

Proposed In-Training Electrocardiogram Interpretation Competencies for Undergraduate and Postgraduate Trainees

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Despite its importance in everyday clinical practice, the ability of physicians to interpret electrocardiograms (ECGs) is highly variable. ECG patterns are often misdiagnosed, and electrocardiographic emergencies are frequently missed, leading to adverse patient outcomes. Currently, many medical education programs lack an organized curriculum and competency assessment to ensure trainees master this essential skill.

ECG patterns that were previously mentioned in literature were organized into groups from A to D based on their clinical importance and distributed among levels of training. Incremental versions of this organization were circulated among members of the International Society of Electrocardiology and the International Society of Holter and Noninvasive Electrocardiology until complete consensus was reached.

We present reasonably attainable ECG interpretation competencies for undergraduate and postgraduate

trainees. Previous literature suggests that methods of teaching ECG interpretation are less important and can be selected based on the available resources of each education program and student preference. The evidence clearly favors summative trainee evaluation methods, which would facilitate learning and ensure that appropriate competencies are acquired. Resources should be allocated to ensure that every trainee reaches their training milestones and should ensure that no electrocardiographic emergency (class A condition) is ever missed.

We hope that these guidelines will inform medical education programs and encourage them to allocate sufficient resources and develop organized curricula. Assessments must be in place to ensure trainees acquire the level-appropriate ECG interpretation skills that are required for safe clinical practice. *Journal of Hospital Medicine* 2018;13:185-193. Published online first November 8, 2017. © 2018 Society of Hospital Medicine

The 12-lead electrocardiogram (ECG) remains one of the most widely used and readily available diagnostic tests in modern medicine.¹ Reflecting the electrical behavior of the heart, this point-of-care diagnostic test is used in almost every area of medicine for diagnosis, prognostication, and selection of appropriate treatment. The ECG is sometimes the only and most efficient way of detecting life-threatening conditions, thus allowing a timely delivery of emergency care.² However, the practical power of the 12-lead

ECG relies on the ability of the clinician to interpret this test correctly.

For decades, ECG interpretation has been a core component of undergraduate and postgraduate medical training.³⁻⁵ Unfortunately, numerous studies have demonstrated alarming rates of inaccuracy and variability in interpreting ECGs among trainees at all levels of education.^{4,6,7} Senior medical students have been repeatedly shown to miss 26% to 62% of acute myocardial infarctions (MI).^{6,8-10} Another recent study involving internal medicine residents demonstrated that only half of the straightforward common ECGs were interpreted correctly, while 26% of trainees missed an acute MI and 56% missed ventricular tachycardia (VT).¹¹ Even cardiology subspecialty fellows demonstrated poor performance, missing up to 26% of ST-elevation MIs on ECGs that had multiple findings.¹² Inaccurate interpretations of ECGs can lead to inappropriate management decisions, adverse patient outcomes, unnecessary additional testing, and even preventable deaths.^{4,13-15}

Several guidelines have emphasized the importance of

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	Common	Uncommon
Emergency	<p>Group A - Common</p> <p>Electrocardiographic Emergencies</p> <p>Common patterns that require recognition within minutes to deliver potentially life saving care</p> <p>(Example: ST-Elevation MI)</p>	<p>Group C - Uncommon</p> <p>Electrocardiographic Emergencies</p> <p>Uncommon patterns that, if recognized, can prevent serious adverse patient outcomes</p> <p>(Example: Ventricular Pre-excitation)</p>
Non-Emergency	<p>Group B - Common Non-Emergency</p> <p>Common patterns that are seen on a daily basis that may impact patient care</p> <p>(Example: Left Ventricular Hypertrophy)</p>	<p>Group D - Uncommon Non-Emergencies</p> <p>Less common patterns that do not require urgent medical attention, but may impact patient care in an appropriate context</p> <p>(Example: Right Atrial Abnormality)</p>

FIG 1. Grouping ECG interpretation patterns. ECG findings were grouped under classes A to D based on emergency/nonemergency and common/uncommon criteria. Medical students must be proficient in class A and class B patterns, whereas residents at the end of postgraduate year 1 should additionally be proficient in classes C and D (with a few exceptions).

NOTE: Abbreviations: ECG, electrocardiogram; MI, myocardial infarction.

teaching trainees 12-lead ECG interpretation and have recognized the value of assessments in ensuring that learners acquire the necessary competencies.¹⁶⁻¹⁹ Similarly, there have been many calls for more rigorous and structured curricula for ECG interpretation throughout undergraduate and postgraduate medical education.^{11,16} However, we still lack a thoughtful guideline outlining the specific competencies that medical trainees should attain. This includes medical students, nurses working in hospital and in out-of-hospital settings, and residents of different specialties, including emergency medicine, cardiology, and electrophysiology (EP) fellows.

Setting goals and objectives for target learners is recognized to be the initial step and a core prerequisite for effective curriculum development.²⁰ In this publication, we summarize the objectives from previously published trainee assessments and propose reasonably attainable ECG interpretation competencies for both graduating medical students and residents at the end of their postgraduate training. This document is being endorsed by researchers and educators of 2 international societies dedicated to the study of electrical heart diseases: the International Society of Electrocardiology (ISE) and the International Society of Holter and Noninvasive Electrocardiology (ISHNE).

METHODS

Current Competencies in Literature

We performed a systematic search to identify ECG competencies that are currently mentioned in the literature. Information was retrieved from MEDLINE (1946-2016) and EMBASE (1947-2016) by using the following MeSH terms: electrocardiogram, electrocardiography, electrocardiogram interpretation, electrocardiogram competency, medical school, medical student, undergraduate medicine, undergraduate medical education, residency education, internship, and residency. Our search was limited to English-language articles that studied physician

trainees. The references of the full-length articles were examined for additional citations. The search revealed a total of 65 publications involving medical students and 120 publications involving residents. Abstracts of publications were then assessed for relevance, and the methods of the remaining articles were scrutinized for references to specific ECG interpretation objectives. This strategy narrowed the search to 9 and 14 articles involving medical students and residents, respectively. Studies were not graded for quality because the purpose of the search was to identify the specific ECG competencies that authors expected trainees to obtain. Almost all the articles proposed teaching tools and specific objectives that were defined by the investigators arbitrarily and assessed the trainee's ability to interpret ECGs (summarized in supplementary Table).

Defining ECG Interpretation Competencies

The initial draft of proposed ECG interpretation competencies was developed at Queen's University in Ontario, Canada. A list of ECG patterns and diagnoses previously mentioned in literature was used as a starting point. From there, each item was refined and organized into 4 main categories (see Figures 1 and 2).

Class A "Common electrocardiographic emergencies" represent patterns that are frequently seen in hospitals, in which accurate interpretation of the ECG within minutes is essential for delivering care that is potentially lifesaving to the patient (eg, ST-elevation MI).

Class B "Common nonemergency patterns" represent ECG findings that are encountered daily in patients who are not acutely ill, which may impact their care in the appropriate clinical context (eg, left ventricular hypertrophy).

Class C "Uncommon electrocardiographic emergencies" represent ECG findings that are not encountered on a daily basis but can be potentially lifesaving if recognized (eg ventricular preexcitation).

	Emergency	Non-Emergency
Common	Class A—Common Electrocardiographic Emergencies <ul style="list-style-type: none"> • Acute ST-Elevation Myocardial Infarction^a <ul style="list-style-type: none"> • Hyper-acute T-Waves • Ventricular Tachycardia (VT) <ul style="list-style-type: none"> • Differential Diagnosis for Wide Complex Tachycardia • Ventricular Fibrillation (VF) • Asystole • 3rd Degree AV Block^b • 2nd Degree AV Block Mobitz II • Hyperkalemia/Hypokalemia Pattern • Unstable Supraventricular Tachycardia^c • Long QT 	Class B—Common Non-Emergency <p>Tachycardia Syndromes</p> <ul style="list-style-type: none"> • Sinus Tachycardia • Atrial Fibrillation • Atrial Flutter • Atrial Tachycardia • Multifocal Atrial Tachycardia • Atrioventricular Nodal Reentry Tachycardia • Nonsustained Ventricular Tachycardia • Atrioventricular Reentry Tachycardia <p>Bradycardia Syndromes</p> <ul style="list-style-type: none"> • Sinus Bradycardia • Sinus Arrhythmia • 2nd Degree AV Block Mobitz I • Junction Rhythm <p>Conduction Abnormalities</p> <ul style="list-style-type: none"> • 1st Degree AV Block • Left Bundle Branch Block • Right Bundle Branch Block • Nonspecific Intraventricular Conduction Delay • Left Anterior Fascicular Block <p>Ischemia/Injury</p> <ul style="list-style-type: none"> • Pathological Q-Wave^a • ST Depression • T-Wave Inversion (postischemic) <p>Other</p> <ul style="list-style-type: none"> • Left Ventricular Hypertrophy • Pericarditis^d • Premature Ventricular Contraction • Electronic Pacemaker • Lead Misplacement and Common Artifacts • Left Atrial Abnormality • Interatrial Block • Benign Early Repolarization
	Uncommon	Class C—Uncommon Electrocardiographic Emergencies <ul style="list-style-type: none"> • Pre-Excitation • STEMI with pre-existing LBBB • Sinus Pauses • Brugada Pattern • Hypothermia • Drug Effects • Ventricular Aneurysm • Right Ventricular Hypertrophy

FIG 2. ECG patterns assigned to training levels. ECG patterns that were mentioned previously in literature were grouped under classes A to D and assigned to 2 training levels: graduating medical students and residents at the end of postgraduate year 1 (bold). NOTE: Abbreviations: AV, atrioventricular; LBBB, left bundle branch block; STEMI, ST-elevation myocardial infarction; VF, ventricular fibrillation; VT, Ventricular Tachycardia.

NOTE: Non-bolded terms represent patterns that should be recognized by a graduating medical student, and bolded terms represent patterns that should be recognized by a medical resident at the end of PGY-1

^aIncluding localization of vascular territory

^bDevine escape pattern (wide vs narrow complex)

^cSubtypes of supraventricular tachycardias are in Class B

^dECG findings that would support the diagnosis of pericarditis

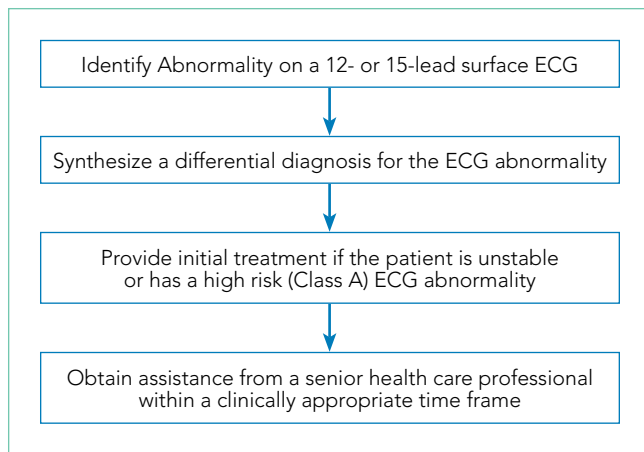


FIG 3. Learning objectives for each ECG pattern defined in Figure 2. These learning objectives should be taught for each ECG finding in Figure 2. NOTE: Abbreviation: ECG, electrocardiogram.

Class D “Uncommon nonemergency patterns” represent findings that are uncommon but may diagnostically contribute to patient care in a clinically appropriate setting (eg, right atrial abnormality).

ECG interpretation patterns were then assigned to medical students and residents based on the specific goals of training. At the time of graduation, medical students should develop the foundation for learning ECG interpretation in residency training, provide ECG interpretation and initial management for electrocardiographic emergencies, and obtain assistance from a more senior medical professional within a clinically appropriate time frame. The training goal for a resident is to develop ECG interpretation competencies for safe independent clinical practice (Figure 1).

The final segregated ECG interpretation competencies were distributed to members of ISE and ISHNE for input, modifications, and revisions. The proposed list of competencies went through several revisions until a consensus was reached.

RESULTS

The final distribution of ECG patterns is illustrated in Figure 2 (Figure 3 defines the learning objectives for each ECG pattern defined in Figure 2). Here, we provide a rationale for assigning ECG diagnoses to each specific class and level of training. It is important to note that medical students must learn the appropriate cardiac anatomy, ECG lead placement, and the EP mechanism associated with each specific ECG pattern. The prerequisite knowledge required for ECG interpretation has been reviewed in the position statement by the American Heart Association (AHA) and the American College of Cardiology (ACC).¹⁹ Similarly, all students should also learn the systematic approach behind ECG interpretation.²¹ Although no specific ECG interpretation structure has been shown to improve diagnostic accuracy, we believe a systematic structured assessment of an ECG is crucial to ensure the interpretation by a junior learner is complete.^{12,22} We propose that students should be instructed to interpret ECGs by using a systematic framework that includes (1)

rate, (2) rhythm, (3) axis, (4) amplitude and duration of waveforms and intervals (including P wave, PR, QRS, QT, and Q wave), and (5) ST-T (morphology, deviations from baseline, and polarity; note: this framework is only valid for nontachycardia ECGs).²³⁻²⁶ Understanding the physiology of depolarization and repolarization, as well as the temporo-spatial relationship between these 2 processes, is also key to the understanding of certain ECG patterns. Vectorcardiography can help in understanding the physiologic and pathophysiologic mechanisms in conduction disease. Expertise and special tools are required to make full use of vectorcardiograms.^{27,28}

Class A: Common Electrocardiographic Emergencies

This group contains ECG findings that require recognition within minutes to deliver potentially lifesaving care. For this reason, undergraduate medical education programs should prioritize mastering class A conditions to minimize the risk of misdiagnosis and late recognition.

Class A patterns include ST elevation MI (STEMI) and localization of territory to ensure ST-segment elevations are seen in contiguous leads.^{29,30} Students should learn the criteria for STEMI as per the “Universal Definition of Myocardial Infarction” and be aware of early signs of STEMI that may be seen prior to ST-segment changes, such as hyper-acute T-waves (increased amplitude and symmetrical).³⁰

Asystole, wide complex tachycardias, and ventricular fibrillation (VF) are all crucial ECG patterns that must be identified to deliver advanced cardiac life support (ACLS) care as per the 2010 AHA Guidelines for cardiopulmonary resuscitation and emergency cardiac care.³¹ Of note, students should understand the differential diagnosis of wide complex tachycardias and should be able to suspect VF in clinically appropriate scenarios. We included the category “unstable/symptomatic supraventricular tachycardia” to represent rapid rhythms that are supraventricular in origin, which either produce symptoms or cause impairment of vital organ function.³¹ In emergency situations, it may not be crucial to correctly identify the specific supraventricular rhythm to deliver ACLS care; hence, the specific supraventricular tachycardia diagnoses were included in Class B.

Finally, we believe that medical students should be able to recognize long QT, hypo/hyperkalemia, and distinguish types of atrioventricular (AV) block. Distinguishing types of AV block is important because both third degree AV block and second degree AV block Mobitz II can be life threatening and require further investigation or emergency treatment in an inpatient setting.³² Prompt recognition of long QT is crucial because it can be associated with ventricular tachyarrhythmias. This includes a polymorphic pattern characterized by the twisting of QRS peaks around the baseline (torsades des pointes), which can eventually lead to VF.

Class B: Common Nonemergency Patterns

Class B patterns represent common findings that are seen on a daily basis that may impact patient care in a clinically appropriate context. Diagnoses in this section were divided into “tachycardia syndromes,” “bradycardia syndromes,” “con-

duction abnormalities," "ischemia," and "other."

Undergraduate trainees should become proficient in identifying the cause of bradycardia and distinguishing types of AV blocks. Similarly, they should also have an approach to differentiate tachycardia syndromes.^{33,34} These skills are required to correctly manage patients in both inpatient and outpatient settings. They should be taught in undergraduate programs and reinforced in postgraduate training.

Common findings, such as bundle branch blocks, left anterior fascicular block, premature ventricular/atrial complexes, electronic pacemakers, and left ventricular hypertrophy, are essential to the daily interpretation of ECGs. Junior learners should be proficient in recognizing these patterns. Findings consistent with pericarditis are not uncommon and can be very helpful to guide the clinician to the diagnosis. Notable exceptions from the medical student competency list include detection of lead misplacement, common artifacts, nonspecific intraventricular conduction delay, interatrial block, and benign early repolarization. These findings require a deeper understanding of electrocardiography and would be more appropriate for senior learners.

Class C: Uncommon Electrocardiographic Emergencies

Class C findings represent uncommon conditions that, if recognized, can prevent serious adverse patient outcomes. These include preexcitation, STEMI with preexisting left bundle branch block sinus pauses, Brugada pattern, hypothermia, effects of toxic drugs, ventricular aneurysm, and right ventricular hypertrophy. The recognition of these patterns is crucial to avoid severe adverse patient outcomes, and independent practicing physicians should be aware of these findings. However, given that a high proportion of senior medical students miss common electrocardiographic emergencies, undergraduate medical education programs should instead focus resources on ensuring medical students are proficient in identifying class A and class B conditions.^{6,8-10} Postgraduate programs should ensure that postgraduate trainees can identify these potentially life-threatening conditions (see section "How to Teach Electrocardiology").

Class D: Uncommon and Nonemergency Patterns

Class D findings represent less common findings that are not seen every day and do not require urgent medical attention. These include right atrial abnormality, left posterior fascicular block, low atrial rhythms, and electrolyte abnormalities that exclude potassium. Notably, electrolyte abnormalities are important to identify; however, typically, treatment is guided by the lab results.³⁵ Overall, postgraduate trainees should certainly be aware of these findings, but medical student training should instead focus on learning the framework and correctly identifying class A and class B ECG patterns.

HOW TO TEACH ELECTROCARDIOLOGY

Teaching ECG Interpretation Strategies

No clear teaching approaches to ECG interpretation have

been described in the literature, and no recommendations on knowledge translation have been formally explored. A possible educational approach to the teaching of electrocardiology could involve several methods for helping students with ECG interpretation:³⁶

1. **Pattern recognition:** The ECG, at its most immediate level, is a graphic image, and recognition of images is essentially recognition of patterns. These patterns can only be learned through repeated visualization of examples with a written or verbal explanation. Repeated visualization over time will help avoid "erosion" of knowledge. Examples of learning tools include periodic in-person ECG rounds, well-illustrated books or atlases, and online tools with good quality ECGs and explanations. These learning opportunities are strongly reinforced by collecting cases from the clinical encounters of the trainee that illustrate the aforementioned patterns. Some of these patterns can be found in guidelines, such as the one published by the AHA and ACC.²⁹
2. **Application of published criteria:** Guidelines, review papers, and books offer diagnostic criteria for many entities, such as chamber enlargement, bundle branch blocks, and abnormal Q waves. Learning these criteria and applying them to the analysis of ECGs is a commonly used learning strategy.
3. **Inductive-deductive reasoning:** This strategy requires a deeper understanding of the pathophysiology behind ECG patterns. It requires ECGs to be interpreted in a certain clinical context, and the goal of ECG interpretation is to answer a clinical question that is used to guide patient care. This strategy typically employs the use of algorithms to lead the interpreter to the correct diagnosis, and mastery of this skill grows from ongoing clinical experience. Examples of the "inductive-deductive reasoning" are localizing an accessory AV pathway, the differential diagnosis of narrow or wide complex tachycardias, and identifying the site of coronary artery occlusion in a patient with a STEMI.
4. **Ladder diagrams:** Ladder diagrams have been used for over 100 years to graphically illustrate the mechanism of arrhythmias. They can be incredibly useful to help learners visualize impulse conduction in reentry mechanisms as well as other abnormal rhythms. However, there are some rhythms that are difficult to illustrate on ladder diagrams.³⁷
5. **Peer and near-peer teaching:** Peer teaching occurs when learners prepare and deliver teaching material to learners of a similar training level. The expectation to deliver a teaching session encourages students to learn and organize information in thoughtful ways. It builds strong teamwork skills and has been shown to positively affect all involved learners.³⁸⁻⁴⁰

Each ECG interpretation strategy has its advantages, and we recommend that students be exposed to all available approaches if teaching resources are available.

Teaching Delivery Format

Each of the above teaching strategies can be delivered to students in various ways. The following teaching formats have

been previously documented in the literature:

1. Classroom-based teaching: This is a traditional learning format that takes place in a large- or small-group classroom. Typically, these sessions are led by a single instructor, and they are focused on the direct sharing of information and group discussion.⁴¹
2. Electronic practice tools: Numerous electronic tools have been developed with the purpose of providing deliberate practice to master ECG interpretation. Some of these tools employ active learner engagement, while others provide a bank of ECGs for self-directed passive learning.⁴²⁻⁴⁶
3. Video lectures: Short video lectures have been created to facilitate self-directed lecture based learning. These lectures are hosted on a variety of web-based platforms, including YouTube and Vimeo.⁴⁷
4. Traditional and electronic books: Numerous traditional textbooks have been published on ECG interpretation and are designed to facilitate independent learning. Some textbooks directly deliver teaching material, while others contain sets of ECGs to allow for repetitive practice. More recently, eBooks incorporating self-assessment tools have been used to assist ECG teaching.³⁴ The advantage of these tools is that they can also be used to supplement in-person classes.
5. Games: A unique ECG interpretation learning strategy consists of using puzzles and games to learn ECGs. This is meant to improve student engagement and interest in learning ECG interpretation.⁴⁸

Given that there is currently a lack of evidence-based data to support 1 instructional format over another, we do not favor any particular one. This decision should be left to instructors and individual learners based on their preference and available resources. Further studies would be helpful to determine the effectiveness of various methods in teaching ECG interpretation and to identify any additional specific factors that facilitate learning.

Evaluation Strategies

1. Longitudinal ongoing feedback: This form of feedback universally takes place in all training programs and focuses on direct observation and point-of-care feedback by a senior healthcare professional during clinical practice. Typically, the feedback is informal and is centered around specific case presentations.
2. Formative testing: This assessment strategy is aimed at monitoring the learning of trainees and providing them with appropriate feedback. Tutors and teachers can use this data to individualize instruction and fill any training gaps that individuals and the class may have. Students themselves can use this information to encourage additional study to ensure they acquire required skills. Examples of formative testing are low-stakes in-training exams and asking audience questions during a workshop or lecture.⁴⁹
3. Summative testing: Summative assessments are created to measure the level of proficiency developed by a learner

and compare it against some standard or benchmark. This form of assessment establishes the extent to which educational objectives have been met. The most common example is an end-of-term examination.

Online ECG examination has been successfully used to provide methods of testing. They are easy to distribute, highly convenient for learners, and allow the display of high-quality graphics. They can also be graded electronically, thereby minimizing the resources required to administer and grade exams.^{36,50}

We recommend using a combination of assessment formats to ensure the optimal evaluation of learner skill and to focus learning on areas of weakness. Summative assessments are highly valuable to ensure learners acquired the necessary ECG interpretation competencies. Remediation strategies should be available to provide additional practice to learners who do not meet competencies expected at their level of training.

DISCUSSION

The Need for ECG Interpretation Competencies and Milestones

Since the introduction of ECG in the late 1800s, there continues to be a significant variation in ECG interpretation skills among trainees and medical professionals.^{4,6-12} Concerns continue to exist about the rate of missed diagnoses involving critical ECGs, leading to inappropriate patient management decisions. Despite the obvious need, teaching ECG interpretation is given little emphasis in medical education, and the curriculum remains quite disorganized. In this position paper, we call for a more structured ECG interpretation curriculum in medical education and hope to assist this process by assigning ECG patterns to 2 milestones in training: graduating medical students and first year postgraduate medical residents.

Defining competencies would help medical education programs to focus resources on teaching clinically important conditions for the appropriate level of training. We divide ECG findings into 4 categories (classes A to D), and we place emphasis on learning electrocardiographic emergencies early in training and spending less time on ECG findings that are unlikely to change patient management.

The goal is to ensure 100% recognition of class A (electrocardiographic emergencies) by the end of medical school. To ensure each medical education program fulfils this goal, a structured curriculum including a summative assessment is required.

Methods of Teaching

Various instructional mediums have been successfully implemented to teach ECG interpretation competencies, including lectures, puzzles, web-based programs, eBooks, and YouTube.^{34-41-44,47,48,51-53} A survey of clerkship directors in internal medicine revealed that 75% of clerkship programs teach ECG interpretation in a classroom lecture-based setting, 44% use teaching rounds, and only 17% utilize online/web-based instruction.³ Canadian family medicine programs have a relatively equal distribution between classroom-based, comput-

er-based, and bedside teaching.⁵

In comparing the efficacy of instructional styles, several small comparative studies favor an electronic teaching format because of the enhanced learner interaction and visual learning, but there does not appear to be a consistently proven large advantage of 1 teaching format over another.^{43,48,51,54} The overall theme emerging from this literature is the importance of repetition and active engagement in ECG interpretation, which appear to be more important than 1 particular strategy.²² Computer-based training appears to deliver these 2 qualities, unlike the traditional lecture-style passive learning model. The concept of repetition and engagement is also well supported in medical education literature outside ECG interpretation.^{55,56}

Given these data, we recommend that each medical education program select teaching methods based on their available resources, as long as adequate teaching time is allotted to ensure that trainees acquire the competencies defined in this publication.

Assessment Methods

It appears that the larger factor in determining ECG interpretation performance is not the learning format, but the form of assessment. Two studies have demonstrated that summative assessment substantially improves ECG interpretation performance when compared with formative assessment; in fact, this effect was so large that it overshadowed any small difference in teaching formats.^{57,58} This concept aligns with medical education literature, which acknowledges that assessment drives learning by raising the stakes, thereby boosting student effort and encouraging learning to an effect much larger than can be generated by any particular learning style.^{57,59} Nevertheless, well-designed formative assessment can focus students on effective learning by identifying gaps and important information.⁶⁰ Only 33% of Canadian family medicine residency programs and 71% of American clerkship programs have formal assessment of ECG interpretation skills.^{3,5} There is no doubt that assessment, both formative and summative, should be implemented in all undergraduate and postgraduate medical training programs. Online assessment methods have the advantage of delivering high-quality images and a variety of question formats; hence, their use should be encouraged.^{36,50,61-63}

Teaching Personnel and Timing of Training

Who should teach ECG interpretation and when should this teaching take place? ECG interpretation in training programs is typically taught by attending physicians in each respective field. However, given that there is a large ECG interpretation error rate by noncardiologist physicians, we advise that ECG training content be created with input from own-specialty attending physicians and cardiologists.⁴ This teaching should take place early in medical school at the time medical students learn pathophysiology of the heart and should continue throughout training. Longitudinal training is preferred to block-based training because of improved resident satisfaction, but medical education literature did not reveal a difference in student performance with either strategy.⁶⁴⁻⁶⁶

CONCLUSIONS

Despite its immense clinical value, there continues to be a lack of a comprehensive ECG interpretation curriculum in medical education programs. The goal of this position paper is to encourage the development of organized curricula in undergraduate and postgraduate medical education programs, and to ensure the acquisition of level-appropriate ECG interpretation skills while maintaining patient safety. We assist this process by grouping ECG findings into 4 classes (A to D) based on the frequency of encounter and emergent nature and by assigning them to each level of training. Methods of teaching ECG interpretation are less important and can be selected based on the available resources of each education program and student preference; however, online learning is encouraged. We also recommend that summative trainee evaluation methods be implemented in all programs to ensure that appropriate competencies are acquired and to further encourage self-directed learning. Resources should be allocated to ensure that every trainee is reaching their training milestones and should ensure that no electrocardiographic emergency (class A condition) is ever missed by a trainee. We hope that these guidelines will inform medical education systems and help prevent adverse patient outcomes caused by the misinterpretation of this valuable clinical diagnostic tool.

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References

1. Baranchuk A, Chiale PA, Green M, Caldwell JC. Editorial: surface electrocardiogram remains alive in the XXI century. *Curr Cardiol Rev*. 2014;10(3):173-174. <http://www.ncbi.nlm.nih.gov/pubmed/24856069>. Accessed January 4, 2017.
2. Fisch C. Evolution of the clinical electrocardiogram. *J Am Coll Cardiol*. 1989;14(5):1127-1138. doi:10.1016/0735-1097(89)90407-5.
3. O'Brien KE, Cannarozzi ML, Torre DM, Mechaber AJ, Durning SJ. Training and assessment of ECG interpretation skills: results from the 2005 CDIM survey. *Teach Learn Med*. 2005;21(2):111-115. doi:10.1080/10401330902791255.
4. 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(9):751-760. doi:10.1016/S1062-1458(03)00283-6.
5. Paul B, Baranchuk A. Electrocardiography teaching in Canadian family medicine residency programs: A national survey. *Fam Med*. 2011;43(4):267-271. <http://www.ncbi.nlm.nih.gov/pubmed/21500000>. Accessed January 4, 2017.
6. Jablonover RS, Lundberg E, Zhang Y, Stagnaro-Green A. Competency in electrocardiogram interpretation among graduating medical students. *Teach Learn Med*. 2014;26(3):279-284. doi:10.1080/10401334.2014.918882.
7. Elnicki DM, van Londen J, Hemmer PA, Fagan M, Wong R. US and Canadian internal medicine clerkship directors' opinions about teaching procedural and interpretive skills to medical students. *Acad Med*. 2004;79(11):1108-1113. <http://www.ncbi.nlm.nih.gov/pubmed/15504782>. Accessed January 31, 2017.
8. Shams M, Sullivan A, Abudureyimu S, et al. Optimizing Electrocardiogram Interpretation and Catheterization Laboratory Activation in ST-Segment Elevation Myocardial Infarction: a Teaching Module for Medical Students. *J Am Coll Cardiol*. 2016;67(13):643. doi:10.1016/S0735-1097(16)30644-1.
9. Grum CM, Gruppen LD, Woolliscroft JO. The influence of vignettes on EKG interpretation by third-year students. *Acad Med*. 1993;68:S61-S63.
10. Little B, Ho KJ, Scott L. Electrocardiogram and rhythm strip interpretation by final year medical students. *Ulster Med J*. 2001;70(2):108-110.
11. Eslava D, Dhillion S, Berger J, Homel P, Bergmann S. Interpretation of electrocardiograms by first-year students: the need for change. *J Electrocardiol*. 2009;42(6):693-697. doi:10.1016/j.jelectrocard.2009.07.020.

12. Sibbald M, Davies EG, Dorian P, Yu EHC. Electrocardiographic Interpretation Skills of Cardiology Residents: Are They Competent? *Can J Cardiol*. 2014;30(12):1721-1724. doi:10.1016/j.cjca.2014.08.026.
13. Lee TH, Rouan GW, Weisberg MC, et al. Clinical characteristics and natural history of patients with acute myocardial infarction sent home from the emergency room. *Am J Cardiol*. 1987;60(4):219-224. <http://www.ncbi.nlm.nih.gov/pubmed/3618483>. Accessed January 4, 2017.
14. Todd KH, Hoffman JR, Morgan MT. Effect of cardiologist ECG review on emergency department practice. *Ann Emerg Med*. 1996;27(1):16-21. <http://www.ncbi.nlm.nih.gov/pubmed/8572442>. Accessed January 4, 2017.
15. Denes P, Larson JC, Lloyd-Jones DM, Prineas RJ, Greenland P. Major and Minor ECG Abnormalities in Asymptomatic Women and Risk of Cardiovascular Events and Mortality. *JAMA*. 2007;297(9):978. doi:10.1001/jama.297.9.978.
16. Salerno SM, Alguire PC, Waxman HS. Training and Competency Evaluation for Interpretation of 12-Lead Electrocardiograms: Recommendations from the American College of Physicians. *Ann Intern Med*. 2003;138(9):747-750. doi:10.7326/0003-4819-138-9-200305060-00012.
17. Accreditation Council for Graduate Medical Education. ACGME Program Requirements for Graduate Medical Education in Cardiovascular Disease (Internal Medicine); 2016. https://www.acgme.org/Portals/0/PFAssets/ProgramRequirements/152_interventional_cardiology_2017-07-01.pdf. Accessed January 4, 2017.
18. American Board of Internal Medicine. Policies and Procedures For Certification; 2016. <http://www.abim.org/~media/ABIMPublic/Files/pdf/publications/certification-guides/policies-and-procedures.pdf>. Accessed January 4, 2017.
19. Kadish AH, Buxton AE, Kennedy HL, et al. ACC/AHA Clinical Competence Statement on Electrocardiography and Ambulatory Electrocardiography. *J Am Coll Cardiol*. 2001;38(7):3169-3178.
20. Kern D, Thomas PA, Hughes MT, editors. *Curriculum Development for Medical Education: A Six-Step Approach*. 2nd edition. Baltimore: The Johns Hopkins University Press; 2009.
21. De Fer T, Fazio S, Goroll A. Core Medicine Clerkship: Curriculum Guide V3.0. Alliance for Academic Internal Medicine; 2006. <http://www.im.org/p/cm/ld/fid=385>. Accessed January 12, 2017.
22. Hatala RM, Brooks LR, Norman GR. Practice makes perfect: The critical role of mixed practice in the acquisition of ECG interpretation skills. *Adv Heal Sci Educ*. 2003;8(1):17-26. doi:10.1023/A:1022687404380.
23. Bayes de Luna A. *ECGs For Beginners*. Barcelona: Wiley Blackwell; 2014.
24. O'Keefe J, Hammill S, Freed M, Pogwizd S. *The Complete Guide to ECGs*. Third edition. Kansas City: Physicians' Press - Jones and Bartlett Publishers; 2008.
25. Khan G. *Rapid ECG Interpretation*. Third edition. Ottawa: Humana Press (Springer Science); 2008.
26. Garcia T. *12-Lead ECG: The Art of Interpretation*. Second edition. Burlington: Jones & Bartlett Learning; 2015.
27. Olson CW, Warner RA, Wagner GS, Selvester RH. A dynamic three-dimensional display of ventricular excitation and the generation of the vector and electrocardiogram. *J Electrocardiol*. 2001;34 Suppl:7-15. doi:10.1054/jelc.2001.29793.
28. Olson CW, Lange D, Chan JK, et al. 3D Heart: A new visual training method for Electrocardiographic Analysis. *J Electrocardiol*. 2007;40(5):1-7. doi:10.1016/j.jelectrocard.2007.04.001.
29. Wagner GS, Macfarlane P, Wellens H, et al. AHA/ACCF/HRS Recommendations for the Standardization and Interpretation of the Electrocardiogram. Part VI: Acute Ischemia/Infarction A Scientific Statement From the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Endorsed by the International Society for Computerized Electrocardiology. *J Am Coll Cardiol*. 2009;53(11):1003-1011. doi:10.1016/j.jacc.2008.12.016.
30. Thygesen K, Alpert JS, White HD. Universal definition of myocardial infarction. *Eur Heart J*. 2007;28(20):2525-2538. doi:10.1093/eurheartj/ehm355.
31. Neumar RW, Otto CW, Link MS, et al. Part 8: Adult advanced cardiovascular life support: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2010;122(Suppl 3). doi:10.1161/CIRCULATIONAHA.110.970988.
32. Barold SS, Hayes DL. Second-Degree Atrioventricular Block: A Reappraisal. *Mayo Clin Proc*. 2001;76(1):44-57. doi:10.4065/76.1.44.
33. Borloz MP, Mark DG, Pines JM, Brady WJ. Electrocardiographic differential diagnosis of narrow QRS complex tachycardia: an ED-oriented algorithmic approach. *Am J Emerg Med*. 2010;28(3):378-381. doi:10.1016/j.ajem.2008.12.019.
34. Nadeau-Routhier C, Baranchuk A. *Electrocardiography in Practice: What to Do?* 1st ed. Kingston: Apple Inc. iBook; 2015.
35. Diercks DB, Shumaik GM, Harrigan RA, Brady WJ, Chan TC. Electrocardiographic manifestations: electrolyte abnormalities. *J Emerg Med*. 2004;27(2):153-160. doi:10.1016/j.jemermed.2004.04.006.
36. Quinn KL, Crystal E, Lashevsky I, Arouny B, Baranchuk A. Validation of a Novel Digital Tool in Automatic Scoring of an Online ECG Examination at an International Cardiology Meeting. *Ann Noninvasive Electrocardiol*. 2016;21(4):376-381. doi:10.1111/anec.12311.
37. Johnson NP, Denes P. The Ladder Diagram (A 100+ Year History). *Am J Cardiol*. 2008;101(12):1801-1804. doi:10.1016/j.amjcard.2008.02.085.
38. Bulte C, Betts A, Garner K, Durning S. Student teaching: views of student near-peer teachers and learners. *Med Teach*. 2007;29(0):583-590. doi:10.1080/01421590701583824.
39. Nestojko JF, Bui DC, Kornell N, Ligon Bjork E. Expecting to teach enhances learning and organization of knowledge in free recall of text passages. *Mem Cogn*. 2014;42:1038-1048. doi:10.3758/s13421-014-0416-z.
40. Bené KL, Bergus G. When learners become teachers: A review of peer teaching in medical student education. *Fam Med*. 2014;46(10):783-787. doi:10.4300/JGME-D-13-00426.
41. Lucas J, McKay S, Baxley E. EKG arrhythmia recognition: a third-year clerkship teaching experience. *Fam Med*. 2003;35(3):163-164. <http://www.ncbi.nlm.nih.gov/pubmed/12670106>. Accessed January 31, 2017.
42. DeBonis K, Blair TR, Payne ST, Wigan K, Kim S. Viability of a Web-Based Module for Teaching Electrocardiogram Reading Skills to Psychiatry Residents: Learning Outcomes and Trainee Interest. *Acad Psychiatry*. 2015;39(6):645-648. doi:10.1007/s40596-014-0249-x.
43. Chudgar SM, Engle DL, Grochowski COC, Gagliardi JP. Teaching crucial skills: An electrocardiogram teaching module for medical students. *J Electrocardiol*. 2016;49(4):490-495. doi:10.1016/j.jelectrocard.2016.03.021.
44. Nathanson LA, Safran C, McClennen S, Goldberger AL. ECG Wave-Maven: a self-assessment program for students and clinicians. *Proc AMIA Symp*. 2001:488-492. <http://www.ncbi.nlm.nih.gov/pubmed/11825236>. Accessed January 31, 2017.
45. Farré J, Wellens H. ECGcorner (Online). ECGcorner. <http://www.ecgcorner.org>. Published 2017. Accessed February 15, 2017.
46. Waechter J. Teaching Medicine (Online). <https://www.teachingmedicine.com/> Accessed Feb 15, 2017.
47. Akgun T, Karabay CY, Kocabay G, et al. Learning electrocardiogram on YouTube: How useful is it? *J Electrocardiol*. 2014;47(1):113-117. doi:10.1016/j.jelectrocard.2013.09.004.
48. Rubinstein J, Dhoble A, Ferenchick G. Puzzle based teaching versus traditional instruction in electrocardiogram interpretation for medical students – a pilot study. *BMC Med Educ*. 2009;9(1):4. doi:10.1186/1472-6920-9-4.
49. Black P, William D. Assessment and Classroom Learning. *Assess Educ*. 1998;5(1):7-73. doi:10.1080/0969595980050102.
50. Quinn KL, Baranchuk A. Feasibility of a novel digital tool in automatic scoring of an online ECG examination. *Int J Cardiol*. 2015;185:88-89. doi:10.1016/j.ijcard.2015.03.135.
51. Nilsson M, Bolinder G, Held C, et al. Evaluation of a web-based ECG-interpretation programme for undergraduate medical students. *BMC Med Educ*. 2008;8(1):25. doi:10.1186/1472-6920-8-25.
52. Lessard Y, Sinteff J-P, Siregar P, et al. An ECG analysis interactive training system for understanding arrhythmias. *Stud Health Technol Inform*. 2009;150:931-935. <http://www.ncbi.nlm.nih.gov/pubmed/19745450>. Accessed January 31, 2017.
53. Zakowski, Dean Keller L. An effective ECG curriculum for third-year medical students in a community-based clerkship. *Med Teach*. 2000;22(4):354-358. doi:10.1080/014215900409447.
54. Mahler SA, Wolcott CJ, Swoboda TK, Wang H, Arnold TC. Techniques for teaching electrocardiogram interpretation: Self-directed learning is less effective than a workshop or lecture. *Med Educ*. 2011;45(4):347-353. doi:10.1111/j.1365-2923.2010.03891.x.
55. Biggs J. What the Student Does: Teaching for enhanced learning. *High Educ Res Dev*. 1999;18(1):57-75.
56. Ericsson KA. Deliberate practice and acquisition of expert performance: A general overview. *Acad Emerg Med*. 2008;15(11):988-994. doi:10.1111/j.1553-2712.2008.00227.x.
57. Raupach T, Hanneforth N, Anders S, Pukrop T, Th J Ten Cate O, Harendza S. Impact of teaching and assessment format on electrocardiogram interpretation skills. *Med Educ*. 2010;44(7):731-740. doi:10.1111/j.1365-2923.2010.03687.x.
58. Raupach T, Brown J, Anders S, Hasenfuss G, Harendza S. Summative assessments are more powerful drivers of student learning than resource intensive teaching formats. *BMC Med*. 2013;11:61. doi:10.1186/1741-7015-11-61.
59. Roediger HL, Karpicke JD. Test-enhanced learning: Taking memory tests improves long-term retention. *Psychol Sci*. 2006;17(3):249-255. doi:10.1111/j.1467-9280.2006.01693.x.

60. Ferris HA, O' Flynn D. Assessment in Medical Education; What Are We Trying to Achieve? *Int J High Educ.* 2015;4(2):139-144. doi:10.5430/ijhe.v4n2p139.
61. Hartman ND, Wheaton NB, Williamson K, Quattromani EN, Branzetti JB, Aldeen AZ. A Novel Tool for Assessment of Emergency Medicine Resident Skill in Determining Diagnosis and Management for Emergent Electrocardiograms: A Multicenter Study. *J Emerg Med.* 2016;51(6):697-704. doi:10.1016/j.jemermed.2016.06.054.
62. Pines JM, Perina DG, Brady WJ. Electrocardiogram interpretation training and competency assessment in emergency medicine residency programs. *Acad Emerg Med.* 2004;11(9):982-984. doi:10.1197/j.aem.2004.03.023.
63. Demircan A, Bildik F, Ergin M. Electrocardiography interpretation training in emergency medicine : methods, resources, competency assessment, and national standardization. *Signa Vitae.* 2015;10(1):38-52.
64. Ferrell BG, Camp DL. Comparing a Four-Week Block Clerkship to a Twelve-Week Longitudinal Experience in Family Medicine. In: Scherpbier AJJA, van der Vleuten CPM, Rethans JJ, and van der Steeg AFW, editors. *Advances in Medical Education.* Dordrecht: Springer Netherlands; 1997:744-746. doi:10.1007/978-94-011-4886-3_226.
65. Marinović D, Hren D, Sambunjak D, et al. Transition from longitudinal to block structure of preclinical courses: outcomes and experiences. *Croat Med J.* 2009;50(5):492-506. doi:10.3325/cmj.2009.50.492.
66. Melo J, Kaneshiro B, Kellett L, Hiraoka M. The impact of a longitudinal curriculum on medical student obstetrics and gynecology clinical training. *Hawaii J Med Public Health.* 2014;73(5):144-147. <http://www.ncbi.nlm.nih.gov/pubmed/24843837>. Accessed January 31, 2017.