controlled trials were assessed using the Cochrane Risk of Bias 2 (RoB 2) tool, which evaluates bias across domains related to randomization, deviations from intended interventions, outcome measurement, and selective reporting. Quasi-experimental and observational studies were appraised using the Joanna Briggs Institute Critical Appraisal Checklists, which assess criteria such as clarity of aims, appropriateness of methods, control of confounding variables, validity of measurement tools, and adequacy of statistical analysis. Quality assessment was completed independently by two reviewers, and disagreements were resolved

through discussion. This systematic evaluation ensured that the synthesis considered the strength and limitations of each study and informed interpretation of the overall evidence base (Aromataris & Munn, 2020).

Data Synthesis and Analysis

Given the heterogeneity in study designs, intervention formats, participant groups, and outcome measures, a narrative synthesis approach was employed. Study findings were integrated thematically to highlight patterns, differences, and emerging concepts across the body of literature. The synthesis focused on the effectiveness of web-based ECG learning applications, the impact of digital platforms on learner knowledge, accuracy, confidence, and satisfaction, and the usability and design considerations that influence the success of such interventions. Quantitative results were presented descriptively using reported metrics such as mean differences, p-values, and effect sizes. Qualitative findings were synthesized using thematic analysis principles to identify learners' experiences, perceived benefits, and challenges associated with digital ECG learning tools. The integration of findings across methods provided a comprehensive understanding of the role of web-based ECG learning applications in supporting BT&CLS competency development (Braun & Clarke, 2021).

Ethical Considerations

This study did not involve primary data collection and was therefore exempt from ethics review board approval. Nevertheless, all ethical principles in scholarly reporting were upheld. These included accurate attribution of ideas through proper citation, avoidance of plagiarism, and faithful representation of findings from original studies. The review was conducted with a commitment to ensuring that interpretations remained consistent with the intentions of the original authors and that no data were altered or misrepresented.

3. RESULTS

Searching results

The updated PRISMA flow diagram outlines the systematic process used to identify and select studies for inclusion in the review. A total of 1,243 records were retrieved from database searches, and no additional records were obtained from registers. Before screening, 257 duplicate records were removed, along with 96 items flagged as ineligible by automated tools and 57 records excluded for other reasons. This resulted in 833 records that proceeded to title and abstract screening. During this stage, 568 records were excluded because they did not meet the predefined eligibility criteria. The remaining 265 reports were examined for retrieval, although 153 could not be accessed due to unavailable full texts or access restrictions. A total of 112 full-text articles were successfully retrieved and assessed for eligibility. Of these, 94 were excluded because they involved non-digital or traditional ECG education, lacked ECG or BT&CLS training components, or included non-healthcare populations. Ultimately, 18 studies met all inclusion criteria and were incorporated into the final review (Figure 1).

Quality of study assessment

The methodological quality of the included studies was evaluated using the Cochrane RoB 2 tool for randomized controlled trials and the Joanna Briggs Institute Critical Appraisal Checklists for quasi-experimental, observational, and mixed-methods designs. Overall, the RCTs demonstrated low to moderate risk of bias, with generally appropriate randomization procedures, validated outcome measures, and consistent reporting. Minor concerns were related to the lack of blinding and limited description of allocation concealment, which are inherent challenges in educational intervention research. The quasi-experimental studies showed moderate quality, with clear descriptions of interventions and reliable ECG testing instruments. However, several studies used single-group pretest–posttest designs without control groups, which reduced control over confounding factors. Observational and usability-focused studies demonstrated acceptable methodological rigor, although reliance on self-reported measures introduced subjective bias. Across all study types, intervention fidelity, measurement validity, and appropriateness of

statistical analyses were adequate. Most studies used standardized ECG interpretation tests and reported significant learning improvements. Independent assessment by two reviewers ensured consistency in appraisal. Taken together, the evidence base was judged to be methodologically sound enough to support meaningful synthesis and interpretation (Aromataris & Munn, 2020).

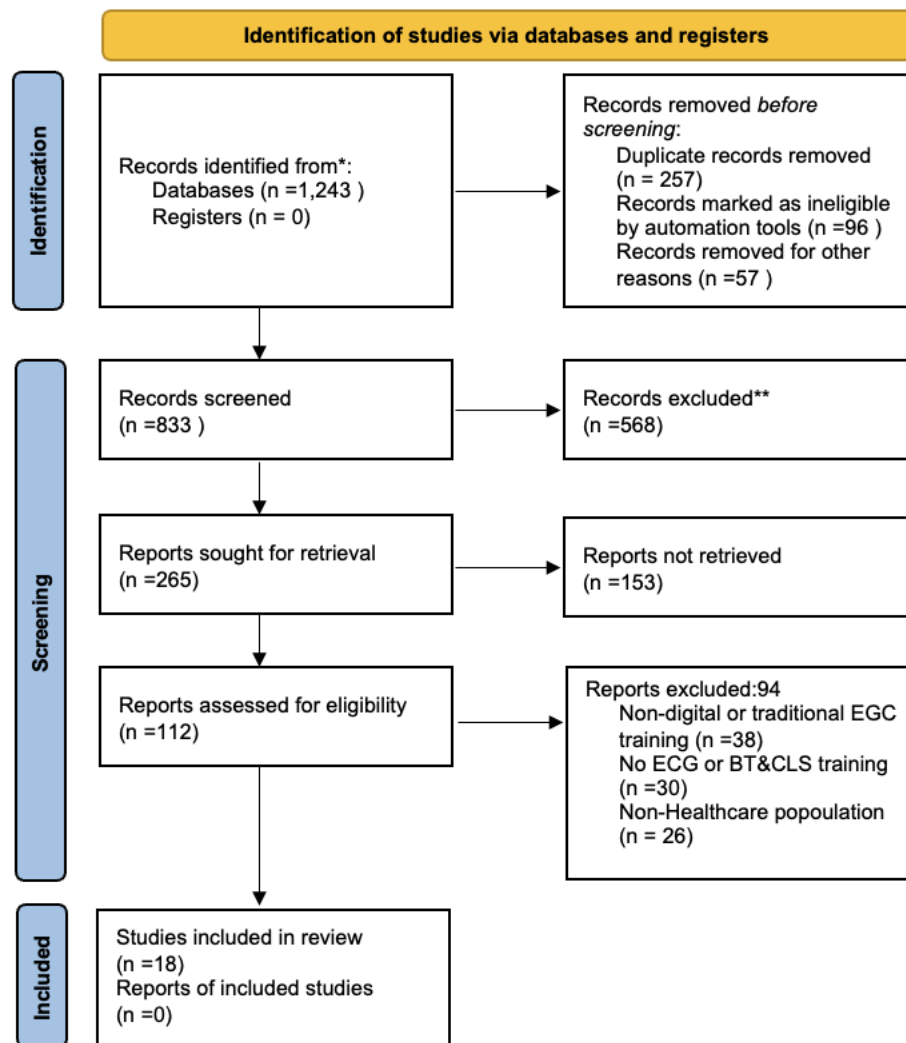


Figure 1. PRISMA flow diagram

Characteristics of included studies

The studies included in this review demonstrated substantial methodological diversity, encompassing randomized controlled trials, quasi-experimental pre–post designs, mixed-methods evaluations, observational interventions, and methodological usability studies. This heterogeneity reflects the range of approaches used to examine the impacts of digital ECG education across different learner groups, including medical students, nursing students, clinical nurses, residents, and general practitioners. Randomized controlled trials, such as those conducted in Egypt, India, and within international multi-center contexts, provided strong experimental evidence regarding the comparative effectiveness of digital platforms versus traditional instruction (Salem et al., 2023; Iqbal et al., 2024; Kashou et al., 2024). Quasi-experimental and pre–post studies contributed robust descriptive data on learner improvement over time, documenting substantial gains in ECG knowledge and interpretation accuracy among diverse clinical trainees (Viljoen et al., 2020; Gumilang et al., 2021; Abdelwahab et al., 2024; Kılıç et al., 2025). Mixed-methods investigations enriched these findings by capturing user behavior, perceived usefulness, and contextual barriers to implementation (Nilsson et al., 2019). Furthermore, usability and methodological development studies highlighted the importance of design quality, intuitive navigation, and pedagogical value in mobile and web-based ECG applications (Lima et al., 2019; Kohan et al., 2024). Collectively, this methodological variation enabled a comprehensive examination of both the measurable learning outcomes and the experiential dimensions of digital ECG education, supporting a nuanced synthesis of the effectiveness, usability, and adaptability of web-based ECG learning tools across different educational and regional settings.

Because of substantial heterogeneity in intervention design, learner population, digital platform characteristics, and measured outcomes, findings were organised into thematic categories rather than pooled quantitatively. This thematic synthesis enabled identification of recurring patterns across studies and improved transparency in interpreting how web-based ECG learning applications contribute to ECG-related educational outcomes and their potential relevance to BT&CLS.

Main findings

Synthesizing quantitative and qualitative insights revealed coherent and complementary evidence supporting the effectiveness of web-based ECG learning applications. Quantitative results showed consistent improvements in ECG competency, while qualitative themes highlighted enhanced confidence, favorable usability experiences, and appreciation for flexible digital learning formats. This integrated narrative, informed by thematic analysis, provides a comprehensive understanding of how digital platforms contribute to the development of BT&CLS-related competencies (Braun & Clarke, 2021).

Table 1. Summary Of Methodological Quality Appraisal Of Included Studies

Study	Appraisal Tool	Summary of Appraisal Findings	Overall Appraisal
Nilsson et al., 2019	JBI (Mixed-methods)	Clear objectives and appropriate data collection; limited evidence regarding integration into curriculum and transferability	Moderate
Viljoen et al., 2020	JBI (Quasi-experimental)	Appropriate intervention and outcome measurement; limited long-term follow-up	Moderate
Klein et al., 2020	JBI (Observational)	Adequate educational intervention and reporting; no comparator group	Moderate
Lima et al., 2019	JBI (Usability / observational)	Well-described intervention and usability assessment; limited evaluation of learning outcomes	Moderate
Gumilang et al., 2021	JBI (Quasi-experimental)	Appropriate outcome assessment; absence of control group reduced methodological strength	Moderate
Joseph et al., 2022	JBI (Pre-post intervention)	Clear educational objectives and outcome reporting; limited comparator assessment	Moderate
Gharini et al., 2023	JBI (Quasi-experimental)	Relevant intervention and outcome measures; pilot design and limited sample size	Moderate
Jiang et al., 2023	JBI (Educational intervention)	Appropriate blended intervention and learner evaluation; absence of randomization	Moderate
Salem et al., 2023	RoB 2	Generally low concerns across domains; intervention and outcome measurement adequately described	Low risk
Abdelwahab et al., 2024	JBI (Quasi-experimental)	Appropriate comparison and outcome assessment; limited follow-up duration	Moderate
Iqbal et al., 2024	RoB 2	Low risk of bias with adequate randomization and outcome assessment	Low risk
Lee et al., 2024	JBI (Quasi-experimental)	Clear intervention description and repeated assessment; no parallel control	Moderate
Kashou et al., 2024	RoB 2	Overall low risk with robust comparison across intervention groups	Low risk
Kohan et al., 2024	JBI (Quasi-experimental)	Adequate comparator and learning assessment; limited external validity	Moderate
Kashou et al., 2025	RoB 2	Low risk with clear intervention protocol and retention assessment	Low risk
Kılıç et al., 2025	JBI (Pre-post)	Strong outcome reporting; absence of comparator group	Moderate

Van Der Bosch & Soohoo, 2024	JBI (Longitudinal intervention)	Appropriate longitudinal assessment; limited sample size	Moderate
Sharma et al., 2025	JBI (Pre-post intervention)	Adequate outcome measurement; lack of control group	Moderate

Note: Randomized controlled trials were assessed using RoB 2, while non-randomized and observational studies were evaluated using JBI critical appraisal checklists. Numerical scores were not calculated because methodological appraisal was interpreted descriptively rather than through aggregate scoring.

The methodological appraisal findings are summarized in Table 1. Overall, included studies demonstrated moderate-to-good methodological quality. Randomized controlled trials generally showed low risk of bias according to RoB 2 assessment, whereas non-randomized and observational studies fulfilled most JBI appraisal criteria. Common limitations included lack of control groups, small sample sizes, and limited long-term follow-up. No aggregate quality score was calculated because appraisal findings were interpreted descriptively.

Given the heterogeneity of intervention formats, learner populations, and outcome measures, findings were synthesised using thematic analysis to identify recurring patterns across studies rather than direct quantitative comparison. Five major themes emerged.

Theme 1. Improvement in ECG Knowledge and Interpretation Accuracy

The most consistent finding across included studies was improvement in ECG knowledge and interpretation performance following exposure to web-based learning interventions. Studies employing web modules, mobile applications, blended learning, simulation software, and immersive digital platforms generally reported significant gains in post-intervention ECG test scores, diagnostic literacy, and rhythm interpretation ability. Improvements were observed across medical students, nursing students, nurses, general practitioners, and residents (Viljoen et al., 2020; Gumilang et al., 2021; Joseph et al., 2022; Salem et al., 2023; Abdelwahab et al., 2024; Kohan et al., 2024; Kılıç et al., 2025; Sharma et al., 2025). Randomised studies frequently demonstrated superior outcomes compared with lecture-based instruction, suggesting that interactive and repeated digital exposure supports acquisition of ECG interpretation competence.

Theme 2. Enhancement of Learner Confidence, Engagement, and Learning Experience

Several studies identified improvements extending beyond objective performance measures. Increased learner confidence, engagement, perceived competence, and satisfaction were frequently reported following participation in digital ECG education. Interactive case-based activities, self-paced learning opportunities, and accessible online formats contributed positively to learner experience (Nilsson et al., 2019; Klein et al., 2020; Gharini et al., 2023; Lee et al., 2024; Kashou et al., 2024; Van Der Bosch & Soohoo, 2024). However, engagement remained influenced by contextual factors such as workload, curriculum integration, and sustained learner participation.

Theme 3. Retention and Sustained Learning Through Digital and Immersive Approaches

A smaller but important group of studies evaluated learning retention beyond immediate post-testing. Findings suggested that immersive and longitudinal learning models may support longer-term maintenance of ECG competence. Virtual reality-based interventions and serial exposure strategies produced stronger delayed retention outcomes than conventional approaches, indicating potential advantages of repeated and experiential digital learning designs (Iqbal et al., 2024; Kashou et al., 2025; Van Der Bosch & Soohoo, 2024). These findings support the value of sustained engagement rather than one-time educational exposure.

Theme 4. Usability, Accessibility, and Feasibility Across Educational Settings

Usability emerged as an important determinant of successful implementation. Studies evaluating mobile applications, MOOCs, and web platforms consistently reported positive perceptions regarding accessibility, flexibility, ease of navigation, and educational usefulness (Lima et al., 2019; Nilsson et al., 2019; Gharini et al., 2023; Lee et al., 2024). These features appeared particularly relevant in settings with limited educational resources and support the feasibility of scaling ECG learning across diverse contexts, including LMICs.

Theme 5. Relevance to BT&CLS Competencies and Existing Gaps

Although ECG interpretation is conceptually linked to competencies required in trauma and cardiac life support—particularly rhythm recognition, arrhythmia identification, and decision support during emergency care—direct evaluation of BT&CLS outcomes was uncommon across included studies. Most interventions measured educational outcomes such as knowledge, confidence, usability, and interpretation accuracy rather than performance during resuscitation, simulation, or clinical emergency scenarios. Consequently, evidence supporting direct transfer of ECG learning into BT&CLS performance remains limited. This finding highlights an important gap between digital ECG education and integrated life-support training and supports the need for future research incorporating simulation-based BT&CLS assessment and real-world emergency performance indicators.

Table 2. Characteristics of Included Studies on Web-Based ECG Learning

Study / Country	Study Design	Sample Characteristics	Digital Platform Type	Comparator	Outcome Measures	Key Findings
Nilsson et al., 2019 (Sweden)	Mixed-methods (survey + interviews)	Medical students (N ≈ 150) using a voluntary ECG learning platform	Web-based ECG learning resource; self-directed modules; interactive cases	None (exploratory)	Usage behavior, perceived usefulness, engagement	Students used the platform for convenience, relevance, and interactive practice. Barriers included time constraints and unclear integration into curriculum.
Viljoen et al., 2020 (South Africa)	Quasi-experimental (pre-post with parallel group)	Medical students (N = 115)	Web-based ECG deliberate practice tool + lectures (blended learning)	Traditional lectures only	ECG interpretation accuracy, confidence	Blended learning significantly improved ECG accuracy and confidence vs. lectures alone (p < .05).
Klein et al., 2020 (USA)	Educational intervention; observational	Pediatric residents (N = 30)	Email-based ECG curriculum (weekly case-based ECG)	None	ECG interpretation confidence, satisfaction	Participants reported increased confidence and valued serial exposure; email format improved accessibility.
Lima et al., 2019 (Brazil)	Methodological development + usability evaluation	Medical students (N = 109)	Purpose-built mobile ECG teaching application	None	Usability, usefulness, satisfaction	The app demonstrated high usability and acceptance. Students rated it as easy, pedagogically strong, and motivating—supporting its role as a supplemental ECG learning tool.
Gumilang et al., 2021 (Indonesia)	Quasi-experimental (pre-post)	General practitioners and medical students (N = 82)	Mobile-based ECG application (m-ECG); web-supported	No control group	ECG knowledge scores, interpretation accuracy	m-ECG app significantly improved knowledge and interpretation scores; feasible for low-resource settings.
Joseph et al., 2022 (USA)	Pre-post educational intervention	Medical students (N = 143)	Web-integrated ECG interpretation course (online modules + digital quizzes)	None	ECG literacy, competency scores	Significant improvements in ECG literacy; digital modules supported repeated practice.
Gharini et al., 2023 (Indonesia)	Pilot pre-post intervention study	General practitioners enrolled in a national ECG MOOC; ≈30	Fully online MOOC: asynchronous video lectures, downloadable	No concurrent control; pre-	ECG knowledge test scores, proportion reaching competency threshold, and	Mean ECG test scores significantly increased after the MOOC, and a larger proportion of GPs met the competency

participants completed both pre- and post-tests (Indonesia)

materials, online quizzes, and forum interactions focused on ECG interpretation in primary care

vs post-course comparisons

self-reported confidence/satisfaction with MOOC format

threshold. Participants rated the MOOC as acceptable and useful for flexible upskilling. Results support MOOC-style web-based ECG education to improve GP competence in resource-constrained settings.

Study / Country	Study Design	Sample Characteristics	Digital Platform Type	Comparator	Outcome Measures	Key Findings
Salem et al., 2023 (Egypt)	Randomized controlled trial (prospective RCT)	64 undergraduate nursing students (divided into intervention and control groups)	Computer-based simulation software presenting ECG strips for interpretation (digital simulation)	Traditional live classroom lectures with printed ECG strips (control)	ECG interpretation accuracy (20 ECG strips test pre- and post-intervention)	Post-test scores in the simulation (intervention) group were significantly higher than in the control group ($t(37.47) = -9.628, p = .000$), indicating that simulation-based ECG training is more effective than traditional lecture-based teaching.
Abdelwahab et al., 2024 (Egypt)	Quasi-experimental pretest–posttest with control group	130 intern nursing students	ECG interpretation training program (structured course/training program)	Control group with standard/no specialized ECG training	ECG knowledge scores; ECG interpretation / practice skills	Knowledge increased ($15.23 \rightarrow 22.80; p < .05$); practice/interpretation skills improved significantly ($15.40 \rightarrow 23.46; p < .05$).
Iqbal et al., 2024 (India)	Randomized Controlled Trial (RCT)	140 final-year undergraduate medical students randomly assigned to two groups (immersion vs traditional)	Immersive Virtual Reality (VR) simulation platform simulating ECG acquisition & interpretation in a virtual clinical environment (virtual patient, placing leads, reading ECG)	Traditional teaching using didactic lectures and standard ECG teaching	ECG interpretation test scores (normal & abnormal ECG), post-test (immediately after), retention test (after 2 months), plus learner engagement & satisfaction	Both groups improved, but the VR group had significantly better retention scores for both normal and abnormal ECG interpretation compared to traditional group ($p < 0.001$). VR training improved not only initial acquisition but retention over time. Authors suggested VR as a promising tool for ECG education, with better long-term retention than traditional lecture-based teaching.
Lee et al., 2024 (South Korea)	Quasi-experimental (18-week program)	Clinical nurses (N = 84)	Webpage-based ECG learning platform + mixed learning (cases, videos, micro-learning tasks)	No control	ECG accuracy, confidence, learning satisfaction	Mixed learning + webpage improved accuracy and confidence over time; nurses valued flexibility of online modules.

Kashou et al., 2024 (International RCT)	Randomized controlled trial (4-arm)	Healthcare professionals & trainees (N = 1,200+)	Web-based ECG training (question bank, video lectures, hybrid model)	Control (no resource)	ECG performance (arrhythmia, STEMI recognition), confidence	All digital-learning arms significantly improved performance vs. control; hybrid model produced highest gains.
Kohan et al., 2024 (Iran)	Non-equivalent control group pretest–posttest	Undergraduate nursing students (N = 75)	Custom ECG interpretation software with tutorials + practice modules	Traditional classroom teaching	ECG knowledge; interpretation accuracy; learner satisfaction	Both groups improved, but the software group achieved significantly higher knowledge and interpretation scores and reported high satisfaction and relevance, supporting integration of software into undergraduate nursing curricula.

Study / Country	Study Design	Sample Characteristics	Digital Platform Type	Comparator	Outcome Measures	Key Findings
Kılıç et al., 2025 (Turkey)	Single-group pretest–posttest quasi-experimental study	282 nurses (volunteer participants) from various settings	Fully online educational program covering ECG basics, arrhythmias, blocks, pacemakers, ACS/MI, etc.	No separate control (pre-test vs post-test within same group)	ECG-Knowledge Test (ECG-KT) scores overall and by subcategory (normal rhythm, atrial arrhythmias, ACS, etc.)	Post-test scores were significantly higher than pre-test. Improvements were especially noted in categories “normal sinus rhythm & derivations,” “atrial arrhythmias,” and “acute coronary syndrome.” Nurses with intensive care certificates or advanced degrees tended to score higher overall. The study concluded that the online ECG program effectively improves ECG interpretation skills among nurses.
Van Der Bosch & Soohoo, 2024 (USA)	Longitudinal educational intervention	Pediatric residents (N = 34)	Serial ECG email curriculum (biweekly cases + interpreted answers)	None	Confidence, frequency of ECG use, perceived competence	Improved long-term ECG confidence; email-based learning effective for distributed practice.
Sharma et al., (2025) India	Quasi-experimental pretest–posttest design (online course)	76–80 registered nurses from various institutions across India	Fully online interactive ECG training program (certificate course) delivered via online platform	Pre-test vs post-test (within-subject comparison)	ECG knowledge, arrhythmia identification ability (interpretation skills)	Significant improvement in ECG knowledge (mean pre-test $12.30 \pm 3.51 \rightarrow$ post-test 17.42 ± 3.64) and arrhythmia identification skills. Poor performers dropped from 36 ($\approx 47\%$) to 4 ($\approx 6\%$) after course; good performers increased from 3 ($\approx 5\%$) to 30 ($\approx 39\%$).

4. DISCUSSION

Effectiveness of Web-Based ECG Learning for Improving ECG Competencies

This review demonstrates consistent evidence that web-based ECG learning applications improve ECG-related competencies across healthcare learners and professionals. Across studies, improvements were repeatedly observed in ECG knowledge, interpretation accuracy, diagnostic confidence, and learning retention (Viljoen et al., 2020; Joseph et al., 2022; Abdelwahab et al., 2024; Kashou et al., 2024).

The effectiveness of digital ECG learning may be explained by several common instructional mechanisms identified across studies. Interactive case exposure, repeated practice opportunities, immediate feedback, and learner-controlled pacing enable more active engagement compared with traditional lecture-based approaches (Nilsson et al., 2019; Lima et al., 2019). Blended and digitally supported learning models consistently demonstrated stronger educational outcomes than lecture-only approaches, suggesting that combining independent digital learning with structured instruction may enhance acquisition and retention of ECG competencies (Viljoen et al., 2020; Jiang et al., 2023).

Learner Engagement and Accessibility Across Diverse Educational Settings

Beyond cognitive outcomes, included studies consistently highlighted improvements in learner confidence, engagement, and satisfaction. Participants frequently perceived web-based ECG learning as flexible, convenient, and easier to incorporate into personal learning schedules (Nilsson et al., 2019; Klein et al., 2020; Lee et al., 2024; Van Der Bosch & Soohoo, 2024).

Importantly, evidence from LMIC settings suggests that digital ECG learning may support broader access to emergency and cardiovascular education. Mobile applications and MOOC-based approaches implemented in Indonesia demonstrated measurable improvements in ECG knowledge while maintaining accessibility and feasibility in resource-constrained contexts (Gumilang et al., 2021; Gharini et al., 2023). These findings suggest that digital delivery models may reduce barriers to ECG education; however, sustained learner engagement still appears dependent on curriculum integration, institutional support, and protected learning time (Nilsson et al., 2019).

Emerging Digital Approaches and Their Educational Implications

Recent studies indicate a progression from conventional online learning toward simulation-enhanced and immersive educational environments. Computer-based simulation and virtual reality interventions demonstrated advantages not only in immediate performance but also in longer-term retention and learner engagement (Salem et al., 2023; Iqbal et al., 2024; Kashou et al., 2025).

This trend may reflect the ability of immersive learning environments to simulate contextual clinical decision-making rather than focusing solely on content acquisition. Similarly, distributed and repeated exposure approaches, such as serial ECG interpretation delivered through email or online modules, appeared to strengthen confidence and long-term retention (Klein et al., 2020; Van Der Bosch & Soohoo, 2024). Large-scale evaluations further supported the educational value of combining question banks, videos, and hybrid learning approaches to improve arrhythmia recognition and STEMI identification (Kashou et al., 2024).

Persistent Fragmentation Between ECG Learning and BT&CLS Competencies

Despite encouraging educational outcomes, a major finding across the included literature is the persistent separation between ECG education and broader BT&CLS competencies. Most interventions focused on interpretation scores, knowledge acquisition, confidence, usability, and learner satisfaction rather than evaluating performance in integrated emergency care contexts (Joseph et al., 2022; Kashou et al., 2024).

Several factors may explain this fragmentation. First, ECG education has traditionally evolved within diagnostic and cardiology-oriented curricula rather than emergency systems training. Second, educational interventions are often designed to evaluate short-term cognitive outcomes because these outcomes are easier to measure than real-world clinical performance. Third, integrating ECG learning into trauma and cardiac arrest simulation requires greater logistical, technological, and curricular investment than stand-alone educational modules.

Consequently, current evidence remains limited regarding whether improved ECG competency translates into faster rhythm recognition, more accurate defibrillation decisions, or improved performance during actual BT&CLS scenarios.

Implications for Education and Future BT&CLS Integration

The findings suggest that web-based ECG learning applications have strong potential as complementary educational tools within BT&CLS curricula. Their demonstrated benefits include improved access, repeated exposure, learner engagement, and enhanced ECG-related competence across diverse settings.

However, current evidence supports integration cautiously. Rather than assuming direct improvement in resuscitation outcomes, digital ECG learning may be viewed as an enabling educational component that could support preparedness for emergency care when combined with simulation, team-based training, and context-specific BT&CLS practice.

This implication may be particularly relevant for LMIC settings where mobile learning, MOOCs, and scalable digital delivery can expand access to ECG education despite limitations in faculty availability and simulation infrastructure (Gumilang et al., 2021; Gharini et al., 2023). Future interventions should evaluate whether combining digital ECG learning with simulation-based BT&CLS education improves performance during realistic emergency scenarios.

Study Limitations

Several limitations should be considered when interpreting these findings. First, many included studies employed pre–post or quasi-experimental designs without randomised controls, limiting causal interpretation of intervention effectiveness (Gumilang et al., 2021; Gharini et al., 2023). Second, sample sizes were frequently modest and drawn from single institutions, reducing generalisability.

Third, outcome measures predominantly focused on educational indicators such as knowledge, confidence, and interpretation performance rather than objective BT&CLS outcomes. Few studies assessed emergency decision-making, simulation performance, or clinical application of ECG skills during resuscitation scenarios. Consequently, conclusions regarding the contribution of digital ECG learning to BT&CLS should remain cautious and interpreted as indirect rather than demonstrated effects.

Finally, substantial heterogeneity across intervention formats, populations, and outcome definitions limited direct comparison across studies and prevented quantitative synthesis.

5. CONCLUSION

This scoping review demonstrates substantial progress in the development and implementation of web-based ECG learning applications across diverse educational and clinical settings. Across the included studies, digital ECG learning interventions—including mobile applications, MOOCs, blended learning platforms, interactive software, and virtual reality simulation consistently improved ECG-related educational outcomes, particularly interpretation accuracy, knowledge acquisition, learner confidence, engagement, and, in some cases, learning retention. These findings support the value of web-based ECG learning as an effective approach for strengthening ECG-related competencies among healthcare learners and professionals. Because ECG interpretation represents an important component of emergency and resuscitation care, such educational gains may have potential relevance for competencies required in Basic Trauma and Cardiac Life Support (BT&CLS). However, current evidence remains largely limited to educational outcomes and does not directly demonstrate improvements in resuscitation performance, clinical decision-making during emergencies, or patient outcomes.

Although integration of web-based ECG learning into BT&CLS education appears promising, explicit incorporation into life-support curricula remains limited. Future research should prioritise embedding ECG learning technologies within simulation-based trauma and cardiac emergency training, evaluating competency transfer to clinical and resuscitation performance, and expanding implementation studies across resource-constrained settings. Such

work will help determine whether improvements in ECG learning translate into meaningful improvements in emergency care practice.

6. ACKNOWLEDGEMENTS

The authors would like to express their sincere appreciation to all individuals and institutions who provided support, guidance, and valuable input throughout the preparation and completion of this scoping review. The authors also acknowledge the contribution of colleagues and academic peers whose discussions and feedback helped strengthen the development of this manuscript.

7. FUNDING STATEMENT

This research received no external funding.

8. AUTHOR CONTRIBUTIONS

Conceptualization: NH, IBA

Methodology: NH, IBA, NMDW

Literature search and screening: NH, IWES

Data extraction and analysis: NH, NMDW

Writing-original draft preparation: NH

Writing-review and editing: IBA, NMDW, IWES

Supervision: IBA

All authors have read and approved the final version of the manuscript.

9. CONFLICT OF INTEREST DISCLOSURE

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

10. DATA AVAILABILITY STATEMENT

No new datasets were generated or analyzed in this study. All data supporting the findings of this scoping review are available within the article and its referenced sources.

11. REFERENCES

- Abdelwahab, S. R., Mohamed, M. K., Eldesoky, H. A., Mohammed, F. A., Shalby, A. Y., Awad, W. H., ... & Badr, M. N. (2024). *The Impact of Electrocardiogram Interpretation Training Program on Intern Nursing Students' Competencies: A Quasi-Experimental Study* (Doctoral dissertation, Faculty of Nursing, Cairo University). Research Square. <https://doi.org/10.21203/rs.3.rs-4533702/v1>
- Amini, M., Bazrafkan, L., Abadi, A., Hadadgar, A., Zand, F., & Gharavi, M. (2022). Assessment of electrocardiogram interpretation competency among healthcare professionals and students of a medical sciences university: A multidisciplinary study. *BMC Medical Education*, 22, Article 447.
- Aromataris, E., & Munn, Z. (2020). *JBIM manual for evidence synthesis*. Joanna Briggs Institute. <https://doi.org/10.46658/JBIMES-20-01>
- Bazrgar, A., Rahmanian, M., Ghaedi, A., Heidari, A., Bazrafshan, M., Amini, M., Bazrafshan, H., Ahmadpour, M., & Bazrafshan Drissi, H. (2023). Face-to-face, online, or blended: Which method is more effective in teaching electrocardiogram to medical students. *BMC Medical Education*, 23, 566. <https://doi.org/10.1186/s12909-023-04546-0>
- Braun, V., & Clarke, V. (2021). To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 13(2), 201–216. <https://doi.org/10.1080/2159676X.2020.1778928>
- Capustin, M., Weintraub, S., Hsieh, J.-C., Alboucai, J., Antara, F., & Friedman, K. (2025). A novel microlearning asynchronous curriculum to improve internal medicine trainees' confidence and skill in interpreting ECGs. *Journal of Medical Education and Curricular Development*, 12, 23821205251358038. <https://doi.org/10.1177/23821205251358038>

- Chong, K. M., et al. (2023). The effectiveness of online-only, blended, and in-person training for basic life support: Systematic review. *Journal of Medical Internet Research*, 25, e46976. <https://doi.org/10.2196/46976>
- Gharini, P. P. R., Gumilang, R. A., Hasana, S., Fatimah, V. A. N., Kokasih, O., Supriami, K., & Solikhah, H. M. (2023). *Pilot study of massive open online course (MOOC) implementation in electrocardiography (ECG) learning: Perspectives from general practitioners*. *Bali Medical Journal*, 12(3), 3192–3195. <https://doi.org/10.15562/bmj.v12i3.4696>
- Gumilang, R. A., Fuad, A., Fatimah, V. A. N., Hasana, S., Kokasih, O., & Gharini, P. P. R. (2021). Development of mobile ECG application to improve ECG interpretation skills of general practitioners and medical students. *Jurnal Pendidikan Kedokteran Indonesia: The Indonesian Journal of Medical Education*, 10(3). <https://doi.org/10.22146/jpki.62977>
- Hammarberg, K., Kirkman, M., & de Lacey, S. (2021). Qualitative research methods: When to use them and how to judge them. *Obstetrics & Gynecology*, 137(3), 435–442. <https://doi.org/10.1097/AOG.0000000000004290>
- Han, S., Lee, C. A., Jeong, W. J., Park, J., & Park, H. A. (2023). Framework development of non-face-to-face training of basic life support for laypersons: A multi-method study. *Healthcare*, 11(14), 2110. <https://doi.org/10.3390/healthcare11142110>
- Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., & Welch, V. A. (2022). *Cochrane handbook for systematic reviews of interventions* (Version 6.3). Cochrane.
- Jiang, L., Wang, D., Yan, J., & Yang, M. (2023). Effect of a blended learning design in an undergraduate nursing electrocardiogram course: A quasi-experimental study. *Nursing open*, 10(7), 4461–4470. <https://doi.org/10.1002/nop2.1688>
- Joseph, R., Fenton, J., & Winchester, D. (2022). Integrated ECG interpretation course for the improvement of medical student electrocardiography literacy. *Medical Science Educator*, 32(6), 1351-1354. <https://doi.org/10.1007/s40670-022-01644-4>
- Kashou, A. H., Noseworthy, P. A., & Gersh, B. J. (2020). The essential skill of ECG interpretation: How do we define and improve competency? *Postgraduate Medical Journal*, 96(1139), 610–616. <https://doi.org/10.1136/postgradmedj-2020-137457>
- Kashou, A. H., Noseworthy, P. A., Beckman, T. J., Anavekar, N. S., Cullen, M. W., Angstman, K. B., ... May, A. M. (2024). EDUCATE: An international, randomized controlled trial for teaching electrocardiography. *Current Problems in Cardiology*, 49(3), 102409. <https://doi.org/10.1016/j.cpcardiol.2024.102409>
- Kiguchi, T., Okubo, M., Nishiyama, C., Maconochie, I., Ong, M. E. H., Kern, K. B., ... Iwami, T. (2020). Out-of-hospital cardiac arrest across the world: First report from the International Liaison Committee on Resuscitation (ILCOR) epidemiology task force. *Resuscitation*, 152, 39–49. <https://doi.org/10.1016/j.resuscitation.2020.02.044>
- Kılıç, G., Mercan Annak, İ., Savaş, H., Ay Kılıçaslan, B., & colleagues. (2025). *The effectiveness of an online educational program on nurses' electrocardiogram interpretation skills*. *BMC Nursing*, 24(1), Article 2997. <https://doi.org/10.1186/s12912-025-02997-y>
- Klein, A. J., et al. (2020). A resident-authored, case-based electrocardiogram email curriculum. *MedEdPORTAL*, 16, 10927. https://doi.org/10.15766/mep_2374-8265.10927
- Lee, S., Kim, H. J., Choi, Y., Kim, J. Y., & Shin, J. S. (2024). Effectiveness of electrocardiogram interpretation education program using mixed learning methods and webpage. *BMC Medical Education*, 24(1), 1039. <https://doi.org/10.1186/s12909-024-05960-8>
- Maia, D. L. M., de Lima, C. J. M., Paiva, N. M. T., Lino, D. O. da C., & Costa Lima, J. L. (2021). Use of digital software as a medical education tool in teaching electrocardiogram interpretation: A systematic review. *Research, Society and Development*, 10(12), e477101220865. <https://doi.org/10.33448/rsd-v10i12.20865>
- Nilsson, M., Bolinder, G., Held, C., Johansson, B. L., Fors, U., & Östergren, J. (2019). Why medical students choose to use or not to use a web-based electrocardiogram learning resource: Mixed methods study. *JMIR Medical Education*, 5(2), e12791. <https://doi.org/10.2196/12791>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>

- Panchal, A. R., Berg, K. M., Hirsch, K. G., Kudenchuk, P. J., Del Rios, M., Cabañas, J. G., Kurz, M. C., Chan, P. S., Morley, P. T., Hazinski, M. F., Donnino, M. W., & Adult Basic and Advanced Life Support Writing Group. (2020). 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care: Part 3. Adult basic and advanced life support. *Circulation*, *142*(16_suppl_2), S366–S468. <https://doi.org/10.1161/CIR.0000000000000916>
- Pollock, A., Campbell, P., Struthers, C., Synnot, A., Nunn, J., Hill, S., ... Morris, J. (2021). Stakeholder involvement in systematic reviews: A scoping review. *Systematic Reviews*, *10*(1), 1–18. <https://doi.org/10.1186/s13643-021-01687-0>
- Roth, G. A., Mensah, G. A., Johnson, C. O., Addolorato, G., Ammirati, E., Baddour, L. M., ... GBD 2019 Diseases and Injuries Collaborators. (2020). Global burden of cardiovascular diseases and risk factors, 1990–2019: Update from the GBD 2019 study. *Journal of the American College of Cardiology*, *76*(25), 2982–3021. <https://doi.org/10.1016/j.jacc.2020.11.010>
- Salem, A. M., Mohamed, N. M. A., & Masadeh, A. (2023). *The effectiveness of computer-based simulation on nursing students' electrocardiogram interpretation*. *Teaching and Learning in Nursing*, *18*(3), e9–e12. <https://doi.org/10.1016/j.teln.2023.01.010>
- Sharma, A., Rani, R., Kumari, V., Dabas, S., & Chowdhary, D. (2025). *Nationwide evaluation of an eight-week interactive online electrocardiogram training program for nurses: A quasi-experimental approach*. *Cureus*, *17*(10), e94122. <https://doi.org/10.7759/cureus.94122>
- Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., ... & Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Annals of internal medicine*, *169*(7), 467–473. <https://doi.org/10.7326/M18-0850>
- Van Der Bosch, M., & Soohoo, M. (2024). Longitudinal email-based electrocardiogram interpretation curriculum for paediatric residents. *Cardiology in the Young*, *34*(11), 2311–2315. <https://doi.org/10.1017/S1047951124026714>
- Viljoen, C. A., Millar, R. S., Manning, K., & Burch, V. C. (2020). Effectiveness of blended learning versus lectures alone on ECG analysis and interpretation by medical students. *BMC Medical Education*, *20*(1), 488. <https://doi.org/10.1186/s12909-020-02403-y>