

e-Learning versus lecture-based courses in ECG interpretation for undergraduate medical students: a randomized noninferiority study

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Objective An ECG is pivotal for the diagnosis of coronary heart disease. Previous studies have reported deficiencies in ECG interpretation skills that have been responsible for misdiagnosis. However, the optimal way to acquire ECG interpretation skills is still under discussion. Thus, our objective was to compare the effectiveness of e-learning and lecture-based courses for learning ECG interpretation skills in a large randomized study.

Participants and methods We conducted a prospective, randomized, controlled, noninferiority study. Participants were recruited from among fifth-year medical students and were assigned to the e-learning group or the lecture-based group using a computer-generated random allocation sequence. The e-learning and lecture-based groups were compared on a score of effectiveness, comparing the 95% unilateral confidence interval (95% UCI) of the score of effectiveness with the mean effectiveness in the lecture-based group, adjusted for a noninferiority margin.

Results Ninety-eight students were enrolled. As compared with the lecture-based course, e-learning was noninferior with regard to the postcourse test score (15.1; 95% UCI 14.2; +∞), which can be compared with 12.5 [the mean effectiveness in the lecture-based group (15.0) minus the noninferiority margin (2.5)]. Furthermore, there

was a significant increase in the test score points in both the e-learning and lecture-based groups during the study period (both $P < 0.0001$).

Conclusion Our randomized study showed that the e-learning course is an effective tool for the acquisition of ECG interpretation skills by medical students. These preliminary results should be confirmed with further multicenter studies before the implementation of e-learning courses for learning ECG interpretation skills during medical school. *European Journal of Emergency Medicine* 23:108–113 Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.

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Introduction

According to the WHO, coronary heart diseases are the leading cause of death worldwide, becoming a truly global pandemic [1]. An ECG is pivotal for the diagnosis of coronary heart disease [2]. Therefore, physicians in all specialties increasingly use ECG, especially in the emergency departments (EDs), as circulatory disorders are one of the most frequent reasons for admission [3]. However, previous data have reported deficiencies in ECG interpretation, even if the patient outcome resulting from ECG misinterpretation seems not to have been impacted [4,5].

Thus, it is crucial to optimize competent ECG interpretation skills [6]. However, the optimal educational strategies for teaching ECG remain unclear. Previous

studies evaluated workshops, traditional lecture-based methods, and self-directed learning for teaching ECG interpretation [7,8]. White *et al.* [8] tested the value of a single seminar given by a consultant cardiologist to emergency physicians. They reported that 21.3% of ECGs had serious misinterpretations in pre-seminar tests compared with 10.7% of ECGs in post-seminar tests ($P < 0.005$), reducing ED patient mismanagement from 3.2 to 1.7% ($P < 0.0001$) [8]. Mahler *et al.* [7], in a prospective randomized study including fourth-year medical students, noted that participants in the self-directed learning group had lower test scores compared with workshops or traditional lecture-based methods. Alternative teaching strategies were also tested, including dance and puzzles, which failed to achieve statistical significance when compared with the classical lecture-based course [9,10].

Over the last decade, because of the introduction of the Internet, online learning methods have been expanding

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and e-learning education has become an interesting option for medical students, presenting reliable, reusable content and providing flexible, geographically independent access [11]. e-Learning has been found to promote critical thinking and decision-making skills in medical students [12]. Moreover, e-learning is said to reduce the learning time required and increase academic achievement and satisfaction with the learning program [13,14]. Overall, in the healthcare field, e-learning methods have been developed for the acquisition of both theoretical and practical skills, including ethics and communications skills [15,16]. To avoid obstacles in medical education, in addition to heavy workloads and limited time and space in today's worldwide large-enrollment classroom environment, e-learning has been shown to be a valuable tool for development [11].

Indeed, e-learning provides promising educational opportunities to facilitate the development of ECG interpretation skills. A recent study evaluated e-learning in teaching ECG interpretation in third-year medical students. They reported that the mean result of a diagnostic test realized at the end of the course in the e-learning group was higher than that of the control group ($P=0.03$). However, this study was not randomized and several students (12/32, 37.5%) in the intervention group did not use the web-based ECG interpretation program, suggesting that the result might be due to positive student selection. Moreover, the control group included students from another teaching hospital, consequently questioning the comparability of the two groups [17].

Thus, the aim of our study was to compare the effectiveness of e-learning and lecture-based courses to enhance ECG interpretation skills in a randomized and controlled study.

Participants and methods

Study design and population

This was a prospective, controlled, randomized, non-inferiority study carried out by the University of Nantes, France, during one semester of the 2012–2013 academic year. The study was designed to determine whether the e-learning course was as effective as (noninferior to) the lecture-based course in the enhancement of ECG interpretation skills. As previous studies evaluating e-learning in healthcare professionals did not meet the primary efficacy objective of superiority, and as we consider e-learning as a supplementary tool for ECG interpretation teaching, we decided to carry out a noninferiority study in terms of efficacy [15,18,19]. Moreover, we expected satisfaction with the e-learning course to be better compared with the lecture-based one.

The participants were fifth-year medical students. This academic year is designed to prepare the students for internship, with ECG teaching included in the curriculum. Thus, before the beginning of our study, all

students had attended ECG interpretation courses based on traditional lectures and PowerPoint (Microsoft Corp., Redmond, Washington, USA) presentations during their second and fourth year of medical study.

The students were randomly assigned to the e-learning group or the lecture-based group using a computer-generated random allocation sequence. The students did not know in advance the group to which they would be assigned. The study investigators were blinded to the students' past academic performance or experience in ECG interpretation. Most important, all students had attended the same previous ECG interpretation courses. Therefore, the background learning was comparable across the groups. However, clinical experience may differ among students, as some postings have more ECG exposure – for example, cardiology.

Electrocardiogram interpretation teaching courses

Lecture and e-learning sessions occurred concurrently during a 2-month period. They covered the same content and included the same ECG sample. Indeed, two teachers at the University of Nantes created the materials for the e-learning and lecture-based courses, with the intention of achieving the same learning objectives. As the teachers were emergency physicians, the learning objectives were centered on emergency medicine to prepare the students caring for cardiovascular disorders seen in the EDs. Moreover, a cardiologist of the institution validated the materials for the e-learning and lecture-based courses.

For the e-learning course, we used the Modular Object-Oriented Dynamic Learning Environment (Moodle). The course consisted of five modules: (i) basic principles of ECG interpretation: ECG paper speed and voltage, rhythm, rate, electrical axis, normal intervals; (ii) acute coronary syndromes and acute coronary syndrome differential diagnoses: pericarditis, hypothermia, left ventricular hypertrophy; (iii) tachycardia; (iv) conduction system abnormalities; and (v) electrolyte disturbances. Each module included PowerPoint (Microsoft Corp.) presentations to present the material that the students had to learn and quizzes based on multiple-choice questions. A quiz is shown in Supplemental digital content 1, <http://links.lww.com/EJEM/A86>. Each quiz presented an ECG with a short description of the clinical situation. Four or five answers were proposed to the students who had to select true or false for each statement. After the student had answered and confirmed the answers, direct feedback was provided to explain briefly why each statement was true or false. Overall, the e-learning course contained the correct interpretations of a sample of 40 ECGs with detailed explanations added in the feedback, covering a wide field of ECG interpretation skills. Moreover, the two tutors were available to answer questions through a chat function included in the e-learning platform. However, the students had no

face-to-face contact with the tutors, and the e-learning program did not include a recorded video of a tutor giving ECG lectures. The e-learning course was available for 6 weeks and was stopped 2 weeks before the postcourse test. Thus, the students were allowed to go through the learning package as many times as they wanted during the study period.

In the lecture-based group, two tutors presented the material covered in the e-learning course during a single 180-min classical lecture-based teaching session. The session took place 3 weeks before the postcourse test. PowerPoint (Microsoft Corp.) presentations included in the e-learning course were presented without substantial alteration. The sample of 40 ECGs used in the quizzes in the e-learning format was extracted and presented to the students using PowerPoint (Microsoft Corp.) presentations in an interactive procedure between the two tutors and the participants.

Measurement of students' electrocardiogram interpretation skills

The students were evaluated by means of a precourse test at the beginning of the study (i.e. before the start of the e-learning and lecture-based courses) and a post-course test 2 months later, at the end of the study (i.e. after the end of the e-learning and lecture-based courses). The two evaluations included the interpretation of 10 different ECGs by means of 10 different questions. For each question, the student had to choose at least one proposition among four or five answers. An answer was scored two points if the student made the right choice, one point if there was one mistake, and zero points otherwise. The maximum score was 20 points. The pretests and post-tests were automatically corrected. The ECGs used during the tests were not used during the e-learning and lecture-based courses, but covered the same content in accordance with the program's learning objectives. Pretest ECGs differed from the post-test ECGs and were previously evaluated by a panel of physicians and validated by a cardiologist of the Nantes University Hospital to ensure that both tests had an equivalent level of difficulty. Students were given 45 min to complete the pretests and post-tests.

Measurement of satisfaction with the e-learning course

Satisfaction with the e-learning course was evaluated using a questionnaire that asked students' opinions about the usefulness and general interest of the course, accessibility and ease of use, and educational value (relevance of materials). Satisfaction with the lecture-based course was evaluated using a questionnaire that asked students' opinions about the usefulness and general interest of the course and educational value. Opinions were graded using a 10-point scale, with a higher score indicating a more positive evaluation.

Ethical considerations

Students were clearly informed that the study would have no effect on their course assessments and that they could withdraw from the study at any time. Informed consent was obtained from all participants. The data were treated with strict confidentiality. After the study, to avoid favoring one group of participants, the students enrolled in the e-learning group attended the lecture-based course and the students enrolled in the lecture-based course were given open access to the e-learning course. Because no ethics committee for research in medical education exists in France, the protocol was approved by the Dean of the Faculty of Medicine of Nantes.

Data analysis

It was estimated that a sample size of 49 participants per group would provide 80% power to show noninferiority using a prespecified noninferiority margin of 2.5 (SD 5), considering a type 1 error (α) of 5% and type 2 error (β) of 20%. The data were analyzed using the GraphPad Prism (version 5; GraphPad Software, La Jolla, California, USA) package. Quantitative data were reported as medians with first and third quartiles or mean \pm SD. Qualitative data were reported as percentages with 95% confidence intervals. All statistical tests were two-tailed, and a *P* value of less than 0.05 was considered statistically significant.

The postcourse test scores of the e-learning and lecture-based groups were compared using a comparison between the 95% unilateral confidence interval (95% UCI) of the effectiveness score of the e-learning group and the mean effectiveness in the lecture-based group, taking into account the noninferiority margin of 2.5: if the minimal boundary of the 95% UCI was less than the mean effectiveness in the lecture-based group minus 2.5 (noninferiority margin), then the noninferiority of the e-learning assumption would not be rejected.

Results

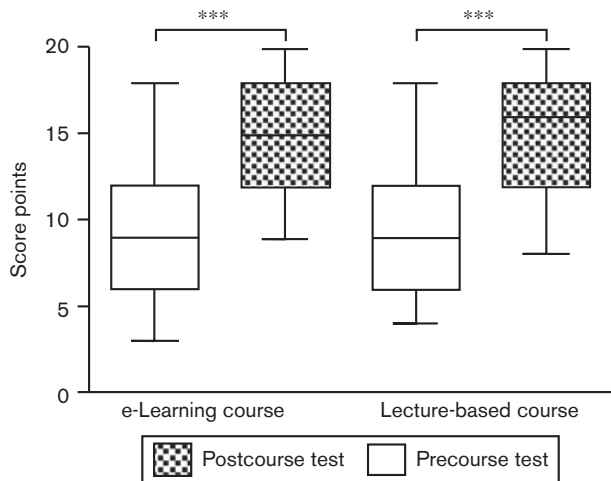
A total of 98 students were enrolled, including 61 [62.2% (52.5–71.2)] women and 37 [37.8% (28.8–47.7)] men, with a median age of 22 (21–23) years. The students were assigned to the e-learning group ($n=49$): 32 [65.3% (51.3–77.1)] women and 17 [34.7% (22.9–48.7)] men [median age 22 (21–23) years] or the control group ($n=49$): 29 [59.2% (45.2–71.8)] women and 20 [40.8% (28.2–54.8)] men [median age 22 (21–23) years]. There were no significant differences between the two groups in terms of age ($P=0.8$) or sex distribution ($P=0.6$). Baseline characteristics of the participants are summarized in Table 1.

The efficacy criteria for the procedure are reported in Fig. 1. The median precourse test score was 9.0 (6.0–12.0) points in the e-learning group and 9.0 (6.0–12.0) points in the lecture-based one. The difference was not statistically

Table 1 Baseline characteristics of the participants

	e-Learning course (n = 49)	Lecture-based course (n = 49)	P value
Male [n (%)] (95% CI)	17 (34.7) (22.9–48.7)	20 (40.8) (28.2–54.8)	0.6
Age [median (first–third quartiles)] (years)	22 (21–23)	22 (21–23)	0.8

CI, confidence interval.

Fig. 1

Precourse and postcourse test scores by teaching method. *** $P < 0.0001$.

significant ($P = 0.9$). Moreover, as compared with the lecture-based course, e-learning was noninferior with regard to the postcourse test score (15.1; 95% UCI 14.2; $+\infty$), which can be compared with 12.5 [the mean effectiveness in the lecture-based group (15.0) minus the noninferiority margin (2.5)]. Furthermore, there was a significant increase in the test score points in both the e-learning and lecture-based groups during the study period (both $P < 0.0001$).

Concerning satisfaction with the e-learning course, the median score for usefulness and general interest was 7.5 (7–8), with 7 (6–8) for accessibility and ease of use and 7 (5.5–8) for the educational value. Concerning satisfaction with the lecture-based course, the median score for usefulness and general interest was 7 (6–8) ($P = 0.03$ compared with the e-learning course), with 6 (5–7.5) ($P = 0.04$ compared with the e-learning) for educational value. Moreover, the median number of connections to the e-learning course per student (i.e. median of the total number of connections to the e-learning platform during the study period for each student) was 3 (2–4) and the median time connection to the e-learning course (i.e. median of the total time passed on the e-learning platform during the study period for each student) was 180 (137.5–200) min/student.

Discussion

The results of our randomized controlled study showed that the e-learning course was as effective as the lecture-based course for enhancing ECG interpretation skills among fifth-year medical students, with increased satisfaction of the students in terms of general interest and educational value. We detected a statistically significant improvement in ECG interpretation skills following either the e-learning or the classical lecture-based course ($P < 0.0001$ in both groups). Moreover, our results showed that most of the participants enjoyed learning ECG with the e-learning course, recommending this method in terms of usefulness, ease of use, and educational value. Overall, our result validated three dimensions of Kirkpatrick's model, a frequently cited model in understanding the impact of e-learning on learning: learner satisfaction, learning outcome, and performance improvement [20].

As previous data showed deficiencies in ECG interpretive skills, it is crucial to optimize competency in ECG interpretation skills. However, the optimal pedagogical strategies for teaching ECG are still being discussed [4,9,10].

During the last decade, in addition to the Internet boom, the development of e-learning in the field of medical education has grown significantly. e-Learning is especially suitable in the healthcare field as it overcomes some of the limitations of traditional lecture-based courses, such as the limited teaching time available and poor student–teacher interaction in the current context of a large enrollment classroom [21]. Moreover, the fast spread of mobile technologies, particularly familiar to students, makes educational content easier to access [22]. Therefore, by delivering content at any time and place, e-learning allows students to control the courses, methods, and timing of the learning in a way that clearly enhances the quality of their learning experience [23]. Our study showed that the e-learning strategy could be applied to teaching ECG, to overcome the difficulty involved in teaching adequate ECG interpretation skills to medical students in the era of large classrooms. e-Learning seems to engage students more fully and actively in the learning process.

In our e-learning ECG interpretation program, we developed the following characteristics. First, the participants have the possibility to chat with a tutor, in one-on-one tutoring. Moreover, the chat contents between

the participants and the tutors were posted in a forum so that other participants could also benefit from these interactions. This educational strategy has previously been shown to produce the most effective learning results [24,25]. Furthermore, previous studies have reported that a high level of interactivity leads to successful e-learning procedures [26–28]. The student can spontaneously ask the tutor about a point in the course content. Moreover, the teacher can ask questions through the chat function, asking students to identify the major points or unclear ones from the course, questioning the students about the pace of lecture or the presentation tools used. Second, our format also included quizzes. This type of e-learning allows the teacher to see, in real time, the strengths and weaknesses of his student panel, as the results to the quizzes are easily accessible to the teacher. Thus, the teacher can adapt the presentation of the course to the students' needs with high reactivity. This avoids spending an unnecessary amount of time on concepts that are already understood and allows the teacher to follow-up only when needed. Moreover, it can help the teacher see how individuals are doing between exams, to test knowledge or survey students on their progress. Third, our format included feedback on the quizzes, which provides extensive information about the ECGs presented. Feedback has previously been reported to be a very important feature of simulation-based medical education [29]. It helps the students to know how they are doing. Indeed, fast, frequent, formative assessments may help students to focus on areas they need to work on, while also increasing student commitment. Finally, our format included animations and clinical cases, which improve participants' satisfaction with the method, participation, and investment [30].

However, e-learning cannot replace on-campus learning. Blended learning, combining face-to-face learning and e-learning, is now in the spotlight. In a one-group study, with a pretest–post-test design, Jang *et al.* [31] reported that the knowledge of and ability to interpret ECG recordings improved from pretest to post-test, with statistical significance. This educational strategy in learning ECG, combining an e-learning program and a lecture-based course, must be tested in a randomized study.

Study limitations

First, our study was carried out in a single center. Therefore, its findings should be generalized with caution, and further studies are warranted to confirm our results in other teaching hospitals. Second, we did not evaluate patient outcome, the fourth dimension of Kirkpatrick's model. As previously reported, most of the studies evaluating the impact of e-learning in medical education have been based on assessment measures, including pretesting and post-testing of knowledge. Therefore, this type of evaluation limits knowledge of the impact of e-learning on learning outcomes or patient

outcomes [23]. Third, we did not evaluate the long-term retention of knowledge, although long-term retention of knowledge after e-learning courses is unclear and needs to be studied in depth [32]. Finally, performing cost–benefit analyses and comparing the e-learning program and the lecture-based course would be of great interest.

The accuracy of ECG interpretation is pivotal in clinical practice, especially in the EDs, as complaints related to cardiac disorders are extremely frequent. The optimal method for acquiring ECG interpretation skills is still being discussed, and several formats have been tested, from traditional lecture-based courses to dance and puzzle. Our results indicate that an e-learning program, including quizzes with feedback and interaction between students and tutors through a chat function, can be a useful tool for teaching ECG. These preliminary results should be confirmed through further multicenter studies before introducing a large-scale e-learning course for learning ECG interpretation skills during medical school.

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E.M., J.S., J.-N.T., B.P., and P.P. participated in the design of the study. E.M., J.-B.H., and E.B. performed the statistical analysis. E.M., P.P., B.P., and G.P. designed the study, participated in its design and coordination, and helped to draft the manuscript. All authors read and approved the final manuscript.

Conflicts of interest

There are no conflicts of interest.

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