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1. ABSTRACT

1.1. Introduction

ECG interpretation is an essential learning outcome in undergraduate medical curricula. However, most graduating medical students lack adequate ECG interpretative skills. Novel teaching methods are increasingly being investigated and implemented to improve undergraduate ECG training. Computer-assisted instruction is one such method under investigation, but its efficacy in achieving better ECG competence amongst medical students remains uncertain.

1.2. Methods and Analysis

This article describes the protocol for a systematic review that will compare the effectiveness of computer-assisted instruction with other teaching methods used for ECG training of medical students. Studies will be selected in which medical students were exposed to online or offline computer-assisted instruction, with the aim of improving their ECG analysis and interpretation skills. Only studies with a comparative research design will be considered. Articles will be searched for in electronic databases (PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC, Africa-Wide Information and Teacher Reference Center), by citation indexes and by means of searches for grey literature. A descriptive analysis of the different teaching modalities will be provided, and their educational impact will be assessed by the modified version of Kirkpatrick's framework for the evaluation of educational interventions. The systematic review aims to provide evidence as to whether or not computer-assisted instruction is an effective teaching modality for the ECG training of medical students. This information may ultimately assist in the development of future curricula and improve ECG training.

1.3. Ethics and Dissemination

As this research is a systematic review of published literature, ethical approval is not required. The results will be reported according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) statement and will be submitted to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

1.4. Trial Registration Number

Systematic review registration: PROSPERO number CRD42017067054.

2. STRENGTHS AND LIMITATIONS

- Due to the lack of ECG competence amongst graduating medical students, it is time to review the way in which ECG analysis and interpretation are taught.
- This systematic review will evaluate the effectiveness of computer-assisted instruction as compared with other teaching methods used for ECG training of medical students.
- The protocol describes a comprehensive search strategy, as well as inclusion and exclusion criteria with no geographical or language restrictions.
- The systematic review might be limited by the predominance of studies with selection and performance bias amongst participants.
- A meta-analysis will only be possible in the absence of heterogeneous data amongst included studies.

3. INTRODUCTION

The electrocardiogram (ECG) remains one of the most frequently performed diagnostic procedures in clinical practice.[1, 2] ECG interpretation is therefore considered an essential learning outcome in undergraduate medical curricula.[3] Incorrect interpretation of an ECG, however, can lead to inappropriate clinical decisions with serious adverse outcomes, especially in the realms of arrhythmias and myocardial infarction.[4, 5] Previous studies have found that the majority of medical students lack confidence when it comes to ECG interpretation, as they find it a difficult skill to master and retain.[6-10] Of greater concern, however, is the finding that graduating medical students are often not able to accurately interpret ECGs, particularly when dealing with life-threatening conditions such as complete heart block and atrial fibrillation.[7-10]

'ECG analysis' refers to the detailed examination of the ECG tracing, which requires the measurement of intervals and the evaluation of the rhythm and each waveform, whereas 'ECG interpretation' refers to the conclusion reached after careful ECG analysis, i.e. making a diagnosis of an arrhythmia, or ischaemia, etc.[11] 'ECG competence' refers to the ability to accurately analyse as well as interpret the ECG,[7, 12] whereas 'ECG knowledge' refers to the understanding of ECG concepts, e.g. knowing that transmural ischaemia or pericarditis can cause ST segment elevation.[6, 13]

It is well known that ECG interpretation is difficult and requires significant training.[14] The reasons for this are multifold. Firstly, students are required to have a sound prior knowledge of the anatomy and physiology of the cardiac conduction system before they can begin studying ECGs.[15] ECG analysis also requires a good understanding of vectors and how these are influenced by lead placement and pathology.[11, 15] Furthermore, ECG interpretation requires two types of reasoning: the non-analytical pattern recognition of abnormal waveforms and rhythms; and the analytical, systematic analysis of the entire 12-lead ECG.[16, 17] The best clinical results are attained when both non-analytical pattern recognition as well as analytic systematic analysis of the ECG are used simultaneously, but which most medical students find overwhelming.[16, 17]

Although a large deal of experience in ECG interpretation depends on clinical exposure,[18] clinical exposure alone does not improve ECG diagnostic accuracy if it is not supplemented by a structured form of teaching.[19] ECGs are commonly taught by means of large group teaching,[7, 14, 19] where a teacher or expert transfers ECG knowledge to a group of learners in the format of a lecture.[20-22] Lectures allow for large groups of medical students to be taught at once, but offer less opportunity for discussion and interaction with the lecturer.[23] Large group teaching therefore facilitates passive learning.[20, 24] Undergraduate ECG teaching also frequently occurs in the small group setting, i.e. during ward rounds and bedside tutorials.[22, 23] Small group teaching

allows for free communication and interaction between the learner and the teacher, or between the learners themselves.[25] Alternative teaching methods are increasingly being implemented and investigated to improve undergraduate ECG training. The 'flipped classroom' refers to the teaching method where students are required to watch short video lectures before attending a classroom lecture. The classroom lecture is then devoted to interactive discussion of the ECG instead of merely tuition.[24] Peer teaching refers to the teaching method during which students are taught by fellow students of the same academic year, whereas near-peer teaching refers to the teaching method during which students are taught by more senior students from the same curriculum.[26] Problem-based learning (PBL) refers to the student-centred teaching method where a clinical problem is assigned to students, who then need to identify what they need to learn from the clinical case and apply their knowledge to solve a clinical problem.[27] Apart from the face-to-face tuition by experts or peers, ECG knowledge can also be acquired by means of self-directed learning, which refers to the independent study of textbooks or other designated study material.[28]

Computer-assisted instruction has been used as an ECG teaching modality since the 1960s.[29] 'Computer-assisted instruction' (CAI) or 'computer assisted learning' (CAL) refers to any teaching method that uses a digital platform as a self-directed learning technique.[30] Although CAI is the broadest term as it encompasses both online or offline modalities, newer terminology specifically referring to online learning modalities includes terms such as 'web-based learning', 'web-based training' and 'e-learning'.[31-34] CAI or web-based learning typically provides the student with text, illustrations and other multimedia material to study, with additional educational features such as test-enhanced learning (e.g. online multiple choice questions) with immediate feedback.[30, 32] Computer-assisted instruction is increasingly being used as a teaching modality, especially in its online form, as a solution for the insufficient time allocated for ECG teaching in undergraduate curricula and the increasing numbers of medical students that lecturers need to teach.[35-37] Web-based learning allows for flexibility in learning, as the student can access the material wherever and whenever convenient.[32, 33] However, the efficacy of this teaching modality, either to be used in the place of didactic lectures or as a supplement to conventional teaching methods, needs to be explored.

The objective measure of a teaching method's effectiveness is the assessment of students' competence after being exposed to the educational intervention.[30] ECG competence is measured by assessing the student's ECG analysis and / or interpretation skills. An assessment shortly after an educational intervention tests the acquisition of ECG competence, whereas delayed testing assesses the retention of ECG competence.[33] More comprehensively, the modified Kirkpatrick model is a widely accepted method of appraising an educational intervention's outcome, as it measures learners' views on the learning experience (level 1), modification of learners' perception of the intervention (level 2a), modification of knowledge or

skills (level 2b), transfer of learning to the workplace (level 3), change in organizational practice (level 4a) and benefits to patients (level 4b).[38-41]

In the face of inadequate ECG competence amongst graduating medical students worldwide,[7-10] it is time to review the way in which ECG analysis and interpretation are taught. Are conventional ECG teaching methods achieving the necessary ECG interpretation skills amongst graduating medical students? Are teaching methods on the digital platform better than the ways that ECGs have traditionally been taught? Or should a blended learning strategy (the combination of CAI and other teaching modalities) be implemented for ECG teaching? There is currently no systematic review of the effectiveness of computer-assisted instruction as compared to other teaching methods used in the ECG training of medical students.

4. OBJECTIVES

The objectives of this systematic review are to:

1. Establish whether computer-assisted instruction achieves better **acquisition** of ECG competence (analysis and interpretation skills) amongst medical students than other ECG teaching methods do;
2. Establish whether computer-assisted instruction achieves better **retention** of ECG competence (analysis and interpretation skills) amongst medical students than other ECG teaching methods do; and to
3. Identify the educational features (e.g. reading material, illustrations, videos, test-enhanced learning tools) that are used by computer-assisted instruction.

5. METHODS AND DESIGN

In accordance with the PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) guidelines,[42] this systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 6 July 2017 with registration number CRD42017067054.

5.1. Criteria for considering studies for this review

A study will only be deemed eligible to be included in this systematic review if it fulfils all inclusion criteria and does not meet any of the exclusion criteria, as outlined in table 1.

Table 1: Criteria to assess a study's eligibility to be included in this systematic review

Inclusion criteria	Exclusion criteria
Population	
• Medical students	• Students other than medical students • Qualified doctors
Intervention	
• Online or offline computer-assisted instruction used to teach the analysis and interpretation of ECGs.	• Computer-assisted instruction not included as teaching modality in study • Teaching modalities were not primarily and solely used to teach ECGs • The subject of teaching was not the conventional 12-lead ECG
Comparator	
• Any comparative ECG teaching method	• Absent or inadequately described comparator or control group
Outcome	
Educational intervention's effectiveness: • Acquisition of ECG competence, or • Retention of ECG competence, or • Level of Kirkpatrick outcomes	• There is no objective outcome measured (i.e. no testing of ECG competence)
Study	
Any comparative research design: • Randomised controlled trial, or • Cohort study, or • Case-control study, or • Before-and-after study, or • Cross-sectional research	Any non-comparative research design: • Audit • Case-series • Historical narrative • Survey based

5.1.1. Types of studies

All studies with a comparative research design, i.e. randomised controlled trial, cohort study, case-control study, before-and-after study or cross-sectional research will be included.

5.1.2. Types of participants

We will include studies in which medical students were the participants. In studies where the participants were not limited to medical students, only data pertaining to the medical students will be extracted.

5.1.3. Types of interventions

Studies must include computer-assisted instruction as an educational intervention, either in an online or an offline format. The comparator education intervention may include any other teaching method to which computer-assisted instruction was compared. We will exclude studies in which teaching modalities were not primarily and solely used to teach ECGs, or if the subject of teaching was not the conventional 12-lead ECG.

5.1.4. Types of outcome measures

Results must include quantitative data in which ECG competence was measured. We will include assessments of the acquisition of ECG competence (measured shortly after educational intervention) and / or assessments of the retention of ECG competence (delayed testing after educational intervention).

5.1.5. Language and years of publication

All articles published before July 2017 will be included, regardless of language. Publications in languages other than English will be translated, wherever possible.

5.2. Primary outcomes

The primary outcome of this systematic review is to determine whether or not CAI is more effective than other teaching methods in achieving acquisition and retention of ECG competence (analysis and interpretation skills) amongst medical students.

5.3. Secondary outcomes

The secondary outcomes of this study are to identify the educational tools (e.g. reading material, illustrations, videos, test-enhanced learning tools) that are used by computer-assisted instruction.

5.4. Search methods for identification of studies

The lead reviewer (CV) and an expert librarian (MS) from the University of Cape Town's Faculty of Health Sciences will conduct an extensive search for peer-reviewed articles.

5.4.1. Electronic searches

The following electronic databases will be used for the search of articles for this systematic review: PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC (Education Resources Information Centre), Africa-Wide Information, Teacher Reference Center and Google Scholar. A combination of Medical Subject Heading (MeSH) terms and free text terms will be used to search for articles. Table 2 shows the main search strategy that we will use.

Table 2: PubMed Search strategy, modified as needed for other electronic databases

Population: medical students		
#1	MeSH terms:	Students, Medical [MeSH] OR Education, Medical, Undergraduate [MeSH]
#2	Free text:	medical student OR undergraduate
#3	#1 OR #2	
Intervention: computer-assisted instruction		
#4	MeSH terms:	Computer-assisted Instruction [MeSH] OR Internet [MeSH] OR Simulation Training [MeSH]

#5	Free text:	app OR application OR computer OR computer-assisted OR digital OR e-learning OR e-modules OR Internet OR multimedia OR online OR simulation OR simulator OR software OR technology OR virtual OR web OR web-aided OR web-assisted OR web-based OR web-supported OR web-enhanced OR webCT OR web 2.0 OR YouTube
#6	#4 OR #5	
Comparator: any other teaching method used		
#7	MeSH terms:	Education [MeSH] OR Models, Educational [MeSH] OR Educational Technology [MeSH] OR Problem-based Learning [MeSH] OR Teaching [MeSH] OR Teaching Rounds [MeSH]
#8	Free text:	activity OR activities OR "asynchronous learning" OR bedside OR blackboard OR "blended learning" OR class OR classroom OR clinical OR competency-based OR conventional OR course OR didactic OR education OR educational OR instruction OR instructional OR "large group" OR lecture OR lecture-based OR "near-peer teaching" OR "near-peer tutorial" OR "near-peer tutoring" OR outcome-based OR PBL OR pedagogy OR pedagogical OR "peer teaching" OR "peer tutorial" OR "peer tutoring" OR problem-based OR rounds OR self-directed OR self-instruction OR self-study OR seminar OR "small group" OR teaching OR "test-enhanced learning" OR traditional OR training OR tutorial OR ward OR "worked example" OR workshop
#9	#7 OR #8	
Outcome: efficacy in acquiring ECG knowledge or skills		
#10	MeSH terms:	Electrocardiography [MeSH]
#11	Free text:	ECG OR EKG OR electrocardiography OR electrocardiogram OR electrocardiographic
#12	#10 OR #11	
#13	MeSH terms:	Clinical Competence [MeSH] OR Cognition [MeSH] OR Learning [MeSH]
#14	Free text:	accuracy OR analysis OR assessment OR cognition OR cognitive OR competence OR competency OR comprehension OR diagnosis OR diagnostic OR effectiveness OR efficacy OR examination OR interpretation OR insight OR knowledge OR learning OR measurement OR memory OR participation OR performance OR practice OR problem-solving OR proficiency OR reasoning OR recall OR reinforcement OR retention OR score OR self-assessment OR self-efficacy OR skills OR test OR "thinking processes" OR understanding
#15	#13 OR #14	
#16	#12 AND #15	
#17	#3 AND #6 AND #9 AND #16	

5.4.2. Searching other sources

Citation indexes and reference lists of all articles found through the database search will be reviewed for any articles that were not identified during the database search. A grey literature search will also be conducted.

5.5. Data collection and analysis

The screening process and study selection will be done according to the guidelines of the *Cochrane Handbook of Systematic Reviews for Interventions*.[43]

5.6. Selection of studies

Two reviewers (CV and RSM) will independently screen all articles identified by the search. The reviewers will complete a standardised coding sheet that will indicate whether an article meets all the inclusion criteria or what the reason for exclusion is.

Duplicate publications of articles will be removed. The more recent publication with the most complete dataset will be used where duplicate publications for the same data are reported.

The screening process will occur in two phases:

- **Phase 1: Screening of title and abstract**
  All titles and abstracts of articles identified in the search will be screened for eligibility. If it is not apparent from the title or abstract whether an article meets eligibility criteria, or if both reviewers (CV and RSM) do not exclude the article, the full text of the article will be reviewed.
- **Phase 2: Screening of full-text article**
  The full text will be reviewed of all potentially eligible articles. A kappa coefficient will be calculated to measure the consistency between the reviewers (CV and RSM).[30] Where there are discrepancies between the reviewers, this will be discussed with a third reviewer (VB) who will act as an adjudicator. Reasons for exclusion will be documented and presented in a table of excluded studies.

5.7. Data extraction and management

References will be managed using EndNote X8 software (Clarivate Analytics).[44] Two reviewers (CV and RSM) will independently extract data from all articles meeting eligibility criteria. The reviewers will use a standardized electronic data collection form on REDCap (Research Electronic Data Capture),[45] which is a secure online database manager hosted at the University of Cape Town. Collected data will be exported from REDCap database to Stata 14.2 (StataCorp, 4905 Lakeway Drive, College Station, Texas 77845 USA) for statistical analysis.

Data extraction will include, but will not be limited to:

- Citation information (e.g. authors, title of article, journal in which article was published, year of publication)
- Study design (e.g. randomised controlled trial, cohort study, case-control study, before-and-after study, cross-sectional research)
- Study population (e.g. country, university, year of study, number of participants, missing participants, response rate)
- Total study duration
- Learning material used in computer-assisted instruction (e.g. text, ECG tracings, diagrams, images, video recording, case scenarios, simulator, student analysis with feedback (quiz); as well as indication of online or offline use)
- Other teaching modalities used for comparison (large group teaching, small group teaching, flipped classroom, peer teaching, near-peer teaching, problem-based learning, self-directed learning)
- ECGs used during teaching (e.g. real ECGs, drawn ECGs, simulator ECGs)
- What was taught? (e.g. normal waveform measurements, normal waveform morphology, abnormal waveform morphology, abnormal rhythms)
- ECG competencies that were measured in the study (e.g. waveform measurements, waveform morphology, arrhythmias)
- Method of testing (e.g. multiple choice questions (MCQ), extended matching items (EMI), written out ECG analysis by student)
- Testing times, i.e. how long before or after the educational intervention (e.g. before intervention to assess baseline ECG competence; shortly after intervention to assess acquisition of ECG competence; delayed testing after intervention to assess retention of competence)
- Results (e.g. mean or median score of pre-intervention test assessing ECG competence; mean or median score of post-intervention tests assessing the acquisition and / or retention of ECG competence)

5.8. Quality assessment

The Medical Education Research Study Quality Instrument (MERSQI) will be used to assess the quality of studies in this systematic review.[46] Designed to evaluate the quality of experimental, quasi-experimental, and observational studies, the MERSQI is a validated quality assessment tool in medical education.[47]

5.9. Assessment of risk of bias

Two reviewers (CV and RSM) will independently assess each included study for risk of bias:[43]

- selection bias, i.e. different baseline characteristics amongst the different groups
- performance bias, i.e. different exposure to factors other than intervention that may have influenced outcome amongst different groups
- attrition bias, i.e. differences between groups in withdrawal of participants
- detection bias, i.e. differences between groups in how outcomes are determined
- reporting bias, i.e. differences in outcome reporting

5.10. Measures of effectiveness of educational intervention

The effectiveness of ECG teaching modalities used in the articles to be reviewed will be scored according to a modified version of Kirkpatrick's framework for the evaluation of educational interventions. This framework is the international preferred framework for evaluation of educational interventions.[38-40] The framework comprises of 4 levels, as shown in table 3.

Table 3: The modified Kirkpatrick's framework for the evaluation of educational interventions

Level 1	Participants reactions
Level 2a	Modifications of attitudes and perceptions
Level 2b	Acquisition of knowledge and skills
Level 3	Change in behaviour
Level 4a	Change in organisational practice
Level 4b	Benefits to patients / students

5.11. Dealing with missing data

Corresponding authors will be contacted in the event of absent or incomplete evidence in the included studies. A delay of 6 weeks will be allowed to receive a response following two email attempts.

5.12. Data synthesis

5.12.1. Systematic review

A descriptive analysis will be provided of computer-assisted instruction and the comparator teaching modalities used for teaching ECGs. The educational impact of the different teaching modalities used for ECG training (computer-assisted instruction and other methods) will be evaluated by the modified version of Kirkpatrick's framework for the evaluation of educational interventions (table 3).[38-40]

5.12.2. Meta-analysis

Heterogeneity of the data will be tested by means of the I^2 and χ^2 tests, as well as by visual inspection of the Forest plot. Where found, the possible reasons for any heterogeneity will be explored, and if unexplainable, findings will be reported in a narrative review. In the absence of heterogeneity, the effects of different teaching modalities will be quantitatively analysed. Relative risk and / or the odds ratio will be used to determine the strength of effects among dichotomous variables, and weighted mean difference will be calculated for continuous variables. The statistical significance will be evaluated through inspection of the 95% confidence intervals.

5.12.3. Mapping review

A mapping review will be done to characterize the quality, quantity and focus of current medical education literature on computer-assisted instruction of ECGs.

5.13. Sensitivity analysis

A sensitivity analysis will be undertaken to evaluate the effect of risk of bias score on the overall result. Should any further arbitrary or unclear characteristics arise from the data extraction, a sensitivity analysis will also be applied.

5.14. Presenting and reporting of results

Results will be discussed in the text and summarised table format, an example of which is given in table 4.

Table 4: Results will be summarised table format

Study	Study design	Participants	Computer-assisted instruction (CAI)	Other teaching methods
Author (year published)	• RCT • Cohort study • Case-control study • Before-and-after study • Cross-sectional research	• Country • University • Year of study • Number of participants	• Educational tools used explained • Content of teaching explored (measurements, rhythms, waveforms)	• Comparator educational methods used explained • Content of teaching explored (measurements, rhythms, waveforms)

Study	Tested ECG knowledge	Baseline knowledge	Acquired knowledge	Retention of knowledge	Kirkpatrick level
Author (year published)	• Measurements • Waveforms • Rhythms	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method	• 1 • 2a • 2b • 3 • 4a • 4b

6. DISCUSSION

6.1. Expected significance of the study

This systematic review aims to explore the pedagogical value computer-assisted instruction as compared with other instructional methods used in the teaching of ECGs. The findings of this systematic review will be important in the review of undergraduate medical curricula. If gaps are identified in the literature, this will inform future research in the field of ECG teaching.

6.2. Ethics and dissemination

This research does not require ethical approval, as the study is a systematic review of published literature. Any changes to the current protocol will be considered protocol amendments, and this will be communicated to the journal, along with a motivation and justification for the protocol amendment. The status of the systematic review will be updated regularly in PROSPERO. We aim to submit the results of this systematic review to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

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8. FOOT NOTES

8.1. Authors' contributions

CV is a PhD student; RSM and VB are his supervisors. CV conceived of the review and undertook the drafting of the manuscript. CV and MS undertook a scoping search and developed the search strategy. CV, RSM and VB will be involved in data acquisition. CV and ME will analyse the data and participate in the interpretation of the results. All authors have read the manuscript and have given their approval for publication.

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8.3. Funding

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8.4. Competing interests

RSM is a lecturer and host of the AO Memorial Advanced ECG and Arrhythmia Course, and receives an honorarium from Medtronic Africa. The other co-authors report no relationships that could be construed as a conflict of interest.

8.5. Keywords

Electrocardiogram (ECG), computer-assisted instruction, web-based learning, medical student(s).

8.6. Abbreviations

CAI: computer-assisted instruction; CAL: computer-assisted learning; ECG: electrocardiogram; EMI: extended matching items; MERSQI: medical education research study quality instrument; MeSH: medical subject heading terms; MCQ: multiple choice question; PBL: problem-based learning; PRISMA-P: preferred reporting items for systematic review and meta-Analysis protocols guidelines; PROSPERO: international prospective register of systematic reviews; RCT: randomised control trial.

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	

PRISMA 2009 Checklist

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit: **www.prisma-statement.org**.

BMJ Open

Is computer-assisted instruction more effective than other educational methods in achieving ECG competence amongst medical students? Protocol for a systematic review and meta-analysis.

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Primary Subject Heading:	Medical education and training
Secondary Subject Heading:	Cardiovascular medicine
Keywords:	electrocardiogram (ECG), computer-assisted instruction, web-based learning, medical student(s)

Is computer-assisted instruction more effective than other educational methods in achieving ECG competence amongst medical students? Protocol for a systematic review and meta-analysis.

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1. ABSTRACT

1.1. Introduction

ECG interpretation is an essential learning outcome in undergraduate medical curricula. However, most graduating medical students lack adequate ECG interpretative skills. Novel teaching methods are increasingly being investigated and implemented to improve undergraduate ECG training. Computer-assisted instruction is one such method under investigation, however, its efficacy in achieving better ECG competence amongst medical students remains uncertain.

1.2. Methods and Analysis

This article describes the protocol for a systematic review and meta-analysis that will compare the effectiveness of computer-assisted instruction with other teaching methods used for the ECG training of medical students. Only studies with a comparative research design will be considered. Articles will be searched for in electronic databases (PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC, Africa-Wide Information and Teacher Reference Center). In addition, we will review citation indexes and conduct a grey literature search. Data extraction will be done on articles that met the predefined eligibility criteria. A descriptive analysis of the different teaching modalities will be provided and their educational impact will be assessed in terms of effect size and the modified version of Kirkpatrick's framework for the evaluation of educational interventions. This systematic review aims to provide evidence as to whether computer-assisted instruction is an effective teaching modality for the ECG training of medical students. It is hoped that the information garnered from this systematic review will assist in future curricular development and improve ECG training.

1.3. Ethics and Dissemination

As this research is a systematic review of published literature, ethical approval is not required. The results will be reported according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) Statement and will be submitted to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

1.4. Trial Registration Number

Systematic review registration: PROSPERO number CRD42017067054.

2. STRENGTHS AND LIMITATIONS

- Due to the lack of competence in ECG analysis and interpretation amongst graduating medical students, it is important to review the way that Electrocardiography is taught.
- This systematic review will evaluate the effectiveness of computer-assisted instruction compared to other teaching methods used in the ECG training of medical students.
- The protocol describes a comprehensive search strategy as well as eligibility criteria, which have no geographical or language restrictions.
- The systematic review might be limited by the presence of selection and / or performance bias inherent in some of the selected studies.
- A meta-analysis will only be possible in the absence of heterogeneous data amongst included studies.

3. INTRODUCTION

The electrocardiogram (ECG) remains one of the most frequently performed diagnostic procedures in clinical practice.[1, 2] ECG interpretation is therefore considered an essential learning outcome in undergraduate medical curricula.[3] Incorrect interpretation of an ECG, however, can lead to inappropriate clinical decisions with serious adverse outcomes, especially in the realms of arrhythmias and myocardial infarction.[4, 5] Previous studies have found that the majority of medical students lack confidence when interpreting ECGs, as they find it a difficult skill to master and retain.[6-10] Of greater concern is the finding that graduating medical students are often unable to accurately interpret ECGs, particularly when dealing with life-threatening conditions such as complete heart block and atrial fibrillation.[7-10]

'ECG analysis' refers to the detailed examination of the ECG tracing, which requires the measurement of intervals and the evaluation of the rhythm and each waveform, whereas 'ECG interpretation' refers to the conclusion reached after careful ECG analysis, i.e. making a diagnosis of an arrhythmia, or ischaemia, etc.[11] 'ECG competence' refers to the ability to accurately analyse as well as interpret the ECG,[7, 12] whereas 'ECG knowledge' refers to the understanding of ECG concepts, e.g. knowing that transmural ischaemia or pericarditis can cause ST-segment elevation.[6, 13]

It is well known that ECG analysis and interpretation are difficult and require significant training.[14] The reasons for this are multifold. To start, students are required to have sound prior knowledge of the anatomy and physiology of the cardiac conduction system before they can begin to study ECGs.[15] ECG analysis also requires a good understanding of vectors and how these are influenced by lead placement and pathology.[11, 15] Furthermore, ECG interpretation requires two types of reasoning: the non-analytical pattern recognition of abnormal waveforms and rhythms; and the analytical, systematic analysis of the entire 12-lead ECG.[16, 17] The best clinical results are attained when both non-analytical pattern recognition as well as analytic systematic analysis of the ECG are used simultaneously, however, most medical students find this overwhelming.[16, 17]

Although a large deal of experience in ECG interpretation depends on clinical exposure,[18] clinical exposure alone does not improve ECG diagnostic accuracy if it is not supplemented by a structured form of teaching.[19] ECGs are commonly taught by means of large group teaching,[7, 14, 19] where a teacher or expert transfers ECG knowledge to a group of learners in the format of a lecture.[20-22] Lectures are a cost efficient and effective method of tuition, as they allow for large groups of medical students to be taught at once.[23, 24] However, large group teaching facilitates passive learning, as didactic lectures often offer students little opportunity for interactive

discussion with the lecturer.[20, 23-25] Undergraduate ECG teaching also frequently occurs in the small group setting, i.e. during ward rounds and bedside tutorials.[22, 24] Small group teaching allows for free communication and interaction between the learner and the teacher, or between the learners themselves.[26]

Alternative teaching methods are increasingly being implemented and investigated to improve undergraduate ECG training and the following are some examples of these. The 'flipped classroom' refers to the teaching method where students are required to watch short video lectures or study written material at their own pace, before attending a classroom lecture.[27, 28] Instead of didactic tuition, lecture time is devoted to a more interactive discussion between the student and lecturer, which allows for problem solving and knowledge application in the classroom.[28, 29] 'Peer teaching' refers to the teaching method in which students are taught by fellow students of the same academic year, whereas 'near-peer teaching' refers to the teaching method in which students are taught by more senior students from the same curriculum.[30] 'Reciprocal peer teaching' allows for students to alternate between the roles of tutor and learner.[31] The tutoring role promotes self-learning by teaching others,[30, 31] whereas the learner role has been shown to be as effective as instruction by lecturers.[31, 32] 'Problem-based learning' (PBL) refers to the student-centred teaching method where a clinical problem is assigned to students, who then need to identify what they need to learn from the clinical case and apply their knowledge to solve a clinical problem.[33] Apart from the face-to-face tuition by experts or peers, ECG knowledge can also be acquired by means of self-directed learning (SDL), which refers to the independent study of textbooks or other designated study material.[34]

Computer-assisted instruction has been used as an ECG teaching modality since the 1960s.[35] Computer-assisted instruction' (CAI) or 'computer assisted learning' (CAL) refers to any teaching method that uses a digital platform as a self-directed learning technique, which includes both online and offline learning opportunities.[36] Although CAI is the broadest term as it encompasses both online and offline modalities, newer terminology specifically referring to online learning modalities includes terms such as 'web-based learning', 'web-based training' and 'e-learning'.[37-40] CAI or web-based learning typically provides the student with text, illustrations and other multimedia material to study. Additional educational features such as practice fields and test-enhanced learning (e.g. online multiple choice questions with immediate feedback) can also be provided by the digital platform.[36, 40-42]

Computer-assisted instruction is increasingly being used as a possible solution for the insufficient time allocated for ECG teaching in undergraduate curricula and the increasing numbers of medical students that lecturers need to teach.[43-45] Web-based learning allows for flexibility in learning, as the student can access the material wherever and whenever

convenient, outside the constraints of time allocated for formal instruction.[39-41]

It is worth reviewing the value of computer-based training in medical education, as the current generation of medical students, who are known as 'Millennials', are computer-literate and often seek technologically enhanced means of education.[46-48] These students grew up during the advent of the world wide web, smartphones and social media and are used to obtaining immediate access to unlimited information through mobile devices and desktop computers.[48, 49] Although today's medical student prefers podcasts and interactive multimedia to conventional classroom teaching and textbooks,[48] there is not enough evidence to suggest that the digital platform should replace traditional teaching methods. Although a meta-analysis showed that web-based learning was as effective as conventional teaching methods in health professionals,[50] more recent subject-specific systematic reviews in Anatomy and Orthopaedics favoured computer assisted-instruction, especially in the setting of blended learning.[36, 51] However, it cannot be extrapolated that the effectiveness of CAI in other domains holds true for teaching Electrocardiography.

The objective measure of a teaching method's effectiveness is the assessment of students' competence after being exposed to the educational intervention.[36] ECG competence is measured by assessing the student's ECG analysis and / or interpretation skills. An assessment shortly after an educational intervention tests the acquisition of ECG competence, whereas delayed testing assesses the retention of ECG competence.[39] More comprehensively, the modified Kirkpatrick model is a widely accepted method of appraising an educational intervention's outcome, as it measures learners' views on the learning experience (level 1), modification of learners' perception of the intervention (level 2a), modification of knowledge or skills (level 2b), transfer of learning to the workplace (level 3), change in organizational practice (level 4a) and benefits to patients (level 4b).[52-55]

In the face of inadequate ECG competence amongst graduating medical students worldwide,[7-10] it is time to review the way that ECG analysis and interpretation are taught. Are conventional ECG teaching methods achieving the necessary ECG competence amongst graduating medical students? Are teaching methods on the digital platform better than the ways that ECGs have traditionally been taught? Or should a blended learning strategy (i.e. the combination of CAI and other teaching modalities) be implemented for ECG teaching? To the best of our knowledge, there is no systematic review of the effectiveness of computer-assisted instruction as compared to other teaching methods used in the ECG training of medical students.

4. OBJECTIVES

The objectives of this systematic review are to:

1. Establish whether computer-assisted instruction (on its own or in a blended learning setting) achieves better **acquisition** of ECG competence amongst medical students than other non-CAI ECG teaching methods do;
2. Establish whether computer-assisted instruction (on its own or in a blended learning setting) achieves better **retention** of ECG competence amongst medical students than other non-CAI ECG teaching methods do;
3. Identify the types of learning material or activities (e.g. reading material, case scenarios, illustrations, videos, test-enhanced learning tools, etc.) in which computer-assisted instruction is delivered for ECG teaching and which of these are associated with better outcomes.

5. METHODS AND DESIGN

In accordance with the PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) guidelines,[56] this systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 6 July 2017 with registration number CRD42017067054.

5.1. Criteria for considering studies for this review

A study will be deemed eligible to be included in this systematic review only if it fulfils all inclusion criteria and does not meet any of the exclusion criteria, as outlined in Table 1.

Table 1: Criteria to assess a study's eligibility to be included in this systematic review

Inclusion criteria	Exclusion criteria
Population	
• Medical students	• Students other than medical students • Qualified doctors
Intervention	
• Online or offline computer-assisted instruction used to teach the analysis and interpretation of ECGs	• Computer-assisted instruction not included as teaching modality in study • Teaching modalities were not primarily and solely used to teach ECGs • The subject of teaching was not the conventional 12-lead ECG
Comparator	
• Any comparative ECG teaching method, not making use of computer-assisted instruction	• Absent or inadequately described comparator or control group
Outcome	
Educational intervention's effectiveness: • Acquisition of ECG competence, or • Retention of ECG competence, or • Level of Kirkpatrick outcomes	• There is no objective outcome measured (i.e. no testing of ECG competence)
Study	
Any comparative research design: • Randomised controlled trial, or • Cohort study, or • Case-control study, or • Before-and-after study, or • Cross-sectional research	Any non-comparative research design: • Audit • Case-series • Historical narrative • Survey based

5.1.1. Types of studies

All studies with a comparative research design, i.e. randomised controlled trial, cohort study, case-control study, before-and-after study or cross-sectional research will be included.

5.1.2. Types of participants

We will include studies in which medical students were the participants. In studies where the participants were not limited to medical students, only data pertaining to the medical students will be extracted.

5.1.3. Types of interventions

Studies must include computer-assisted instruction as an educational intervention, either in an online or an offline format. The comparator education intervention may include any other teaching method to which computer-assisted instruction was compared. We will exclude studies in which teaching modalities were not primarily and solely used to teach ECGs, or if the subject of teaching was not the conventional 12-lead ECG.

5.1.4. Types of outcome measures

Results must include quantitative data in which ECG competence was measured. We will include assessments of the acquisition of ECG competence (measured shortly after educational intervention) and / or assessments of the retention of ECG competence (delayed testing after educational intervention).

5.1.5. Language and years of publication

All articles published before July 2017 will be included. Publications in languages other than English will be translated, wherever possible.

5.2. Primary outcomes

The primary outcome of this systematic review is to determine whether or not CAI, on its own or in a blended learning setting, is more effective than non-CAI teaching methods in achieving acquisition and retention of ECG competence amongst medical students.

ECG competence will be measured by extracting the mean scores and standard deviations of assessments before and after exposure to CAI and non-CAI teaching methods, as well as the *P* values, confidence intervals and effect sizes (Cohen's *d*). If the Cohen's *d* is not reported in the study, this will be calculated using the mean difference between the groups exposed to CAI and non-CAI teaching methods, divided by the standard deviation of the group exposed to non-CIA teaching methods:[57, 58]

$$\text{Cohen's } d = \frac{\text{Mean}_{\text{(group exposed to CAI)}} - \text{Mean}_{\text{(group exposed to non-CAI teaching methods)}}}{\text{Standard deviation}_{\text{(group exposed to non-CAI teaching methods)}}}$$

An effect size of greater than 0.8 will be considered of significant practical importance, whereas effect sizes of 0.5 and 0.2 will be considered as moderate and negligible practical importance respectively.[57, 58]

The effect of the different ECG teaching modalities will also be scored according to a modified version of Kirkpatrick's framework for the evaluation of educational interventions, as shown in Table 2.[52-55]

Table 2: The modified Kirkpatrick's framework for the evaluation of educational interventions

Level 1	Participants' reactions
Level 2a	Modifications of attitudes and perceptions
Level 2b	Acquisition of knowledge and skills
Level 3	Change in behaviour
Level 4a	Change in organisational practice
Level 4b	Benefits to patients or students

5.3. Secondary outcomes

The secondary outcomes of this study are to identify the types of learning material or activities (e.g. reading material, case scenarios, illustrations, videos, test-enhanced learning tools) in which computer-assisted instruction is delivered for ECG teaching; and to identify which of these were associated with better outcomes.

5.4. Search methods for identification of studies

The lead reviewer (CV) and an expert librarian (MS) from the University of Cape Town's Faculty of Health Sciences will conduct an extensive search for peer-reviewed articles.

5.4.1. Electronic searches

The following electronic databases will be used for the search of articles for this systematic review: PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC (Education Resources Information Centre), Africa-Wide Information, Teacher Reference Center and Google Scholar. A combination of Medical Subject Heading (MeSH) terms and free text terms will be used to search for articles. Table 3 shows the main search strategy that we will use.

Table 3: PubMed Search strategy, modified as needed for other electronic databases

Population: medical students		
#1	MeSH terms:	Students, Medical [MeSH] OR Education, Medical, Undergraduate [MeSH]
#2	Free text:	medical student OR undergraduate
#3	#1 OR #2	
Intervention: computer-assisted instruction		
#4	MeSH terms:	Computer-assisted Instruction [MeSH] OR Computer Simulation [MeSH] OR Educational Technology [MeSH] OR Internet [MeSH]
#5	Free text:	app OR application OR "blended learning" OR computer OR computer-assisted OR digital OR e-learning OR e-modules OR "flipped classroom" OR Internet OR multimedia OR online OR software OR technology OR virtual OR web OR web-aided OR web-assisted OR web-based OR web-supported OR web-enhanced OR webCT OR web 2.0 OR YouTube

#6	#4 OR #5	
Comparator: any other teaching method used		
#7	MeSH terms:	Cardiology/Education[MeSH] OR Education/Methods [MeSH] OR Electrocardiography/Education OR Models, Educational [MeSH] OR Problem-based Learning [MeSH] OR Teaching/Methods [MeSH] OR Teaching Rounds [MeSH]
#8	Free text:	activity OR activities OR bedside OR blackboard OR class OR classroom OR clinical OR competency-based OR conventional OR course OR didactic OR educational method OR educational techniques OR instruction OR instructional method OR instructional techniques OR "large group" OR lecture OR lecture-based OR near peer OR outcome-based OR PBL OR pedagogy OR pedagogical OR peer facilitated OR peer led OR peer teaching OR peer tutorial OR peer tutoring OR problem-based OR rounds OR self-directed OR self-instruction OR self-study OR seminar OR simulation OR simulator OR "small group" OR teaching method OR teaching techniques OR test-enhanced learning OR traditional OR training OR tutorial OR ward OR "worked example" OR workshop
#9	#7 OR #8	
Outcome: efficacy in acquiring ECG knowledge or skills		
#10	MeSH terms:	Electrocardiography [MeSH]
#11	Free text:	ECG OR EKG OR electrocardiography OR electrocardiogram OR electrocardiographic
#12	#10 OR #11	
#13	MeSH terms:	Clinical Competence [MeSH] OR Cognition [MeSH] OR Learning [MeSH]
#14	Free text:	accuracy OR analysis OR assessment OR cognition OR cognitive OR competence OR competency OR comprehension OR diagnosis OR diagnostic OR effectiveness OR efficacy OR examination OR interpretation OR insight OR knowledge OR learning OR measurement OR memory OR participation OR performance OR practice OR problem-solving OR proficiency OR reasoning OR recall OR reinforcement OR retention OR score OR self-assessment OR self-efficacy OR skills OR test OR understanding
#15	#13 OR #14	
#16	#12 AND #15	
#17	#3 AND #6 AND #9 AND #16	

5.4.2. Searching other sources

Citation indexes and reference lists of all articles found through the database search will be reviewed for any articles that were not identified during the database search. A grey literature search will also be conducted.

5.5. Data collection and analysis

The screening process and study selection will be done according to the guidelines of the *Cochrane Handbook of Systematic Reviews for Interventions*.[59]

5.6. Selection of studies

Two reviewers (CV and RSM) will independently screen all articles identified by the search. The reviewers will complete a standardised coding sheet that will indicate whether an article meets all the inclusion criteria or what the reason for exclusion is.

Duplicate publications of articles will be removed. The more recent publication with the most complete dataset will be used where duplicate publications for the same data are reported.

The screening process will occur in two phases:

- **Phase 1: Screening of title and abstract**
  All titles and abstracts of articles identified in the search will be screened for eligibility. If it is not apparent from the title or abstract whether an article meets eligibility criteria, or if both reviewers (CV and RSM) do not exclude the article, the full text of the article will be reviewed.
- **Phase 2: Screening of full-text article**
  The full text will be reviewed of all potentially eligible articles. A kappa coefficient will be calculated to measure the consistency between the reviewers (CV and RSM).[30]
  Where there are discrepancies between the reviewers, this will be discussed with a third reviewer (VB) who will act as an adjudicator. Reasons for exclusion will be documented and presented in a table of excluded studies.

5.7. Data extraction and management

References will be managed using EndNote X8 software (Clarivate Analytics).[60] Two reviewers (CV and RSM) will independently extract data from all articles meeting eligibility criteria. The reviewers will use a standardized electronic data collection form on REDCap (Research Electronic Data Capture),[61] which is a secure online database manager hosted at the University of Cape Town. Collected data will be exported from REDCap database to Stata 14.2 (StataCorp, 4905 Lakeway Drive, College Station, Texas 77845 USA) for statistical analysis.

Data extraction will include, but will not be limited to:

- citation information (e.g. authors, title of article, journal in which article was published, year of publication);
- study design (e.g. randomised controlled trial, cohort study, case-control study, before-and-after study, cross-sectional research);
- study population (e.g. country, university, year of study, number of participants, missing participants, response rate);
- total study duration;
- learning material used in computer-assisted instruction (e.g. text, ECG tracings, diagrams, images, video recording, case scenarios, simulator, student analysis with feedback (quiz); as well as indication of online or offline use);
- other teaching modalities used for comparison (e.g. lectures, tutorials, ward rounds, peer teaching, near-peer teaching, problem-based learning, self-directed learning);
- ECGs used during teaching (e.g. real ECGs, drawn ECGs, simulator ECGs);
- topics taught (e.g. normal waveform measurements, normal waveform morphology, abnormal waveform morphology, abnormal rhythms);
- ECG competencies that were measured in the study (e.g. waveform measurements, waveform morphology, arrhythmias);
- method of testing (e.g. multiple choice questions (MCQ), extended matching items (EMI), written out ECG analysis by student);
- testing times, i.e. the length of time before or after the educational intervention that testing occurred (e.g. before intervention to assess baseline ECG competence; shortly after intervention to assess acquisition of ECG competence; delayed testing after intervention to assess retention of competence);
- results (e.g. mean score and standard deviation of pre-intervention test assessing ECG competence; mean score and standard deviation of post-intervention tests assessing the acquisition and / or retention of ECG competence);
- validity and reliability of the results and psychometric properties of the assessment tools used to test ECG competence, as available in articles (e.g. Cronbach's α coefficient).[62]

5.8. Quality assessment

The Medical Education Research Study Quality Instrument (MERSQI) will be used to assess the quality of studies in this systematic review.[63] Designed to evaluate the quality of experimental, quasi-experimental, and observational studies, the MERSQI is a validated quality assessment tool in medical education.[64]

5.9. Assessment of risk of bias

Two reviewers (CV and RSM) will independently assess each included study for risk of bias:[59]

- selection bias, i.e. different baseline characteristics amongst the different groups
- performance bias, i.e. different exposure to factors other than intervention that may have influenced outcome amongst different groups
- attrition bias, i.e. differences between groups in withdrawal of participants
- detection bias, i.e. differences between groups in how outcomes are determined
- reporting bias, i.e. differences in outcome reporting

5.10. Measures of effectiveness of educational intervention

The practical significance of the educational interventions will be determined by reviewing their effect sizes. The effectiveness of ECG teaching modalities used in the articles will also be scored according to a modified version of Kirkpatrick's framework for the evaluation of educational interventions. This framework is the internationally preferred framework for evaluation of educational interventions.[52-54] The framework comprises of 4 levels, as shown in Table 2.

5.11. Dealing with missing data

Corresponding authors will be contacted in the event of absent or incomplete evidence in the included studies. A delay of six weeks will be allowed to receive a response following two email attempts.

5.12. Data synthesis

5.12.1. Systematic review

We will provide a descriptive analysis of computer-assisted instruction and the comparator teaching modalities used for teaching ECGs. The educational impact of the different teaching modalities used for ECG training (computer-assisted instruction and other methods) will be evaluated by the modified version of Kirkpatrick's framework for the evaluation of educational interventions, as shown in Table 2.[52-54]

5.12.2. Meta-analysis

Heterogeneity of the data will be tested by means of the I^2 and χ^2 tests, as well as by visual inspection of the Forest plot. Where found, the possible reasons for any heterogeneity will be explored, and if unexplainable, findings will be reported in a narrative review. In the absence of heterogeneity, the effects of different teaching modalities will be quantitatively analysed. The relative risk and / or the odds ratio will be used to determine the strength of effects among dichotomous variables, and weighted mean difference will be calculated for continuous variables. The statistical significance will be evaluated through inspection of the 95% confidence intervals. In addition, we will consider sub-analyses of studies in terms of teaching methods (i.e. CAI, non-CAI and blended learning) and different learning material or activities used by CAI (where sufficient data exist).

5.12.3. Mapping review

A mapping review will be done to characterize the quality, quantity and focus of current medical education literature on computer-assisted instruction of ECGs.

5.13. Sensitivity analysis

A sensitivity analysis will be undertaken to evaluate the effect of the risk of bias score on the overall result.[59] Should any further arbitrary or unclear characteristics arise from the data extraction, a sensitivity analysis will also be applied.

5.14. Presenting and reporting of results

Results will be discussed in the text and summarised in table format, an example of which is given in Table 4.

Table 4: Results will be summarised in table format

Study	Study design	Participants	Computer-assisted instruction (CAI)	Comparator teaching methods (not using CAI)
• Author • Journal • Year of publication	• Randomised control trial • Cohort study • Case-control study • Before-and-after study • Cross-sectional research	• Country • University • Year of study • Number of participants	• CAI learning material / activities explained • Content of teaching explored (measurements, rhythms, waveforms)	• Comparator educational methods explained • Content of teaching explored (measurements, rhythms, waveforms)

Study	ECG knowledge that was tested	Baseline ECG knowledge	Acquired ECG knowledge	Retention of ECG knowledge
• Author • Journal • Year of publication	• Measurements • Waveforms • Rhythms	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method

Study	Modified Kirkpatrick model[52-55]	Quality assessment	Risk of bias	Significance of study results
• Author • Journal • Year of publication	• Level 1 • Level 2a • Level 2b • Level 3 • Level 4a • Level 4b	• MERSQI score[63, 64] • Validity of results • Reliability of results • Psychometric properties of assessments testing ECG competence	• Selection bias • Performance bias • Attrition bias • Detection bias • Reporting bias	• Findings of study summarised • Practical significance of findings (effect size)

6. DISCUSSION

6.1. Expected significance of the study

This systematic review aims to explore the pedagogical value computer-assisted instruction as compared with other instructional methods used in the teaching of ECGs. The findings of this systematic review will be important in the review of undergraduate medical curricula. If gaps are identified in the literature, this will inform future research in the field of ECG teaching. The goal is to provide evidence of best teaching practices, as patient care will ultimately benefit from improved ECG competence amongst graduating medical students.

6.2. Ethics and dissemination

This research does not require ethical approval, as the study is a systematic review of published literature. Any changes to the current protocol will be considered protocol amendments, and this will be communicated to the journal, along with a motivation and justification for the protocol amendment. The status of the systematic review will be updated regularly in PROSPERO. We aim to submit the results of this systematic review to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

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8. FOOT NOTES

8.1. Authors' contributions

CV is a PhD student; RSM and VB are his supervisors. CV conceived of the review and undertook the drafting of the manuscript. CV and MS undertook a scoping search and developed the search strategy. CV, RSM and VB will be involved in data acquisition. CV and ME will analyse the data and participate in the interpretation of the results. All authors have read the manuscript and have given their approval for publication.

8.2. Acknowledgements

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8.3. Funding

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8.4. Competing interests

RSM is a lecturer and host of the AO Memorial Advanced ECG and Arrhythmia Course, and receives an honorarium from Medtronic Africa. The other co-authors report no relationships that could be construed as a conflict of interest.

8.5. Keywords

Electrocardiogram (ECG), computer-assisted instruction, web-based learning, medical student(s).

8.6. Abbreviations

CAI: computer-assisted instruction; CAL: computer-assisted learning; ECG: electrocardiogram; EMI: extended matching items; MERSQI: medical education research study quality instrument; MeSH: medical subject heading terms; MCQ: multiple choice question; PBL: problem-based learning; PRISMA-P: preferred reporting items for systematic review and meta-Analysis protocols guidelines; PROSPERO: international prospective register of systematic reviews; RCT: randomised control trial, SD: standard deviation.

PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

Section and topic	Item No	Checklist item
ADMINISTRATIVE INFORMATION		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review
Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments
Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review

Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

*** It is strongly recommended that this checklist be read in conjunction with the PRISMA-P Explanation and Elaboration (cite when available) for important clarification on the items. Amendments to a review protocol should be tracked and dated. The copyright for PRISMA-P (including checklist) is held by the PRISMA-P Group and is distributed under a Creative Commons Attribution Licence 4.0.**

From: Shamseer L, Moher D, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart L, PRISMA-P Group. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. BMJ. 2015 Jan 2;349(jan02 1):g7647.

BMJ Open

Is computer-assisted instruction more effective than other educational methods in achieving ECG competence amongst medical students and residents? Protocol for a systematic review and meta-analysis.

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Is computer-assisted instruction more effective than other educational methods in achieving ECG competence amongst medical students and residents? Protocol for a systematic review and meta-analysis.

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1. ABSTRACT

1.1. Introduction

Although ECG interpretation is an essential skill in clinical medicine, medical students and residents often lack ECG competence. Novel teaching methods are increasingly being implemented and investigated to improve ECG training. Computer-assisted instruction is one such method under investigation, however, its efficacy in achieving better ECG competence amongst medical students and residents remains uncertain.

1.2. Methods and Analysis

This article describes the protocol for a systematic review and meta-analysis that will compare the effectiveness of computer-assisted instruction with other teaching methods used for the ECG training of medical students and residents. Only studies with a comparative research design will be considered. Articles will be searched for in electronic databases (PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC, Africa-Wide Information and Teacher Reference Center). In addition, we will review citation indexes and conduct a grey literature search. Data extraction will be done on articles that met the predefined eligibility criteria. A descriptive analysis of the different teaching modalities will be provided and their educational impact will be assessed in terms of effect size and the modified version of Kirkpatrick's framework for the evaluation of educational interventions. This systematic review aims to provide evidence as to whether computer-assisted instruction is an effective teaching modality for the ECG training. It is hoped that the information garnered from this systematic review will assist in future curricular development and improve ECG training.

1.3. Ethics and Dissemination

As this research is a systematic review of published literature, ethical approval is not required. The results will be reported according to the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) Statement and will be submitted to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

1.4. Trial Registration Number

Systematic review registration: PROSPERO number CRD42017067054.

2. STRENGTHS AND LIMITATIONS

- In the face of inadequate ECG competence amongst graduating medical students and residents worldwide, it is important to review how electrocardiography is taught.
- This systematic review will evaluate the effectiveness of computer-assisted instruction compared to other teaching methods used in the ECG training of medical students and residents.
- The protocol describes a comprehensive search strategy as well as eligibility criteria, which have no geographical or language restrictions.
- The systematic review might be limited by the presence of selection and / or performance bias inherent in some of the selected studies.
- A meta-analysis will only be possible in the absence of heterogeneous data amongst included studies.

3. INTRODUCTION

The electrocardiogram (ECG) remains one of the most frequently performed diagnostic procedures in clinical practice.[1, 2] ECG interpretation is therefore considered an essential learning outcome in undergraduate medical curricula.[3] Incorrect interpretation of an ECG, however, can lead to inappropriate clinical decisions with serious adverse outcomes, especially in the realms of arrhythmias and myocardial infarction.[4, 5] Previous studies have found that the majority of medical students lack confidence when interpreting ECGs, as they find it a difficult skill to master and retain.[6-10] Of greater concern is the finding that graduating medical students are often unable to accurately interpret ECGs, particularly when dealing with life-threatening conditions such as complete heart block and atrial fibrillation.[7-10] Sub-optimal ECG competence has also been shown in residents in Cardiology, Internal Medicine and Emergency Medicine, all of which are specialties where the ECG is considered a core skill of daily practice.[11-16]

'ECG analysis' refers to the detailed examination of the ECG tracing, which requires the measurement of intervals and the evaluation of the rhythm and each waveform, whereas 'ECG interpretation' refers to the conclusion reached after careful ECG analysis, i.e. making a diagnosis of an arrhythmia, or ischaemia, etc.[17] 'ECG competence' refers to the ability to accurately analyse as well as interpret the ECG,[7, 18] whereas 'ECG knowledge' refers to the understanding of ECG concepts, e.g. knowing that transmural ischaemia or pericarditis can cause ST-segment elevation.[6, 19]

It is well known that ECG analysis and interpretation are difficult and require significant training.[20] The reasons for this are multifold. To start, students are required to have sound prior knowledge of the anatomy and physiology of the cardiac conduction system before they can begin to study ECGs.[21] ECG analysis also requires a good understanding of vectors and how these are influenced by lead placement and pathology.[17, 21] Furthermore, ECG interpretation requires two types of reasoning: the non-analytical pattern recognition of abnormal waveforms and rhythms; and the analytical, systematic analysis of the entire 12-lead ECG.[22, 23] The best clinical results are attained when both non-analytical pattern recognition as well as analytic systematic analysis of the ECG are used simultaneously, however, most medical students and postgraduate trainees find this overwhelming.[22, 23]

Although a large deal of experience in ECG interpretation depends on clinical exposure,[24] clinical exposure alone does not improve ECG diagnostic accuracy if it is not supplemented by a structured form of teaching.[25] In undergraduate and postgraduate courses, ECGs are commonly taught by means of large group teaching,[2, 7, 20, 25, 26] where a teacher or expert transfers ECG knowledge to a group of learners in the format of a lecture.[27-29] Lectures are a cost efficient and

effective method of tuition, as they allow for large groups of students to be taught at once.[30, 31] However, large group teaching facilitates passive learning, as didactic lectures often offer students little opportunity for interactive discussion with the lecturer.[27, 30-32] Undergraduate ECG teaching also frequently occurs in the small group setting, i.e. during ward rounds and bedside tutorials.[29, 31] Small group teaching allows for free communication and interaction between the learner and the teacher, or between the learners themselves.[33]

Alternative teaching methods are increasingly being implemented and investigated to improve ECG training and the following are some examples of these. The 'flipped classroom' refers to the teaching method where students are required to watch short video lectures or study written material at their own pace, before attending a classroom lecture.[34, 35] Instead of didactic tuition, lecture time is devoted to a more interactive discussion between the student and lecturer, which allows for problem solving and knowledge application in the classroom.[35, 36] 'Peer teaching' refers to the teaching method in which students are taught by fellow students of the same academic year, whereas 'near-peer teaching' refers to the teaching method in which students are taught by more senior students from the same curriculum.[37] 'Reciprocal peer teaching' allows for students to alternate between the roles of tutor and learner.[38] The tutoring role promotes self-learning by teaching others,[37, 38] whereas the learner role has been shown to be as effective as instruction by lecturers.[38, 39] 'Problem-based learning' (PBL) refers to the student-centred teaching method where a clinical problem is assigned to students, who then need to identify what they need to learn from the clinical case and apply their knowledge to solve a clinical problem.[40] Apart from the face-to-face tuition by experts or peers, ECG knowledge can also be acquired by means of self-directed learning (SDL), which refers to the independent study of textbooks or other designated study material.[41]

Computer-assisted instruction has been used as an ECG teaching modality since the 1960s.[42] Computer-assisted instruction' (CAI) or 'computer assisted learning' (CAL) refers to any teaching method that uses a digital platform as a self-directed learning technique, which includes both online and offline learning opportunities.[43] Although CAI is the broadest term as it encompasses both online and offline modalities, newer terminology specifically referring to online learning modalities includes terms such as 'web-based learning', 'web-based training' and 'e-learning'.[44-47] CAI or web-based learning typically provides the student with text, illustrations and other multimedia material to study. Additional educational features such as practice fields and test-enhanced learning (e.g. online multiple choice questions with immediate feedback) can also be provided by the digital platform.[43, 47-49] Computer-assisted instruction is increasingly being used as a possible solution for the increasing numbers of medical students that lecturers need to teach and the insufficient time allocated for ECG instruction in undergraduate and postgraduate curricula.[50-53] Web-based learning allows for flexibility in learning, as the student can access the

material wherever and whenever convenient, outside the constraints of time allocated for formal instruction.[46-48]

It is worth reviewing the value of computer-based training in medical education, as the current generation of medical students and residents, who are known as 'Millennials', are computer-literate and often seek technologically enhanced means of education.[54-56] These students and residents grew up during the advent of the world wide web, smartphones and social media and are used to obtaining immediate access to unlimited information through mobile devices and desktop computers.[56, 57] Although today's medical student prefers podcasts and interactive multimedia to conventional classroom teaching and textbooks,[56] there is not enough evidence to suggest that the digital platform should replace traditional teaching methods. Although a meta-analysis showed that web-based learning was as effective as conventional teaching methods in health professionals,[58] more recent subject-specific systematic reviews in Anatomy and Orthopaedics favoured computer assisted-instruction, especially in the setting of blended learning.[43, 59] However, it cannot be extrapolated that the effectiveness of CAI in other domains holds true for teaching Electrocardiography.

The objective measure of a teaching method's effectiveness is the assessment of students' competence after being exposed to the educational intervention.[43] ECG competence is measured by assessing the student's ECG analysis and / or interpretation skills. An assessment shortly after an educational intervention tests the acquisition of ECG competence, whereas delayed testing assesses the retention of ECG competence.[46] More comprehensively, the modified Kirkpatrick model is a widely accepted method of appraising an educational intervention's outcome, as it measures learners' views on the learning experience (level 1), modification of learners' perception of the intervention (level 2a), modification of knowledge or skills (level 2b), transfer of learning to the workplace (level 3), change in organizational practice (level 4a) and benefits to patients (level 4b).[60-63]

However, the effectiveness of an instructional method should not be interpreted in isolation, as there are several educational approaches that also have a significant impact on learning. The learning environment (i.e. whether instruction occurs in the classroom, computer lab or clinical setting)[64] and the spacing of instructional events (i.e. massed versus distributed instruction)[65-67] should be borne in mind when assessing the efficacy of instructional methods. It should also be considered whether provision was made for deliberate practice (e.g. paper-based or computer-based ECG analysis)[68-70] and whether the instruction included any formative or summative assessment with feedback.[71, 72]

A distinction should be made between the method of instruction (how knowledge is transferred from the expert to the learner) and learning theories (how knowledge is acquired and assimilated by the learner).[73] Different learning theories underpin a range of instructional methods.[74] Although there is some overlap, learning theories can be categorised as

- instrumental learning theories,[74] which include behaviourism (learning with through practice, feedback and reinforcement),[73-75] cognitivism (learning with demonstrations and explanations, understanding concepts),[74-76] constructivism (critical thinking and elaboration)[75-78] and experiential learning (learning through experience);[64, 74, 79, 80]
- humanistic learning theories,[74] which include andragogy (adult learning driven by intrinsic instead of extrinsic motivation)[74, 81, 82] and self-directed learning (self-regulated learning, where the learner plans and monitors their own learning);[83, 84]
- the transformative learning theory (critical reflection);[74]
- social learning theories,[74] which include collaborative learning (interaction with peers and tutors)[85, 86] and contextual learning (with case scenarios or multiple examples with different perspectives).[87, 88]

In the face of inadequate ECG competence amongst graduating medical students and residents worldwide,[7-10] it is time to review the way that ECG analysis and interpretation are taught. Are conventional ECG teaching methods achieving the necessary ECG competence? Are teaching methods on the digital platform better than the ways that ECGs have traditionally been taught? Or should a blended learning strategy (i.e. the combination of CAI and other teaching modalities) be implemented for ECG teaching? And which learning theories underpin computer-assisted ECG instruction? To the best of our knowledge, there is no systematic review of the effectiveness of computer-assisted instruction as compared to other teaching methods used in the ECG training of medical students and residents.

4. OBJECTIVES

The objectives of this systematic review are to:

1. Establish whether computer-assisted instruction (on its own or in a blended learning setting) achieves better **acquisition** of ECG competence amongst medical students and residents than other non-CAI ECG teaching methods do;
2. Establish whether computer-assisted instruction (on its own or in a blended learning setting) achieves better **retention** of ECG competence amongst medical students and residents than other non-CAI ECG teaching methods do;
3. Establish whether there is a difference in the effectiveness of computer-assisted ECG instruction between medical students and residents enrolled for specialty training;
4. Identify the types of learning material or activities (e.g. reading material, case scenarios, illustrations, videos, test-enhanced learning tools, etc.) in which computer-assisted instruction is delivered for ECG teaching, and to establish which computer-assisted learning material or activities are associated with better outcomes;
5. Identify the educational approaches that are possible with computer-assisted ECG instruction, and to establish which of these are associated with better outcomes;
6. Identify the learning theories that may underpin computer-assisted ECG instruction.

5. METHODS AND DESIGN

In accordance with the PRISMA-P (Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols) guidelines,[89] this systematic review protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on 6 July 2017 with registration number CRD42017067054.

5.1. Criteria for considering studies for this review

A study will be deemed eligible to be included in this systematic review only if it fulfils all inclusion criteria and does not meet any of the exclusion criteria, as outlined in Table 1.

Table 1: Criteria to assess a study's eligibility to be included in this systematic review

Inclusion criteria	Exclusion criteria
Population	
• Medical students; or • Residents enrolled for specialty training in e.g. Cardiology, Internal Medicine, Emergency Medicine, Family Medicine, Anaesthetics or Paediatrics	• Students other than medical students; or • Health care professionals who are not medical doctors
Intervention	
• Online or offline computer-assisted instruction used to teach the analysis and interpretation of ECGs	• Computer-assisted instruction not included as teaching modality in study • Teaching modalities were not primarily and solely used to teach ECGs • The subject of teaching was not the conventional 12-lead ECG
Comparator	
• Any comparative ECG teaching method, not making use of computer-assisted instruction	• Absent or inadequately described comparator or control group
Outcome	
Educational intervention's effectiveness: • Acquisition of ECG competence, or • Retention of ECG competence, or • Level of Kirkpatrick outcomes	• There is no objective outcome measured (i.e. no testing of ECG competence)
Study	
Any comparative research design: • Randomised controlled trial, or • Cohort study, or • Case-control study, or • Before-and-after study, or • Cross-sectional research	Any non-comparative research design: • Audit, or • Case-series, or • Historical narrative, or • Survey based

5.1.1. Types of studies

All studies with a comparative research design, i.e. randomised controlled trial, cohort study, case-control study, before-and-after study or cross-sectional research will be included.

5.1.2. Types of participants

We will include studies in which the participants were medical students or residents enrolled for specialty training (e.g. Cardiology, Internal Medicine, Emergency Medicine, Family Medicine, Paediatrics, Anaesthetics). In studies where the participants were not limited to medical students or residents, only data pertaining to the medical students and residents will be extracted.

5.1.3. Types of interventions

Studies must include computer-assisted instruction as an educational intervention, either in an online or an offline format. The comparator education intervention may include any other teaching method to which computer-assisted instruction was compared. We will exclude studies in which teaching modalities were not primarily and solely used to teach ECGs, or if the subject of teaching was not the conventional 12-lead ECG.

5.1.4. Types of outcome measures

Results must include quantitative data in which ECG competence was measured. We will include assessments of the acquisition of ECG competence (measured shortly after educational intervention) and / or assessments of the retention of ECG competence (delayed testing after educational intervention).

5.1.5. Language and years of publication

All articles published before July 2017 will be included. Publications in languages other than English will be translated, wherever possible.

5.2. Primary outcomes

The primary outcome of this systematic review is to determine whether or not CAI, on its own or in a blended learning setting, is more effective than non-CAI teaching methods in achieving acquisition and retention of ECG competence amongst medical students and residents.

ECG competence will be measured by extracting the mean scores and standard deviations of assessments before and after exposure to CAI and non-CAI teaching methods, as well as the *P* values, confidence intervals and effect sizes (Cohen's *d*). If the Cohen's *d* is not reported in the study, this will be calculated using the mean difference between the groups exposed to CAI and non-CAI teaching methods, divided by the standard deviation of the group exposed to non-CIA teaching methods:[90, 91]

$$\text{Cohen's } d = \frac{\text{Mean}_{\text{(group exposed to CAI)}} - \text{Mean}_{\text{(group exposed to non-CAI teaching methods)}}}{\text{Standard deviation}_{\text{(group exposed to non-CAI teaching methods)}}}$$

An effect size of greater than 0.8 will be considered of significant practical importance, whereas effect sizes of 0.5 and 0.2 will be considered as moderate and negligible practical importance respectively.[90, 91]

The effect of the different ECG teaching modalities will also be scored according to a modified version of Kirkpatrick's framework for the evaluation of educational interventions, as shown in Table 2.[60-63]

Table 2: The modified Kirkpatrick's framework for the evaluation of educational interventions

Level 1	Participants' reactions
Level 2a	Modifications of attitudes and perceptions
Level 2b	Acquisition of knowledge and skills
Level 3	Change in behaviour
Level 4a	Change in organisational practice
Level 4b	Benefits to patients or students

5.3. Secondary outcomes

The secondary outcomes of this study are to

1. determine whether there is a difference in the effectiveness of computer-assisted ECG instruction between medical students and residents enrolled for specialty training;
2. identify the types of learning material or activities that are possible with computer-assisted ECG instruction (e.g. annotated ECGs, text, illustrations, videos, case scenarios, worked examples, deliberate practice tools) and to establish which CAI learning material or activities were associated with better outcomes;
3. identify the educational approaches (combined or implemented separately) that are possible with computer-assisted ECG instruction and to establish whether these are more successful when used with computer-assisted instruction, conventional teaching methods or in a blended learning setting;
4. identify the learning theories that underpin the methods of ECG instruction, i.e. computer-assisted instruction and other methods used for ECG teaching.

5.4. Search methods for identification of studies

The lead reviewer (CV) and an expert librarian (MS) from the University of Cape Town's Faculty of Health Sciences will conduct an extensive search for peer-reviewed articles.

5.4.1. Electronic searches

The following electronic databases will be used for the search of articles for this systematic review: PubMed, Scopus, Web of Science, Academic Search Premier, CINAHL, PsycINFO, ERIC (Education Resources Information Centre), Africa-Wide Information, Teacher Reference Center and Google Scholar. A combination of Medical Subject Heading (MeSH) terms and free text terms will be used to search for articles. Table 3 shows the main search strategy that we will use.

Table 3: PubMed Search strategy, modified as needed for other electronic databases

Population: medical students / residents enrolled for specialty training		
#1	MeSH terms:	Education, Medical [MeSH] OR Students, Medical [MeSH]
#2	Free text:	fellow OR fellowship OR graduate OR medical student OR postgraduate OR residency OR resident OR registrar OR registrarship OR specialty OR specialties OR undergraduate
#3	#1 OR #2	
Intervention: computer-assisted instruction		
#4	MeSH terms:	Computer-assisted Instruction [MeSH] OR Computer Simulation [MeSH] OR Educational Technology [MeSH] OR Internet [MeSH]
#5	Free text:	app OR application OR "blended learning" OR computer OR computer-assisted OR digital OR e-learning OR e-modules OR "flipped classroom" OR Internet OR multimedia OR online OR software OR technology OR virtual OR web OR web-aided OR web-assisted OR web-based OR web-supported OR web-enhanced OR webCT OR web 2.0 OR YouTube
#6	#4 OR #5	
Comparator: any other teaching method used		
#7	MeSH terms:	Cardiology/Education[MeSH] OR Education/Methods [MeSH] OR Electrocardiography/Education OR Models, Educational [MeSH] OR Problem-based Learning [MeSH] OR Teaching/Methods [MeSH] OR Teaching Rounds [MeSH]
#8	Free text:	activity OR activities OR bedside OR blackboard OR class OR classroom OR clinical OR competency-based OR conventional OR course OR didactic OR educational method OR educational techniques OR instruction OR instructional method OR instructional techniques OR interactive OR "large group" OR lecture OR lecture-based OR near peer OR outcome-based OR PBL OR pedagogy OR pedagogical OR peer facilitated OR peer led OR peer teaching OR peer tutorial OR peer tutoring OR problem-based OR rounds OR self-directed OR self-instruction OR self-study OR seminar OR simulation OR simulator OR "small group" OR teaching method OR teaching techniques OR test-enhanced learning OR traditional OR training OR tutorial OR tutoring OR ward OR "worked example" OR workshop
#9	#7 OR #8	
Outcome: efficacy in acquiring ECG knowledge or skills		
#10	MeSH terms:	Electrocardiography [MeSH]
#11	Free text:	ECG OR EKG OR electrocardiography OR electrocardiogram OR electrocardiographic
#12	#10 OR #11	
#13	MeSH terms:	Clinical Competence [MeSH] OR Cognition [MeSH] OR Learning [MeSH]
#14	Free text:	accuracy OR analysis OR assessment OR cognition OR cognitive OR competence OR competency OR comprehension OR diagnosis OR diagnostic OR effectiveness OR efficacy OR examination OR interpretation OR insight OR knowledge OR learning OR measurement OR memory OR participation OR performance OR practice OR problem-solving OR proficiency OR reasoning OR recall OR reinforcement OR retention OR score OR self-assessment OR self-efficacy OR skills OR test OR understanding
#15	#13 OR #14	
#16	#12 AND #15	
#17	#3 AND #6 AND #9 AND #16	

5.4.2. Searching other sources

Citation indexes and reference lists of all articles found through the database search will be reviewed for any articles that were not identified during the database search. A grey literature search will also be conducted.

5.5. Data collection and analysis

The screening process and study selection will be done according to the guidelines of the *Cochrane Handbook of Systematic Reviews for Interventions*.[92]

5.6. Selection of studies

Two reviewers (CV and RSM) will independently screen all articles identified by the search. The reviewers will complete a standardised coding sheet that will indicate whether an article meets all the inclusion criteria or what the reason for exclusion is.

Duplicate publications of articles will be removed. The more recent publication with the most complete dataset will be used where duplicate publications for the same data are reported.

The screening process will occur in two phases:

- **Phase 1: Screening of title and abstract**
  All titles and abstracts of articles identified in the search will be screened for eligibility. If it is not apparent from the title or abstract whether an article meets eligibility criteria, or if both reviewers (CV and RSM) do not exclude the article, the full text of the article will be reviewed.
- **Phase 2: Screening of full-text article**
  The full text will be reviewed of all potentially eligible articles. A kappa coefficient will be calculated to measure the consistency between the reviewers (CV and RSM).[30] Where there are discrepancies between the reviewers, this will be discussed with a third reviewer (VB) who will act as an adjudicator. Reasons for exclusion will be documented and presented in a table of excluded studies.

5.7. Data extraction and management

References will be managed using EndNote X8 software (Clarivate Analytics).[93] Two reviewers (CV and RSM) will independently extract data from all articles meeting eligibility criteria. The reviewers will use a standardized electronic data collection form on REDCap (Research Electronic Data Capture),[94] which is a secure online database manager hosted at the University of Cape Town. Collected data will be exported from REDCap database to Stata 14.2 (StataCorp, 4905 Lakeway Drive, College Station, Texas 77845 USA) for statistical analysis.

Data extraction will include, but will not be limited to:

- citation information;
- study design;
- total study duration;
- study population;
- ECGs used during teaching;
- teaching methods (CAI vs other teaching methods);
- digital learning material;
- educational approaches in study;
- learning theories underpinning instructional methods;
- ECG competencies measured;
- testing times;
- results;
- validity and reliability of results;
- psychometric properties of the assessment tools (e.g. Cronbach's α coefficient).[95]

A more detailed data extraction set is included in the supplementary material.

5.8. Quality assessment

The Medical Education Research Study Quality Instrument (MERSQI) will be used to assess the quality of studies in this systematic review.[96] Designed to evaluate the quality of experimental, quasi-experimental, and observational studies, the MERSQI is a validated quality assessment tool in medical education.[97]

5.9. Assessment of risk of bias

Two reviewers (CV and RSM) will independently assess each included study for risk of bias:[92]

- selection bias, i.e. different baseline characteristics amongst the different groups
- performance bias, i.e. different exposure to factors other than intervention that may have influenced outcome amongst different groups
- attrition bias, i.e. differences between groups in withdrawal of participants
- detection bias, i.e. differences between groups in how outcomes are determined
- reporting bias, i.e. differences in outcome reporting

5.10. Measures of effectiveness of educational intervention

The practical significance of the educational interventions will be determined by reviewing their effect sizes. The effectiveness of ECG teaching modalities used in the articles will also be scored according to a modified version of Kirkpatrick's framework for the evaluation of educational interventions. This framework is the internationally preferred framework for evaluation of educational interventions.[60-62] The framework comprises of 4 levels, as shown in Table 2.

5.11. Dealing with missing data

Corresponding authors will be contacted in the event of absent or incomplete evidence in the included studies. A delay of six weeks will be allowed to receive a response following two email attempts.

5.12. Data synthesis

5.12.1. Systematic review

We will provide a descriptive analysis of computer-assisted instruction and the comparator teaching modalities used for teaching ECGs. The educational impact of the different teaching modalities used for ECG training (computer-assisted instruction and other methods) will be evaluated by the modified version of Kirkpatrick's framework for the evaluation of educational interventions, as shown in Table 2.[60-62]

5.12.2. Meta-analysis

Heterogeneity of the data will be tested by means of the I^2 and χ^2 tests, as well as by visual inspection of the Forest plot. Where found, the possible reasons for any heterogeneity will be explored, and if unexplainable, findings will be reported in a narrative review. In the absence of heterogeneity, the effects of different teaching modalities will be quantitatively analysed. The relative risk and / or the odds ratio will be used to determine the strength of effects among dichotomous variables, and weighted mean difference will be calculated for continuous variables. The statistical significance will be evaluated through inspection of the 95% confidence intervals.

We will do sub-analyses of the efficacy of CAI and conventional teaching methods on medical students versus residents. In addition, we will consider sub-analyses of studies in terms of teaching methods (i.e. CAI, non-CAI and blended learning), different learning material or activities used by CAI (where sufficient data exist), different educational approaches, as well as different learning theories underpinning CAI and other teaching methods.

5.12.3. Mapping review

A mapping review will be done to characterize the quality, quantity and focus of current medical education literature on computer-assisted instruction of ECGs.

5.13. Sensitivity analysis

A sensitivity analysis will be undertaken to evaluate the effect of the risk of bias score on the overall result.[92] Should any further arbitrary or unclear characteristics arise from the data extraction, a sensitivity analysis will also be applied.

5.14. Presenting and reporting of results

Results will be discussed in the text and summarised in table format, an example of which is given in Table 4.

Table 4: Results will be summarised in table format

Study	Study design	Participants	Computer-assisted instruction (CAI)	Comparator teaching methods (not using CAI)
• Author • Journal • Year of publication	• Randomised control trial • Cohort study • Case-control study • Before-and-after study • Cross-sectional research	• Students / residents • Year of study • University • Country • Number of participants • Response rate	• CAI learning material / activities explained • Topics taught • Educational approaches used • Learning theories underpinning by CAI	• Comparator teaching method explained • Topics taught • Educational approaches used • Learning theories underpinning non-CAI teaching method

Study	ECG knowledge that was tested	Baseline ECG knowledge	Acquired ECG knowledge	Retention of ECG knowledge
• Author • Journal • Year of publication	• Measurements • Waveforms • Rhythms	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method	• CAI cohort • Cohort with comparator educational method

Study	Modified Kirkpatrick model[60-63]	Quality assessment	Risk of bias	Significance of study results
• Author • Journal • Year of publication	• Level 1 • Level 2a • Level 2b • Level 3 • Level 4a • Level 4b	• MERSQI score • Validity of results • Reliability of results • Psychometric properties of assessments testing ECG competence	• Selection bias • Performance bias • Attrition bias • Detection bias • Reporting bias	• Findings of study summarised • Practical significance of findings (effect size)

6. DISCUSSION

6.1. Expected significance of the study

This systematic review aims to explore the pedagogical value computer-assisted instruction as compared with other instructional methods used in the teaching of ECGs. The findings of this systematic review will be important in the review of undergraduate medical curricula. If gaps are identified in the literature, this will inform future research in the field of ECG teaching. The goal is to provide evidence of best teaching practices, as patient care will ultimately benefit from improved ECG competence amongst graduating medical students.

6.2. Ethics and dissemination

This research does not require ethical approval, as the study is a systematic review of published literature. Any changes to the current protocol will be considered protocol amendments, and this will be communicated to the journal, along with a motivation and justification for the protocol amendment. The status of the systematic review will be updated regularly in PROSPERO. We aim to submit the results of this systematic review to a peer-reviewed journal. The protocol and systematic review will be included in a PhD dissertation.

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8. FOOT NOTES

8.1. Authors' contributions

CV is a PhD student; RSM and VB are his supervisors. CV conceived of the review and undertook the drafting of the manuscript. CV and MS undertook a scoping search and developed the search strategy. CV, RSM and VB will be involved in data acquisition. CV and ME will analyse the data and participate in the interpretation of the results. All authors have read the manuscript and have given their approval for publication.

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8.4. Competing interests

RSM is a lecturer and host of the AO Memorial Advanced ECG and Arrhythmia Course, and receives an honorarium from Medtronic Africa. The other co-authors report no relationships that could be construed as a conflict of interest.

8.5. Keywords

Electrocardiogram (ECG), computer-assisted instruction, web-based learning, medical student(s).

8.6. Abbreviations

CAI: computer-assisted instruction; CAL: computer-assisted learning; ECG: electrocardiogram; EMI: extended matching items; MERSQI: medical education research study quality instrument; MeSH: medical subject heading terms; MCQ: multiple choice question; PBL: problem-based learning; PRISMA-P: preferred reporting items for systematic review and meta-Analysis protocols guidelines; PROSPERO: international prospective register of systematic reviews; RCT: randomised control trial, SD: standard deviation.

Supplementary material

Data extraction will include, but will not be limited to:

- citation information (e.g. authors, title of article, journal, year of publication);
- study design (e.g. randomised controlled trial, cohort study, case-control study, before-and-after study, cross-sectional research);
- total study duration;
- study population (e.g. medical students or residents, year of study, university, country);
- voluntary participation or incentivised recruitment;
- number of participants and response rate in each cohort;
- ECGs used during teaching (e.g. real ECGs, drawn ECGs, simulator ECGs);
- topics taught (e.g. normal waveform measurements, normal waveform morphology, abnormal waveform morphology, abnormal rhythms);
- teaching methods used in study:
    - computer-assisted instruction (e.g. desktop or handheld device; online or offline use) and presentation of digital learning material (e.g. text, annotated ECGs, images, diagrams, videos, podcasts, simulator, quizzes, chat rooms, social media);
    - other methods of instruction, which are not computer-based (e.g. lectures, tutorials, ward rounds, peer teaching, near-peer teaching, textbooks);
- instructional design and educational approaches in study:
    - CAI alone or in blended learning setting (combination of CAI and other methods of instruction);
    - learning environment (e.g. classroom, clinical setting, computer lab, home);
    - spacing of instruction (e.g. massed instruction, distributed instruction, asynchronous learning);
    - deliberate practice (ECG analysis on digital platform or with paper-based ECGs);
    - instruction associated with formative assessment with feedback or not;
    - instruction associated with summative assessment or not;
- learning theories which could potentially underpin the method of instruction described
    - explicit (mentioned and discussed in paper) or implicit (implied by discussion);
    - categories of learning theories:
        - instrumental learning theories, i.e. behaviourist learning (e.g. practice with feedback), cognitivism (learning with demonstrations and explanations), constructive learning (e.g. critical thinking, mind maps), experiential learning (learning through experience);

    - humanistic learning theory, i.e. motivation to learn (extrinsic or intrinsic motivation), self-directed learning (e.g. provision of learning objectives, self-regulation)
    - transformative learning theory, i.e. critical reflection;
    - social theories of learning, i.e. collaborative learning (e.g. interaction with peers, interaction with tutors) and contextual learning (e.g. ECG with clinical vignette, multiple examples with different perspectives);
- ECG competencies that were measured in the study (e.g. waveform measurements, waveform morphology, arrhythmias);
- method of testing (e.g. multiple-choice questions (MCQ), extended matching items (EMI), written out ECG analysis by student);
- testing times, i.e. the length of time before or after the educational intervention that testing occurred (e.g. before intervention to assess baseline ECG competence; shortly after intervention to assess acquisition of ECG competence; delayed testing after intervention to assess retention of competence);
- results (e.g. mean score and standard deviation of pre-intervention test assessing ECG competence; mean score and standard deviation of post-intervention tests assessing the acquisition and / or retention of ECG competence);
- validity and reliability of the results and psychometric properties of the assessment tools used to test ECG competence, as available in articles (e.g. Cronbach's α coefficient).[95]

PRISMA-P (Preferred Reporting Items for Systematic review and Meta-Analysis Protocols) 2015 checklist: recommended items to address in a systematic review protocol*

Section and topic	Item No	Checklist item
ADMINISTRATIVE INFORMATION		
Title:		
Identification	1a	Identify the report as a protocol of a systematic review
Update	1b	If the protocol is for an update of a previous systematic review, identify as such
Registration	2	If registered, provide the name of the registry (such as PROSPERO) and registration number
Authors:		
Contact	3a	Provide name, institutional affiliation, e-mail address of all protocol authors; provide physical mailing address of corresponding author
Contributions	3b	Describe contributions of protocol authors and identify the guarantor of the review
Amendments	4	If the protocol represents an amendment of a previously completed or published protocol, identify as such and list changes; otherwise, state plan for documenting important protocol amendments
Support:		
Sources	5a	Indicate sources of financial or other support for the review
Sponsor	5b	Provide name for the review funder and/or sponsor
Role of sponsor or funder	5c	Describe roles of funder(s), sponsor(s), and/or institution(s), if any, in developing the protocol
INTRODUCTION		
Rationale	6	Describe the rationale for the review in the context of what is already known
Objectives	7	Provide an explicit statement of the question(s) the review will address with reference to participants, interventions, comparators, and outcomes (PICO)
METHODS		
Eligibility criteria	8	Specify the study characteristics (such as PICO, study design, setting, time frame) and report characteristics (such as years considered, language, publication status) to be used as criteria for eligibility for the review
Information sources	9	Describe all intended information sources (such as electronic databases, contact with study authors, trial registers or other grey literature sources) with planned dates of coverage
Search strategy	10	Present draft of search strategy to be used for at least one electronic database, including planned limits, such that it could be repeated
Study records:		
Data management	11a	Describe the mechanism(s) that will be used to manage records and data throughout the review

Selection process	11b	State the process that will be used for selecting studies (such as two independent reviewers) through each phase of the review (that is, screening, eligibility and inclusion in meta-analysis)
Data collection process	11c	Describe planned method of extracting data from reports (such as piloting forms, done independently, in duplicate), any processes for obtaining and confirming data from investigators
Data items	12	List and define all variables for which data will be sought (such as PICO items, funding sources), any pre-planned data assumptions and simplifications
Outcomes and prioritization	13	List and define all outcomes for which data will be sought, including prioritization of main and additional outcomes, with rationale
Risk of bias in individual studies	14	Describe anticipated methods for assessing risk of bias of individual studies, including whether this will be done at the outcome or study level, or both; state how this information will be used in data synthesis
Data synthesis	15a	Describe criteria under which study data will be quantitatively synthesised
	15b	If data are appropriate for quantitative synthesis, describe planned summary measures, methods of handling data and methods of combining data from studies, including any planned exploration of consistency (such as I^2, Kendall's τ)
	15c	Describe any proposed additional analyses (such as sensitivity or subgroup analyses, meta-regression)
	15d	If quantitative synthesis is not appropriate, describe the type of summary planned
Meta-bias(es)	16	Specify any planned assessment of meta-bias(es) (such as publication bias across studies, selective reporting within studies)
Confidence in cumulative evidence	17	Describe how the strength of the body of evidence will be assessed (such as GRADE)

*** It is strongly recommended that this checklist be read in conjunction with the PRISMA-P Explanation and Elaboration (cite when available) for important clarification on the items. Amendments to a review protocol should be tracked and dated. The copyright for PRISMA-P (including checklist) is held by the PRISMA-P Group and is distributed under a Creative Commons Attribution Licence 4.0.**

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