Teaching the Anatomical Three-Dimensional Relation of the ECG: EduECG

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Abstract

Correct interpretation of the standard 12 lead electrocardiogram (ECG) is one of the fundamental skills in medical practice. Since the medical curriculum allows limited educational hours for its teaching, which often does not exceed 2 hours, the adoption of innovative techniques to enhance the ECG educational landscape is required.

EduECG represents a novel approach to teach the basics of ECG, offering direct anatomical insights into the cardiac activation and recovery processes associated with different cardiac diseases. The EduECG concept integrates cardiac anatomy with a vectorial representation of the electrical cardiac activity. The vectorcardiogram (VCG) provides the (dipole)direction of cardiac activation and recovery, and thus enables the relation to cardiac anatomy. The same VCG is also used to estimate the position of the average electrical activity as a moving (dipole) vector, the PathECG. The current version of EduECG contains four different clinical case types: normal ECG, acute coronary syndromes of different culprit vessels, bundle branch blocks, and several premature ventricular contractions.

The combination of the ECG waveforms, VCG, PathECG, and cardiac anatomy provides a whole new educational platform to teach the electro-anatomical relation to the heart. With the first version of EduECG we aim to provide material for problem-based learning by visual representation of mechanisms underlying each pathology.

1. Introduction

Clinical correct interpretation of electrocardiographic records is one of the fundamental medical skills as the standard 12-lead electrocardiographic (ECG) assessment remains an important first-line examination method and risk marker while encountering cardiovascular diseases in clinical practice [1]. Nevertheless, its reliable interpretation requires thorough training and is still subject to considerable inter- and intra variability between physicians [2-4].

Currently, owing to the internet, knowledge dissemination is more available, and many other forms of its spreading have appeared. Consequently, many online websites, courses and podcasts designed for education purposes were created. Considering materials for the ECG interpretation, the majority of them have a case-based format with active online discussion board and regular updates, however, as they can be beneficial for strengthening and advancing knowledge, some of them partially assume a basic level of knowledge of ECG interpretation from the users at the very beginning (see below).

EduECG represents a novel approach to interactively teaching the basics of ECG offering direct insights into the cardiac activation process associated with diseases routinely met in clinical practice. The concept integrates cardiac anatomy with electrical cardiac activity, which has been previously used in several studies relating to Brugada patients [5], bundle branch block and ischemia [6]. Utilizing the VCG, EduECG leverages available advanced modalities such computed 12-lead ECG, and a 3D model of the heart and chest to visualize the position and direction of the cardiac activity. Consequently, the software emerges as a solution to overcome one of the major limitations of ECG itself which is the difficulty to directly relate observed changes to cardiac anatomy.

The aim of the following paper is to introduce and discuss the educational concepts behind EduECG, as well as to demonstrate the application of presented software in providing educational concepts for learning ECG interpretation in combination with the 3D cardiac anatomy and the electrodes on the chest.

2. Materials and methods

EduECG represents the vector direction-oriented approach for visualizing the cardiac activation and recovery sequence. The whole concept relies on combining two different modalities including the standard digital 12-lead ECG, which provides data regarding cardiac activation waveforms, and cardiothoracic medical

 ISSN: 2325-887X DOI: 10.22489/CinC.2024.409

imaging data used for creation of the three-dimensional anatomical heart/torso model. Furthermore, the known location of the ECG electrodes is needed.

The concepts behind this anatomical view on the ECG has been introduced by Boonstra et al. [7]. In summary:

1) The 12 lead ECG and a model of the heart and torso with the 12 lead ECG electrodes is used to construct the VCG (dipole), i.e. the direction of electrical activity.
2) Based on the VCG direction over time the position of the average electrical activity (moving dipole) is estimated: referred to as PathECG
3) This PathECG is anchored to the center of gravity of the heart model at the PathECG position at mid QRS.

The constructed PathECG is presented within the anatomical 3D heart model. The VCG vector at any time point in the ECG can also be visualised, which gives a 3D illustration of electrical activity direction in relation to the heart, either atria and ventricles.

In this work we will focus on the functionality of EduECG in relation to the ventricular anatomy, i.e. the QRS and T-wave. Based on several ECG examples the educational concepts of EduECG will be introduced:

- The PathECG representation of the 12 lead ECG
- How to interpret the PathECG and VCG in relation to the ECG signals
- The anatomical relation to the ECG

The selected examples are the ones provided within the free download of EduECG.

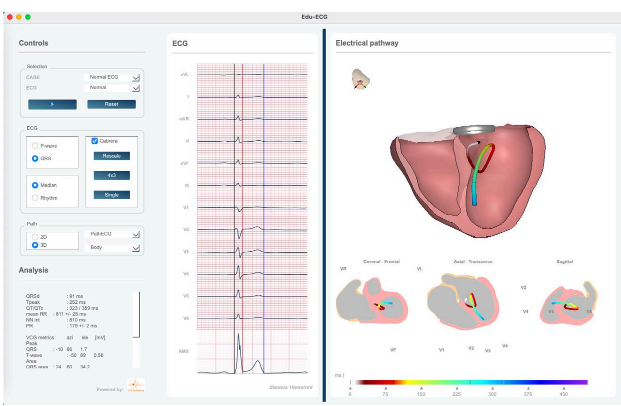

Figure 1. Programme interface

Results

The normal ECG

The normal ECG case is vital for understanding the initial cardiac activation sequence in the heart without underlying pathologies. Gaining insights into the morphology of components of a normal ECG build the fundament for its future accurate interpretation and solidify the knowledge of what "normal" looks like. The normal cardiac activation is initiated by the His-Purkinje system, starting in the left septum in humans. This left septal initiation created a transseptal activation and consequently a trans-septal vector. Subsequently the activation moves towards the apex of the left ventricle, and terminally towards the left base, as this is where the most myocardial mass is located, producing the ECG waveforms. The T-wave moves towards the apex again. The normal PathECG shows all these 4 phases clearly and thus can be used as a baseline reference allowing for direct comparison between the cases in order to identify abnormalities. Repeatedly comparing pathological cases to a normal ECG allows for sharpening ability to detect subtle changes.

Conduction disorders

Bundle branch blocks (BBBs) are conduction disorders altering the sequence and direction of depolarization through the ventricles. That may lead to ventricular dyssynchrony, where the left and right ventricles do not contract in a coordinated manner.

In LBBB, the depolarization of the left ventricle and the septum is delayed, now the ventricles are activated from right-to-left due to the fact that the right ventricle is activated first (see Figure 1). As the initial septal depolarization is reversed, the normal septal Q wave in left-side leads is lost. Furthermore, the delayed depolarization implies shifting the QRS vector leftward and slightly posterior. Previously discussed changes in vector along with delayed depolarization result in discordant ST segment changes as ST segment and T waves are directed oppositely to the main vector. Such changes in LBBB can mask or mimic ischemic changes, and hinder the diagnosis of myocardial infarction based on standard ECG criteria.

Acute coronary syndromes

Acute coronary syndromes cases highlight ischemic ECG changes related to the occlusion of one of the major epicardial arteries involving different vessel segments. The recognition of this life-threatening condition myocardial infarction is important to provide necessary treatment, often with urgent reperfusion strategies.

The PathECG related to the occlusion within different segments of LAD was shown in Figure 2 to highlight that vector showing the direction of the cardiac electrical activity differs between the cases. In the setting of proximal occlusion, when the depolarisation of the ventricles starts, the PathECG starts in the right ventricle, right to the septum moving towards the left ventricle, and again transseptal pointing to the right ventricle. In the case of mid occlusion, the PathECG starts within the left ventricle moving firstly superior, followed by change in the vector direction towards apex. Lastly, considering the

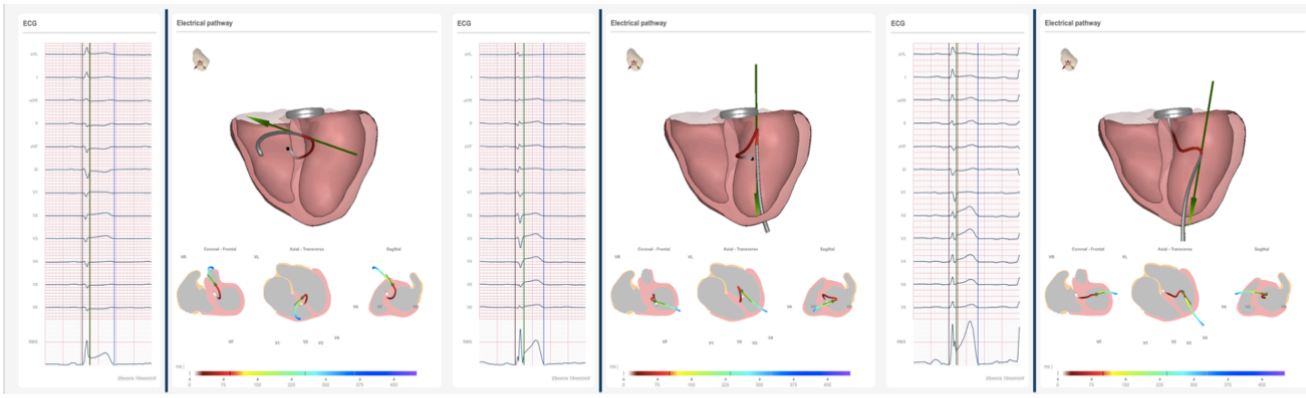

Figure 2. The PathECG showing the direction of the electrical activity in the setting of the proximal, mid and distal LAD occlusion.

distal occlusion, the PathECG begins in the superior part of the left ventricle, next to the septum, moving at the beginning inferior, followed by change in the direction towards left ventricle, before pointing to the apex as the final direction.

Premature ventricular contractions

Premature ventricular contractions (PVCs) are related to the presence of ectopic origin of the electrical impulses within the ventricles, which fires prematurely causing the disruption of the normal sequence of cardiac activation processes. Consequently, the vector of depolarization directly depends on the location of the ectopic origin, and since PVCs can originate from any place within the ventricles, the vector can vary widely. Understanding the vector changes, and shape and duration of QRS complexes provide information regarding the origin of the ectopic beat, which has further clinical implications affecting patient's management.

4. Discussion

EduECG improves the teaching and understanding of the ECG waveforms by showing the relationship between the cardiac anatomy, ECG signals, the activation pathway (PathECG) and the vector direction (VCG). In this paper we showed the features of the different visualization of the electrical activity in relation with the cardiac anatomy. EduECG thus provides a method to explain the cause effect relationship, i.e. function of the heart to (Path)V/ECG waveforms.

Cardiovascular diseases have been invariably one of the leading issues in global health, and the need for establishing proper prevention and intervention approaches is well recognized. Since its introduction over a century ago, the ECG examination established its fundamental role while encountering any cardiovascular diseases in daily clinical practice, which is highlighted in guidelines as class 1A recommendations [1,8]. However, due to significant advances in medical technologies including the development of new modalities, the ECG is treated more like a pattern recognition, rather than a primary tool offering a variety of instantaneous insights in the functioning of the heart. The aforementioned issue regarding the transformation of the ECG role over decades was thoroughly discussed by Yong et al. [9]. Authors pointed out unfavourable changes leading to underestimation of the ECG potential, particularly the extreme simplification of the ECG learning approach focusing on distinguishing main, obvious pathologies such as ST-segment elevation myocardial infarction or conduction disorders like bundle branch blocks. The transformation of that matter should start from the basics, thus from proper educating and mentoring. Sadly, time for the ECG course during medical training often does not exceed a few hours, which creates a lack of functional understanding of cardiac activation mechanisms. Relying on well-thought simplification and understanding the underlying mechanisms of cardiac activity is critical for increasing proper clinical thinking among young adepts of medical sciences.

The concept behind the creation of EduECG is similar to one used in the CineECG. Created rather for research purposes, the CineECG proved to be an useful tool while encountering more advanced cardiovascular pathologies seen in the ECG such as progressive AV-junctional conduction block [10], familial ST-segment depression syndrome [11], and Brugada syndrome [12]. Such examples highlight the clinical relevance of used methodology and concept, therefore it is safe to say that exploring the educational ECG landscape via EduECG is a good method of learning ECG interpretation.

5. Conclusions

The combination of the ECG waveforms, VCG, PathECG, and cardiac anatomy provides a whole new educational platform to teach the electro-anatomical relation between the electrical processes in the heart and the ECG waveforms. We believe that creation and further development of EduECG as an educational tool will help in better understanding the electrophysiological processes underlying the commonly-met cardiological pathologies, along with providing proper educational background for medical students and ECG enthusiasts.

Acknowledgments

Peter M van Dam is an owner of Peacs BV, the Netherlands.

Downloads for EduECG: www.peacs.nl (**Downloads**)

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