Differential Diagnosis of Wide QRS Complex Arrhythmias Using a Novel Slow Conduction Index Algorithm

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Abstract

The study investigates the utility of a slow conduction index for differential diagnosis of wide QRS complex arrhythmias with left bundle branch block (LBBB) morphology across all 12 ECG leads, aiming to improve diagnostic accuracy without reliance on identifying RS complex types based on Brugada algorithm.

Including 280 single premature wide QRS complexes from 28 randomly selected patients, the research employs ROC analysis to assess the diagnostic value of the slow conduction index.

Results indicate the highest sensitivity and specificity values in leads aVL, V2, aVF, V5, and III, with statistically significant findings ($p < 0.001$) across all leads.

The conclusion underscores the potential of using the slow conduction index across all ECG leads for diagnosing wide QRS complex arrhythmias with LBBB morphology, proposing a more universal and accurate approach to arrhythmia classification.

1. Introduction

In clinical practice, the differential diagnosis of arrhythmias with wide QRS complexes remains a complex challenge [1, 2]. Electrocardiography (ECG) and Holter monitoring are essential for interpreting these arrhythmias. Despite years of research and the development of numerous criteria and algorithms, their real-world accuracy and efficacy are often inadequate [3, 4], as evidenced by numerous publications and case reports highlighting the limitations of these methods [5, 6].

The primary difficulty in differentiating arrhythmias with wide QRS complexes involves analyzing the interplay between atrial and ventricular rhythms, particularly identifying signs of atrioventricular (AV) dissociation and other indicators of ventricular tachycardia (VT). When visualization of atrial waves is poor, reliance on these methods is problematic, necessitating an alternative focus on the morphological characteristics of wide QRS complexes that suggest VT or aberrant conduction. Even as the list of various algorithms grows, their diagnostic precision remains questionable across various patient groups [6].

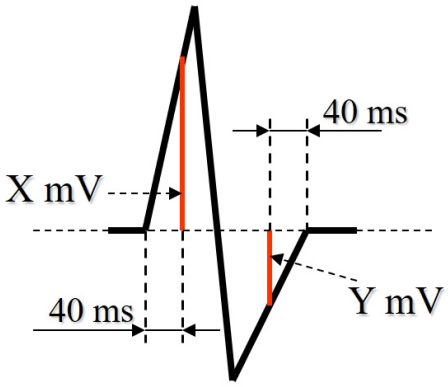
The issue partly lies in the subjective interpretation of ECG features by different clinicians and partly in the failure to account for individual variations in myocardial conduction, which occurs in arrhythmias with wide QRS complexes.

Various voltage-duration parameters of QRS can be categorized into three groups. The first examines the contours of individual QRS complex deflections, the second measures the durations of the QRS components, and the third assesses the amplitude changes in the initial and terminal parts of the QRS complex and their ratios. However, criteria from the first two groups consistently demonstrate limited diagnostic accuracy when applied to different clinical populations [6].

The reasons for these inconsistent outcomes often involve structural changes in the myocardium and individual variations in thoracic shape and cardiac position. These factors significantly influence the amplitude and duration of the QRS complex components, complicating the differential diagnosis of these arrhythmias.

One approach developed to address these diagnostic challenges is the ECG evaluation of excitation propagation velocities across the ventricular myocardium. This approach is based on analyzing the amplitude ratios of the initial and final parts of the QRS complex. A notable criterion for assessing these amplitude ratios is the slow conduction index introduced by A. Vereckei et al. [7]. The slow conduction index is a calculated metric used to determine the origin of wide QRS complexes in one ECG lead by comparing the total amplitude of the complex at the beginning and the end. It's derived from the absolute values of the amplitude at the first and last 40 milliseconds of the QRS complex. A value of the index less than 1 indicates a ventricular origin, while a value greater than 1 suggests a supraventricular origin. This criterion helps in differentiating the source of arrhythmias as shown in Figure 1. This technique significantly reduces the variability in interpreting the morphology of wide QRS complexes among different practitioners, which is

particularly beneficial in complex arrhythmia cases with a left bundle branch block (LBBB) pattern.



$$V_i/V_t = |X|/|Y|$$

Figure 1. A method of determining the amplitudes during the initial (Vi = X mV) and terminal (Vt = Y mV) 40 ms of QRS complex and slow conduction index calculation (Vi / Vt = X / Y).

However, implementing the slow conduction index involves selecting an ECG lead that displays a wide RS-type complex, as originally outlined by the criterion's creators [7]. This selection can be somewhat arbitrary, given that there may be multiple similar leads, potentially leading to inconsistent results. Additionally, in some instances, the absence of an RS-type complex formation precludes the application of the slow conduction index, rendering it impractical. These limitations, in our view, are considerable when considering the utility of this criterion in routine clinical practice.

2. The aim of the study

This study aimed to analyze the feasibility of applying the slow conduction index criterion across all 12 ECG leads for the differential diagnosis of arrhythmias that manifest with a wide QRS complex and left bundle branch block (LBBB) morphology.

As the study progressed, it became clear that a comprehensive comparison of the diagnostic utility of this criterion across the 12 ECG leads was imperative. Furthermore, a meticulous analysis of any incorrect values obtained was necessary. It was also essential to evaluate the association between the diagnostic characteristics derived and the electrophysiological properties of the excitation wave's propagation through the myocardium.

The focus was also on conducting a thorough comparative analysis of the criterion's diagnostic value across all 12 ECG leads. This included the evaluation and comparison of the diagnostic accuracy of the obtained values, as well as an analysis of the results from an electrophysiological perspective.

2. Materials and methods

2.1. Data registration

The study encompassed the analysis of 280 single premature wide QRS complexes with LBBB morphology, recorded during 24-hour and multi-day ECG monitoring of 28 randomly chosen patients receiving inpatient care at the Almazov National Medical Research Centre in Saint-Petersburg, Russia, spanning from 2010 to 2019. ECG recordings were conducted using standard isoline filters at 35 and 50 Hz, with a sampling frequency of 257 Hz (produced by INCART CJSC, Russia). All patients were screened to exclude the presence of additional conduction pathways or pre-existing bundle branch blocks. The differentiation between ventricular and supraventricular arrhythmias was corroborated by experienced cardiologists and arrhythmology specialists through a comparative analysis of the ECG readings and the outcomes of the endocardial electrophysiological study. This also involved examining the ratio of atrial to ventricular rates with clear P wave visualization before the onset of premature wide QRS complexes on both surface and transesophageal ECGs. Atrial premature contractions were documented in 14 patients, and ventricular premature beats concurrent with the sinoatrial rhythm were observed in another 14 patients.

2.2. Data processing

For each of the 280 wide QRS complexes across the 12 leads, the QRS complex boundaries were automatically identified using the KTResult 3 software (INCART CJSC, Russia). A cardiologist reviewed the automatic determinations for accuracy, making corrections as necessary. Voltage-duration parameters for the initial and final 40 ms segments of all QRS complexes were exported from the KTResult 3 software in txt format. This export was facilitated by a custom application developed in the Embarcadero RAD Studio v.10.2 environment (Idera Inc., USA), and the data were then compiled in Microsoft Excel spreadsheets (Microsoft Corporation). The subsequent analysis involved calculating the ratio of the total absolute amplitudes of the QRS complexes over the first and last 40 ms in each ECG lead. For monophasic complexes, absolute amplitude deviations were calculated directly. In the case of bi- or triphasic complexes, the amplitude sums of these deviations were calculated for either the initial or final 40 ms period.

2.3. Statistical analysis

Data distribution was first evaluated with several tests, revealing a need for nonparametric analysis due to non-normality. ROC curves were then used to determine the diagnostic utility of the slow conduction index for premature ventricular contractions (PVCs) and premature atrial complexes (PACs). AUCs were compared, and sensitivity (Sn), specificity (Sp) and accuracy (Acc) were calculated along with 95% confidence intervals (CI). Due to multiple tests on the same data, the Bonferroni correction was applied, setting a higher significance threshold at $p < 0.001$.

Statistical analyses were conducted using IBM SPSS Statistics for Windows, version 23 (IBM Corp., Armonk, NY, USA) and MedCalc Statistical Software v.20.115 (MedCalc Software Ltd, Ostend, Belgium).

3. Results

3.1. Clinical characteristics of the patients

The clinical profile of the participants in the study spanned a broad age range, from 10 to 76 years old, with a median age of 43. The cohort predominantly consisted of male patients, making up 61% of the total with 17 individuals. The occurrence of coronary heart disease (CHD) was confirmed in three patients. Hypertension was present in six individuals, and two were diagnosed with chronic heart failure at functional class II according to the New York Heart Association (NYHA) classification.

Upon echocardiographic evaluation, left ventricular hypertrophy was identified in nine patients, distributed between five patients presenting with PVCs and four with PACs. Furthermore, three patients were found to have dilated cardiomyopathy of nonischemic origin, with the condition observed in one patient with PVCs and two patients with PACs.

3.2. Analysis of the Sn and Sp of the Slow Conduction Index Across 12 ECG Leads

The Sn and Sp for the slow conduction index were determined in leads aVL, V2, aVF, V5, and III with the highest values. In contrast, leads I, V3, and V6 exhibited the lowest values in this analysis. Despite the range in values, a statistically significant difference was evident across all leads with a $p< 0.001$, including those with lower areas under the curve (AUC) values in the receiver operating characteristic (ROC) curve analysis. Confidence intervals (CI) across the leads were consistently narrow, indicating precision in the Sn and Sp estimates.

When assessing the diagnostic utility of the QRS complex shape, the AUC did not surpass 0.83 in any of the leads. This suggests that while the shape of the QRS complex is helpful, it is not highly definitive on its own for diagnostic purposes.

3.3. Diagnostic Accuracy of the Slow Conduction Index Across 12 ECG Leads

Upon evaluating Acc of the slow conduction index across various ECG leads, it was found that none of the leads reached a diagnostic accuracy higher than 94%. The most informative leads for differential diagnosis, based on their diagnostic accuracy, were aVL, V2, aVF, V5, and III, presented in descending order of effectiveness. The diagnostic Acc for these leads is visually represented in Figure 2, allowing for an at-a-glance comparison across the leads. Additionally, the 95% CI for the diagnostic accuracy were relatively narrow for the slow conduction index in each ECG lead, indicating a high level of precision in these measurements.

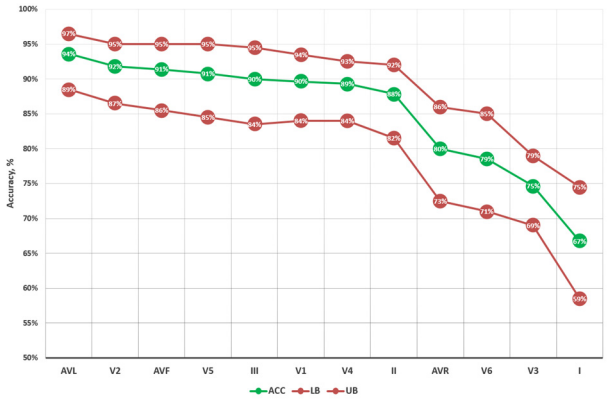


Figure 2. Line plot of slow conduction index Acc with 95% CI in all 12 leads. LB-UB – lower bound-upper bound of 95% CI.

4. Discussion

This study investigated the applicability of the slow conduction index for differential diagnosis of wide QRS arrhythmias with LBBB morphology across all 12 ECG leads. The research assessed the diagnostic value of the index in this context. Findings indicated that the slow conduction index can be reliably utilized in any ECG lead, negating the need to specifically identify a biphasic wide complex with RS-type morphology based on Brugada algorithm.

The results revealed that the diagnostic accuracy of the slow conduction index was notably high in terms of Sn and Sp in 8 out of the 12 leads, specifically leads II, III, aVL, aVF, V1, V2, V4, and V5. This comprehensive utility was supported by the statistically significant ROC areas curves ($p < 0.001$) across all leads, irrespective of the leads with lower AUC values.

A significant distinction was observed upon visual comparison of the diagnostic accuracy of the slow conduction index in all the leads. The index showed superior performance in the eight leads mentioned previously, whereas the accuracy was comparatively lower when the index was utilized in the remaining four leads (I, aVR, V3, and V6). This differentiation underscores the importance of lead selection in maximizing the diagnostic potential of the slow conduction index when evaluating wide QRS arrhythmias with LBBB morphology.

Among various criteria for diagnosing arrhythmias with wide QRS complexes, the slow conduction index is considered most appropriate for capturing the complex ventricular myocardium excitation process. Nonetheless, this index is typically only applicable in leads displaying a biphasic or three-phase wide complex, often of the RS type, complicating the diagnosis process. Initially, this specificity was not clearly outlined, but later, usage of the index was suggested solely for the aVR lead.

However, this study finds that the diagnostic significance of the slow conduction index is not limited by the choice of a lead with a particular QRS complex shape. The index demonstrated high sensitivity, specificity, and accuracy in most leads, supported by a narrow 95% confidence interval in the ROC curve analysis, suggesting low parameter variability and high robustness.

The results from this study are not definitive and should not be seen as a strict guideline. Further analysis and validation with a larger patient cohort without structural cardiac disease are necessary to solidify the findings.

5. Conclusions

This study highlighted the utility of the slow conduction index for differentiating arrhythmias with wide QRS complexes across all ECG leads. The index showed enhanced diagnostic accuracy, particularly in leads II, III, aVL, aVF, V1, V2, V4, and V5 in patients displaying left bundle branch block (LBBB) QRS morphology. Notably, the use of the slow conduction index across various ECG leads is independent of the QRS complex shape and serves to significantly refine the differential diagnosis process for PVC and PAC with LBBB aberrancy.

However, the study acknowledges the limitation of a relatively small sample size and recognizes the need for further validation with a broader patient cohort. This expanded analysis would ideally encompass a diverse array of wide ectopic complexes with LBBB morphology and various ventricular arrhythmia foci, while also considering underlying cardiac structural diseases.

In summary, the findings underscore the importance of a holistic and meticulous approach when analyzing QRS complex morphology and reaffirm the necessity for thorough scrutiny of various diagnostic criteria when evaluating arrhythmias with wide QRS complexes.

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