ORIGINAL ARTICLE

Electrocardiogram reading: a randomized study comparing 2 e-learning methods for medical students

Grzegorz Kopeć[1], Marcin Waligóra[1], Michał Pacia[2], Wojciech Chmielak[2], Agnieszka Stępień[2], Sebastian Janiec[2], Wojciech Magoń[1], Kamil Jonas[1], Piotr Podolec[1]

1 Department of Cardiac and Vascular Diseases, Jagiellonian University Medical College, John Paul II Hospital in Kraków, Kraków, Poland
2 Students' Scientific Group of Pulmonary Circulation and Thromboembolic Diseases, Department of Cardiac and Vascular Diseases, Jagiellonian University Medical College, Kraków, Poland

KEY WORDS

education, internet-based learning, methods of teaching

ABSTRACT

INTRODUCTION Interpretation of the electrocardiogram (ECG) is an essential skill in most medical specialties; however, the best method of teaching how to read ECGs has not been determined.

OBJECTIVES The aim of the study was to compare the effectiveness of collaborative (C-eL) and self (S-eL) e-learning of ECG reading among medical students.

PATIENTS AND METHODS A total of 60 fifth-year medical students were randomly assigned to the C-eL and S-eL groups. S-eL students received 15 ECG recordings with a comprehensive description by email (one every 48 hours), while C-eL students received the same ECG recordings without description. C-eL students were expected to analyze each ECG together within the subgroups using an internet platform and to submit the interpretation within 48 hours. Afterwards, they received a description of each ECG. C-eL students' activity was assessed based on the number of words written on the internet platform during discussion. A final test consisted of 10 theoretical questions and 10 ECG recordings. The final score was a sum of points obtained for the interpretation of ECG recordings. The main endpoint of the study was the number of students whose final score was 56% or higher.

RESULTS The final test was completed by 53 students (88.3%). The main endpoint was achieved in 20 C-eL students (77%) and in 13 S-eL students (48.1%), $P = 0.03$. The final score was 6.4 (interquartile range [IQR], 5.8–7.6) in the C-eL group and 5.6 (IQR, 4.2–7.2) in the S-eL group, $P = 0.04$. It correlated with the results of the theoretical test and students' activity during C-eL ($r = 0.42$, $P = 0.002$ and $r = 0.4$, $P = 0.04$, respectively).

CONCLUSIONS C-eL of ECG reading among fifth-year medical students is superior to S-eL.

Correspondence to:
Grzegorz Kopeć, MD, PhD, Klinika Chorób Serca i Naczyń, Wydział Lekarski Uniwersytet Jagielloński Collegium Medicum, Krakowski Szpital Specjalistyczny im. Jana Pawła II, ul. Pradnicka 80, 31-202 Kraków, Poland, phone: +48 500 099 734, email: grzegorzkrakow1@gmail.com
Received: August 28, 2017.
Revision accepted: November 7, 2017.
Published online: November 7, 2017.
Conflict of interest: none declared.
Pol Arch Intern Med. 2018; 128 (2): 98-104
doi:10.20452/pamw.4146

INTRODUCTION The ability to read an electrocardiogram (ECG) is an essential skill in most medical specialties.[1] The 12-lead ECG is commonly used for screening and diagnosis of heart diseases, including many life-threatening disorders such as arrhythmias, myocardial infarction (MI), and cardiac arrest.[2,3] Guidelines of the European Society of Cardiology recommend that ECG should be performed within 10 minutes after the first medical contact in patients with symptoms of acute MI as its result determines further treatment.[4] ECG is also recommended as a screening tool in atrial fibrillation."[5,6] Inaccurate ECG interpretation may lead to adverse patient outcomes. It is estimated that every year 10 000 deaths in the United States result from incorrect ECG interpretation.[7] In one study, 3.6% of patients from a single medical center were incorrectly diagnosed with atrial fibrillation, and they were consequently inadequately treated with antiarrhythmic and anticoagulant drugs.[8]

Several studies have highlighted gaps in ECG interpretation skills among medical students and residents from different countries.[9] In our recent study,[10] fewer than 60% of Polish medical students were able to diagnose common

TABLE 1 Electrocardiographic abnormalities presented in educational materials during the e-learning course

Case number	Diagnoses
1	First-degree AVB
	Sinus bradycardia
2	Atrial flutter
	Nonspecific intraventricular conduction delay
3	Sinus bradycardia
	Previous inferior MI
	RBBB
4	Right ventricular hypertrophy
	Right atrial enlargement
	NSTEMI
5	Atrial fibrillation
	LBBB
6	Left anterior fascicular block
7	Third-degree AVB
8	Left anterior fascicular block
9	Torsades de pointes
10	Left ventricular hypertrophy
	Left atrial enlargement
	Sinus tachycardia
11	Anterolateral NSTEMI
	First-degree AVB
12	Inferior NSTEMI
13	Left atrial enlargement
	Right atrial enlargement
	Right ventricular hypertrophy
14	Atrial fibrillation
	Ventricular stimulation
15	LBBB
	STEMI

Abbreviations: AVB, atrioventricular block; LBBB, left bundle branch block; MI, myocardial infarction; NSTEMI, non–ST-segment elevation MI; RBBB, right bundle branch block; STEMI, non–ST-segment elevation MI

abnormalities on 12-lead ECG. We hypothesized that it may result from ineffective education on ECG interpretation in medical schools. However, the optimal way to teach ECG interpretation skills is still being debated.[11]

Current research focuses on learning ECG interpretation skills in a group setting. In this collaborative learning model based on a group discussion, students develop effective learning strategies using social interactions.[12] Other studies indicated that online collaboration such as asynchronous discussion also improves students' achievements.[13] Therefore, in our randomized study, we compared the effectiveness of 2 e-learning strategies in developing ECG interpretation skills among medical students: collaborative (C-eL) and self (S-eL) e-learning.

PATIENTS AND METHODS

Study group Students of the fifth year at the Faculty of Medicine of Jagiellonian University Medical College, Kraków, Poland, were invited to participate in the study by the Scientific Students' Group via social media. The first 60 students were enrolled to the study and were randomly assigned in a 1:1 ratio using a computer-generated random allocation sequence to the C-eL or S-eL groups. C-eL students were further randomly divided into 6 subgroups of 5 students each.

Pretest Before starting the e-learning course, all students were gathered together in a lecture room and instructed about the study protocol. During the meeting, students signed an informed consent to be included in the study and then participated in a pretest assessing their basic theoretical knowledge on ECG interpretation. The pretest consisted of 10 questions about the reference values of the PR interval, heart rate, definition of respiratory sinus arrhythmia, types of supraventricular arrhythmias, mechanism of the QRS complexes, PQ interval, and conduction blocks, assessment of the electrical axis of the heart, and nomenclature connected with ECG leads. Each student could achieve a maximum score of 10 points (1 point for each question).

Learning materials For the purpose of the study, 15 ECG cases were prepared. Each case included basic information about the patient (age, sex), a single 12-lead ECG recording, a comprehensive description of the recording, and a set of questions about the recording with answers. The questions were as follows: "Is it a sinus rhythm?", "Is the rhythm regular?", "What is the heart rate?", "What is the electrical axis of the heart?", "Is the PQ duration normal?", "Is the QRS duration normal?", "Is the QT interval normal?", "Are there any significant ST changes?", "Are there any pathological Q waves or QS patterns?".

ECG abnormalities presented during the course are listed in TABLE 1. ECG cases were prepared by an experienced cardiologist and reviewed by 2 other cardiologists. The ECG course was based on the Polish recommendations on ECG interpretation, and all students were encouraged to use these materials during the trial.[14,15]

Self e-learning Students from the S-eL group received an ECG case with a comprehensive description by email every second day. They were encouraged to analyze the recordings but were not asked for any response during the course.

Collaborative e-learning Students from the C-eL group received consecutive ECG recordings by email without any description. They were encouraged to analyze the recordings individually and answer the corresponding questions listed above within 24 hours. Afterwards, they were asked to cooperate in ECG interpretation within their subgroups using a dedicated internet platform and were expected to submit the final answers to a study coordinator within the next 24 hours. The discussion within each subgroup

TABLE 2 Correct answers to specific questions on electrocardiograms during collaborative e-learning

Question	Correct answers, n, median (IQR)[a]
Is it a sinus rhythm?	14.0 (14.0–14.0)
Is the rhythm regular?	14.0 (14.0–14.0)
What is the heart rate?	14.0 (14.0–14.0)
What is the electrical axis of the heart?	12.5 (12.0–14.0)
Is PQ duration normal?	14.0 (13.0–15.0)
Is QRS duration normal?	12.0 (12.0–13.0)
Is QT interval normal?	10.5 (9.0–13.0)
Are there any significant ST-segment changes?	10.0 (9.0 – 11.0)
Are there any pathological Q waves or QS patterns?	14.0 (14.0–14.0)

a The maximal number of correct answers was 15 (one for each ECG case).

Abbreviations: IQR, interquartile range

was moderated by a subgroup leader elected by the students. After submission of the final interpretation, students received the comprehensive description of the ECG case (the same which was sent to the S-eL students). The outcome of C-eL was measured by the sum of correct answers to each ECG case question (as listed above, 1 point per 1 correct answer) and the number of correctly diagnosed ECG abnormalities (1 point per 1 correct diagnosis). The maximum number of points that could be obtained by each group during C-eL was 170. To eliminate the risk of interaction between S-eL and C-eL students, S-eL was delayed to C-eL by 24 hours.

The activity of C-eL students during the course was assessed by the number of words written on the internet platform during discussion on each consecutive ECG case. The activity of S-eL students was not monitored.

Final test and study endpoint At the end of the study, students were invited to take an e-test, which was performed on the internet platform 1 week after completion of the last ECG case. The e-test consisted of 10 single-answer, multiple-choice, theoretical questions (1.5 minute for each question) and 10 ECG recordings (5 minutes for each recording). For every theoretical question, the student could achieve 0 or 1 point. The final score of ECG interpretation was a sum of points obtained from a single ECG recording. Student could collect a maximum of 1 point per ECG if all ECG abnormalities had been diagnosed. Otherwise, the student obtained a fraction of a point calculated as the ratio of correctly diagnosed abnormalities in a single ECG recording to the number of all abnormalities present on the ECG recording. The maximum score for this part of the test was 10 points.

Students passed the final e-test if they obtained at least 5.6 points (56% of the maximum score) for ECG interpretation. The cutoff of 56% is currently used in the final medical examination (Polish, *Lekarski Egzamin Końcowy*), which is taken by the graduates of medical schools in order to become licensed physicians in Poland. The main endpoint of the study was the number of students who passed the final e-test.

Statistical analysis Continuous variables were reported as median (interquartile range [IQR]) and categorical variables as numbers and percentages. The Mann–Whitney test was used for the comparison of continuous variables between the 2 groups, and the χ^2 test was used for categorical variables. Correlations between 2 continuous variables were assessed by Spearman rank correlation analysis. Based on a study by Raupach et al,[16] we assumed that at least 75% of C-eL students and no more than 25% of S-eL students would be able to pass the final test. For an α level of 0.05 and a β level of 0.2, the minimal number of students in each group was 19. The significance level was set at an α level of 0.05. The statistical analysis was performed with the Statistica software version 9.1 (StatSoft, Inc. 2010, Tulsa, Oklahoma, United States), MedCalc version 11.6.1.0 (MedCalc Software, Mariakerke, Belgium), and STATA 14.1 (StataCorp, College Station, Texas, United States).

RESULTS

Characteristics of the study groups A total of 60 medical students of the fifth year were enrolled to the study, including 21 men (35%) and 39 women (65%). They were randomized into 2 groups, C-eL and S-eL, each consisting of 30 students. The C-eL group was further divided randomly into 6 groups of 5 students each. The final test was taken by 53 students including 26 from the C-eL group and 27 from the S-eL group (P = 0.68), and only these students were included in the subsequent analysis.

Pretest The median (IQR) score obtained in the pretest was similar between the C-eL and S-eL groups: 10.0 (9.0–10.0) vs 9.0 (IQR, 9.0–10.0), respectively, P = 0.35.

Collaborative e-learning During the course, all C-eL subgroups answered all the ECG questions. After an individual analysis of the 15 ECG cases, students were able to correctly diagnose all ECG abnormalities in a median (IQR) of 2 (1–3) recordings. After collaborative working, the C-eL subgroups identified all ECG abnormalities in a median (IQR) of 8 (6–9) recordings.

The subgroups 1 to 6 achieved 140, 133, 147, 131, 136, and 145 points in ECG interpretation, respectively, and the median (IQR) score was 138 (133–145). The median numbers of correct answers to specific ECG questions during collaborative e-learning are shown in TABLE 2. The least correct answers were collected for identification of QT-interval prolongation and ST-segment abnormalities.

Students' activity differed during the course between the C-eL subgroups: the number of words used in the discussion about ECG cases were as follows ($P < 0.001$): group 1, 4270; group 2, 4273; group 3, 5163; group 4, 2526; group 5, 1717; and group 6, 6408. This activity correlated with the score achieved by the groups during C-eL ($r = 0.84$, $P = 0.04$).

Results of the final test in the collaborative and self e-learning groups The main endpoint of the study was achieved in 20 students (77%) of the C-eL group and in 13 students (48.1%) of the S-eL group, $P = 0.03$. The median (IQR) final score of ECG interpretation was 6.4 (5.8–7.6) in the C-eL group and 5.6 (4.2–7.2) in the S-eL group, $P = 0.04$. The number of correctly interpreted ECG recordings (all diagnoses in a single ECG recording made correctly) was higher in the C-eL than in the S-eL group (median [IQR], 4.0 [3.0–5.0] vs 3.0 [3.0–4.0], $P = 0.04$).

Students in the C-eL group were able to diagnose the following abnormalities more frequently than those in the S-eL group: ventricular extrasystole, junctional escape rhythm in third-degree atrioventricular block, left atrial enlargement, left axis deviation, first-degree atrioventricular block, left ventricular hypertrophy, and ST-segment elevation MI (FIGURE 1).

The result of the theoretical part of the final test was similar between the C-eL and S-eL groups (median [IQR], 8.0 [7.0–9.0] vs 8.0 [7.0–8.0] respectively, $P = 0.28$). It correlated with the final score of ECG interpretation ($r = 0.42$, $P = 0.002$). Also, a positive correlation between the activity of students during collaborative learning and the final score of ECG interpretation was found ($r = 0.4$, $P = 0.04$).

DISCUSSION In this interventional study, 2 ECG e-learning strategies among fifth-year medical students were compared, and it was shown that collaborative e-learning results in better outcome than self e-learning. It was also shown that the effect of training was related to the theoretical knowledge of ECG gained throughout the course and to the level of students' activity during collaborative e-learning.

There is an ongoing debate on which strategy for teaching ECG interpretation provides the best results.[11] A recent survey revealed that the most frequently used strategy consisted of lectures and teaching rounds.[17] However, e-learning is used more often in medical education given the many advantages such as overcoming barriers of distance, facilitating methods inaccessible to other teaching strategies, and providing more individualized approach.[18,19] Recently, O'Brien et al[17] estimated that 17% of ECG courses are organized using a web-based design.

In a review on ECG-learning strategies by Fent et al,[11] no method was identified as the most effective. E-learning and traditional ECG education were also compared in 2 recent randomized controlled trials. In a study by Montassier et al,[20] e-learning course on ECG was shown to be as effective as traditional lecture-based teaching. It is worth noting that both modes of teaching used the same educational materials. These findings are consistent with the results of a meta-analysis which showed that e-learning is neither inherently superior nor inferior to traditional methods of teaching.[21] These results encouraged us to investigate the effectiveness of different e-learning strategies.

In our study, 2 e-learning strategies were tested. The first (S-eL) represented a more traditional model of education in which students were provided with educational materials during the course and had their skills tested after completion of the course. In the second method (C-eL) students were expected to actively participate in the education process. Each of them was asked to analyze ECG in 15 different sessions and to respond to a set of questions. Then, students were invited to a group discussion about each ECG and were expected to decide together about the final interpretation. We think that the stimulating environment of collaborative e-learning was the main cause of a better outcome in the C-eL as compared with the S-eL group. Self-directed and presentation-based e-learning were recently compared by Fent et al.[22] In this randomized trial, students were provided with an internet-based, self-directed ECG teaching package containing 3-dimensional animations of the heart conductive tissue or standard presentations delivered by experienced cardiologists. Despite the fact that students gave positive feedback on the new method, there were no differences in ECG interpretation competency between the 2 studied groups at the end of the study. Of note, students were not permitted to ask questions regarding ECG interpretation or participate in any form of collaboration with other students during the course.

We found that the different C-eL subgroups showed a different level of collaboration during the course. Whether these differences in activity resulted from individual capabilities or other student activities at the time of the course remains a matter of discussion. Importantly, the intensity of collaboration correlated positively with the final score of each student. Therefore, we can assume that appropriate motivation of students to collaborate during ECG education may have significant impact on its results. This was highlighted by Raupach et al,[16] who revealed that a near-peer teaching, a method of teaching where an older student of the same faculty is a tutor,[23] was more effective than traditional seminars. Of note, the effect provided by near-peer teaching was lost when students were further motivated to work by a summative assessment.

Our study confirmed that a web-based small-group teaching is effective and well received by students as reflected by a low dropout rate. Moreover, this particular format of teaching could also be combined with other effective face-to-face methods, in a blended-learning fashion, to further enhance the effectiveness of ECG education. Recent reports of blended-learning courses

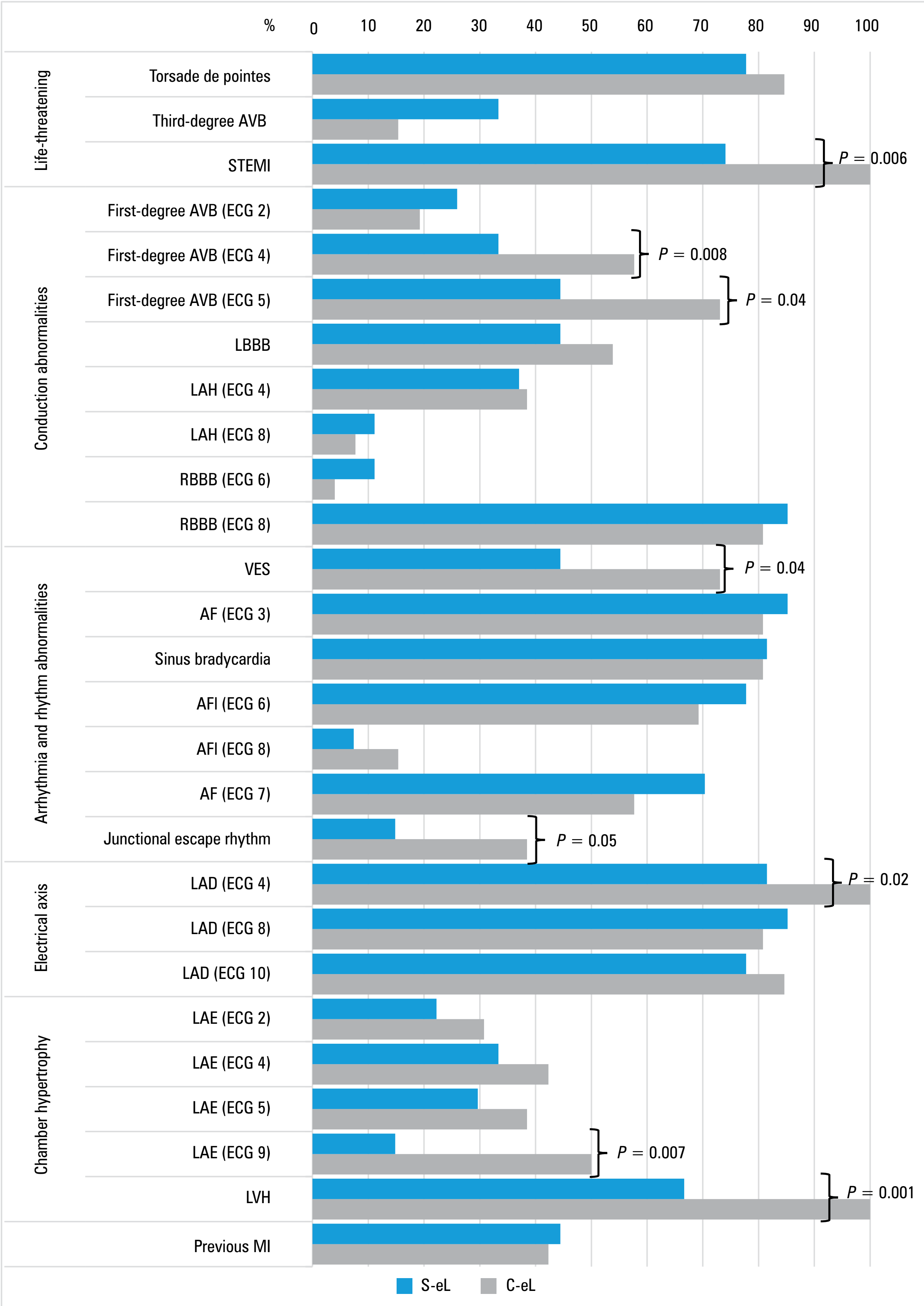

FIGURE 1 Frequency of correct diagnoses of several electrocardiographic abnormalities presented at the final test in collaborative (C-eL) and self-learning (S-eL) groups

Abbreviations: AF, atrial fibrillation; AFl, atrial flutter; ECG, electrocardiogram; LAD, left axis deviation; LAH, left anterior hemiblock; LAE, left atrial enlargement; LVH, left ventricular hypertrophy; VES, ventricular extrasystole; others, see TABLE 1 of ECG interpretation also highlighted their effectiveness.[24,25] Additionally, an appropriate method of assessment is also a significant component of a good ECG teaching course.[16,26]

Our study shows that practical skills in ECG interpretation among medical students are poor despite a relatively good level of theoretical knowledge. This observation is consistent with the results of our previous web-based survey, in which most medical students of clinical years (86%) were able to correctly interpret the primary ECG parameters such as heart rate, heart rhythm, and electrical axis of the heart, but only 58% were able to identify common ECG abnormalities such as ischemia, rhythm disorders, and cardiac chamber hypertrophy.[10] In another study, an accuracy of 52% in interpreting various ECGs among final-year medical students from New Zealand was revealed.[27] Jablonover et al[28] reported an accuracy of 37% in ECG interpretation among 231 graduates. Although there is a considerable discrepancy in the accuracy (17% vs 63%) in ECG interpretation between students as reported by different studies, this basic competency seems to be inadequate.[9]

Strengths and limitations Our study has several strengths. First, to our knowledge, this is the first study to compare web-based small-group ECG teaching with standard e-learning. Second, a randomized trial design allowed us to minimize the allocation bias. Next, a web-based approach was useful to quantitatively assess the level of activity during collaborative e-learning, which would be difficult to obtain in a traditional mode of teaching.

There are also several limitations that should be considered. It was a single-center study and therefore it would be of value to validate our data in a larger sample of students from different medical centers. However, the ECG curriculum is not unified in medical universities in Poland; therefore, students from different universities might have a different level of ECG knowledge at baseline. This could bias the results of a multicenter study. Due to this limitation, to the best of our knowledge, all the studies that have compared 2 methods of teaching of ECG interpretation in medical students so far had a single-center design.[16,20,22,24,29,30] In our study, we were able to enroll students at the same level of education with similar knowledge on ECG at baseline, as shown by the pretest results.

The final assessment was conducted a few days after completion of the study, which represents a short-term effect. We do not know if this effect lasted over time. However, the assessment of the long-term result could be significantly biased by differences in access to ECG education of the participating students after completion of the course. It is possible that some external factors may have influenced students' performance at the final test. During the study period, students participated in standard classes and clinical rounds that could differ between students. However, the study period was planned in between examination sessions to exclude potential distractions from the course. What is more, the course was facultative and we believe that only students interested in ECG learning applied. To minimize the potential role of additional academic commitments, the time from baseline to the final test was limited to 5 weeks.

It is estimated that competency in ECG interpretation can decrease from 30% to 50% during follow-up.[16,24,30] Nevertheless, there is evidence that the decline in ECG competency is inversely correlated with the final performance of students at the end of the course.[26] Based on this, we can assume that students in the C-eL group will perform better than the S-eL students in the future. But we also recognize that one teaching method might provide better retention of knowledge than others; therefore, there is still a need to confirm the long-term effect of collaborative learning of ECG interpretation in students or other groups of medical professions. We believe that our results may be used to appropriately plan such future trials.

We noted a similar dropout rate in the S-eL and C-eL groups: 13% and 10%, respectively. We speculate that because the participation in the final test was voluntary, some students decided to omit the test. An email was sent to each participant with a reminder about the exact time and place of the final test. We did not allow students to participate in another attempt because of the possible risk of interaction with other students.

Only fifth-year students were enrolled in the study, although in our previous study there were no differences in ECG competency between fourth-, fifth-, and sixth-year students.[10] A voluntary participation in the study might generate a disproportionate number of students more interested in cardiology or electrophysiology, which could have potentially introduced a selection bias.

Conclusions Collaborative e-learning of electrocardiography among fifth-year medical students resulted in a better outcome than self e-learning. Its effect was related to the theoretical knowledge of ECG gained throughout the course and to the level of students' activity during C-eL.

CONTRIBUTION STATEMENT GK conceived the concept of the study. GK, MW, MP, WC, AS, and SJ contributed to the design of the research. MP, WC, AS, and SJ were involved in data collection. GK and MW analyzed the data. GK, MW, WM, and KJ were involved in manuscript preparation. All authors edited and approved the final version of the manuscript.

REFERENCES

1 Hurst JW. The interpretation of electrocardiograms: pretense or a well-developed skill? Cardiol Clin. 2006; 24: 305-307.

2 Fisch C. Evolution of the clinical electrocardiogram. J Am Coll Cardiol. 1989; 14: 1127-1138.

3 Kadish AH, Buxton AE, Kennedy HL, et al. ACC/AHA clinical competence statement on electrocardiography and ambulatory electrocardiography: A report of the ACC/AHA/ACP-ASIM task force on clinical competence (ACC/AHA Committee to develop a clinical competence statement on electrocardiography and ambulatory electrocardiography) endorsed by the International Society for Holter and noninvasive electrocardiology. Circulation. 2001; 104: 3169-3178.

4 Roffi M, Patrono C, Collet JP, et al. [2015 ESC Guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation]. Kardiol Pol. 2015; 73: 1207-1294. Polish.

5 Kirchhof P, Benussi S, Kotecha D, et al. [2016 ESC Guidelines for the management of atrial fibrillation developed in collaboration with EACTS]. Kardiol Pol. 2016; 74: 1359-1469. Polish.

6 Zielonka A, Tkaczyszyn M, Mende M, et al. Atrial fibrillation in outpatients with stable coronary artery disease: Results from the multicenter RECENT study. Pol Arch Med Wewn. 2015; 125: 162-171.

7 Mele PF. The ECG dilemma: guidelines on improving interpretation. J Health Risk Manag. 2008; 28: 27-31.

8 Bogun F, Anh D, Kalahasty G, et al. Misdiagnosis of atrial fibrillation and its clinical consequences. Am J Med. 2004; 117: 636-642.

9 Salerno SM, Alguire PC, Waxman HS. Competency in interpretation of 12-lead electrocardiograms: a summary and appraisal of published evidence. Ann Intern Med. 2003; 138: 751-760.

10 Kopeć G, Magoń W, Hołda M, et al. Competency in ECG Interpretation Among Medical Students. Med Sci Monit. 2015; 21: 3386-3394.

11 Fent G, Gosai J, Purva M. Teaching the interpretation of electrocardiograms: Which method is best? J Electrocardiol. 2015; 48: 190-193.

12 Taveira-Gomes T, Saffarzadeh A, Severo M, et al. A novel collaborative e-learning platform for medical students - ALERT STUDENT. BMC Med Educ. 2014; 14: 143.

13 Zhu C. Online collaborative learning: Cultural differences in student satisfaction and performance. J Educ Res Online. 2011; 3: 12-28.

14 Baranowski R, Bieganowska K, Kozłowski D, et al. [Recommendations on electrocardiogram interpretation]. Kardiol Pol. 2010; 68(S. IV): 1-56. Polish.

15 Dąbrowska B. Electrocardiograms: diagnostic problems and clinical interpretations. Pol Arch Med Wewn. 2016; 126 (Spec 2): 1-88.

16 Raupach T, Hanneforth N, Anders S, et al. Impact of teaching and assessment format on electrocardiogram interpretation skills. Med Educ. 2010; 44: 731-740.

17 O'Brien KE, Cannarozzi ML, Torre DM, et al. Training and Assessment of ECG Interpretation Skills: Results From the 2005 CDIM Survey. Teach Learn Med. 2009; 21: 111-115.

18 Ruiz JG, Mintzer MJ, Leipzig RM. The impact of E-learning in medical education. Acad Med. 2006; 81: 207-212.

19 Cook DA. Web-based learning: Pros, cons and controversies. Clin Med J R Coll Physicians London. 2007; 7: 37-42.

20 Montassier E, Hardouin JB, Segard J, et al. e-Learning versus lecture-based courses in ECG interpretation for undergraduate medical students. Eur J Emerg Med. 2016; 23: 108-113.

21 Cook DA, Levinson AJ, Garside S, et al. Internet-based learning in the health professions. JAMA. 2008; 300: 1181.

22 Fent G, Gosai J, Purva M. A randomized control trial comparing use of a novel electrocardiogram simulator with traditional teaching in the acquisition of electrocardiogram interpretation skill. J Electrocardiol. 2016; 49: 112-116.

23 Bulte C, Betts A, Garner K, et al. Student teaching: views of student near-peer teachers and learners. Med Teach. 2007; 29: 583-590.

24 Brooks CA, Kanyok N, O'Rourke C, et al. Retention of baseline electrocardiographic knowledge after a blended-learning course. Am J Crit Care. 2016; 25: 61-67.

25 Jang KS, Kim YM, Park SJ. A blended learning program on undergraduate nursing students' learning of electrocardiography. Stud Health Technol Inform. 2006; 122: 799.

26 Raupach T, Harendza S, Anders S, et al. How can we improve teaching of ECG interpretation skills? Findings from a prospective randomised trial. J Electrocardiol. 2016; 49: 7-12.

27 Lever NA, Larsen PD, Dawes M, et al. Are our medical graduates in New Zealand safe and accurate in ECG interpretation? N Z Med J. 2009; 122: 9-15.

28 Jablonover RS, Lundberg E, Zhang Y, et al. Competency in electrocardiogram interpretation among graduating medical students. Teach Learn Med. 2014; 26: 279-284.

29 Mahler SA, Wolcott CJ, Swoboda TK, et al. Techniques for teaching electrocardiogram interpretation: self-directed learning is less effective than a workshop or lecture. Med Educ. 2011; 45: 347-353.

30 Rolskov Bojsen S, Räder SBEW, Holst AG, et al. The acquisition and retention of ECG interpretation skills after a standardized web-based ECG tutorial – a randomised study. BMC Med Educ. 2015; 15: 36.