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Abstract

Early repolarization (ER) in the inferior/lateral leads of 12-lead ECG increases the risk of arrhythmic death. Automatic methods are needed to robustly locate the J-point in ER positive ECGs so large databases with electrocardiographic ER patterns can be analyzed.

We developed an algorithm (Std-12) to determine J-point location in the 12-lead ECG based on the standard deviation across the 12 leads. The algorithm was compared to J-point locations determined manually by Minnesota coding of 12-lead ECGs with and without ER.

Minnesota coded QRS durations were different in the ER+ and ER- groups. In contrast, the Std-12 algorithm measured similar QRS durations in the ER+ and ER-groups, consistent with the Minnesota coded duration of the ER- group. If the later Minnesota coded J-points were used instead of the earlier J-points otherwise recommended by the Minnesota coding scheme, the QRS durations in the ER- and ER+ groups were similar, and agreed with the Std-12 algorithm.

The results of this study suggest that J-points should always be set after any notches or slurs, to help determine the correct QRS duration. The developed Std-12 algorithm seems to robustly determine correct QRS durations, regardless of the electrocardiographic presence of ER.

1. Introduction

Early repolarization (ER) in the inferior/lateral leads of 12-lead ECG increases the risk of arrhythmic death [1]. The ER pattern associated with highest arrhythmic risk is terminal QRS notching or slurring ≥0.1mV with a horizontal/downsloping ST-segment [2]. Automatic methods are needed to robustly locate the J-point in ER positive ECGs so large databases with electrocardiographic ER patterns can be analyzed.

Early repolarization is thought to be the result of an increased I_{to} current [3-4]. The I_{to} current has no or very little effect on the activation pattern of the heart, and thus should not affect QRS duration. Hence, measurements of QRS duration should not depend on whether subjects present with ER or not.

The Minnesota Coding Manual [5] advocates that in the presence of two J-points (typical for ECG leads showing ER), the earlier should be used to mark QRS offset. However, using this approach the QRS offset point can potentially be marked too early. There is also the potential bias that visual interpretation of small morphological detail will influence the coding and thus the measured QRS duration.

Therefore, a robust automatic method is warranted to consistently determine QRS duration. We developed and tested such an algorithm for J-point location in subjects with and without electrocardiographic ER.

2. Methods

2.1. Study overview

Manual coding of QRS duration based on the Minnesota coding guidelines were compared to QRS duration found by an automatic algorithm in subjects both with and without electrocardiographic ER.

2.2. Data collection

The study population consisted of 100 healthy subjects drawn from a larger population manually coded for presence (ER+) or absence (ER-) of early repolarization. One group drawn randomly from the ER- population consisted of 50 subjects (33 males, 17 females) aged 24 to 82 years (50 y ± 13). A second group drawn randomly from the ER+ population consisted of 50 subjects (24 males, 26 females) aged 23 to 77 years (50 y ± 12).

Standard 12-lead digital ECGs of 10 second duration were recorded from all 100 subjects using the GE Healthcare MAC5000 (*GE Healthcare, Milwaukee, WI*). Each 10 second ECG was used to form a median beat in the recorded leads using MUSE/Interval Editor software (*GE Healthcare, Milwaukee, WI*). All data analysis was performed on these medians using Matlab v8.2 (*Mathworks, Natick, MA*).

2.3. ECG coding

All inferior (II, aVF, III) and lateral leads (aVL, I, V4, V5 and V6) were manually coded for J-point location using the guidelines of the Minnesota Coding Manual [5]. The guideline states that when two J-points are marked in any one lead, the earlier J-point should be used to measure QRS duration in that lead. The latest J-point across all leads is then used to determine QRS duration for an ECG. Coding of J-point location should be done differently for ST-segment elevation measurements. Here, the later J-point in any lead should be used.

Figure 1 shows stylistic illustrations of different typical ECG configurations, and how the J-point should be coded. Generally, a tangent is drawn on the ST segment, and the deviation from this tangent should be coded as the J-point. In the presence of notches or slurs, the beginning of the notch/slur should also be marked, thus giving two J-points. There are configurations where the beginning of a notch is not well-defined. In those cases, only one J-point is coded.

2.4. Std-12 Algorithm

An algorithm for automatic J-point location was developed. The basic assumption of the algorithm is that there is minimal electrical activity in all leads immediately before and after the QRS complex. To find these points, the standard deviation across all 12 standard leads is computed. An example of this is shown in figure 2. The maximum value of the Std-12 beat is the peak activity which is near the middle of the QRS complex. The minimum values on both sides of this peak determine the QRS onset and QRS offset, respectively.

This algorithm bears some resemblance with the RMS ECG [6], but to our knowledge the RMS algorithm has not been used to determine QRS duration.
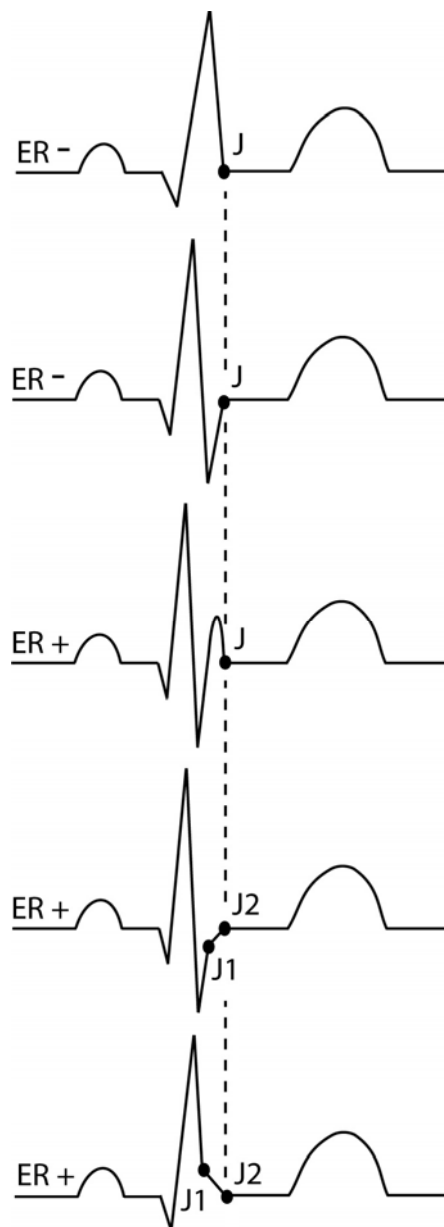

Figure 1. Illustration of Minnesota coding guidelines for different typical ECG configurations. In the absence of ER, the J-point marks the junction between QRS complex and ST segment. In the presence of notches or slurs, two J-points are generally defined. However, there also exists cases in which a notch is present, but only one J-point is well defined, as exemplified in the third trace.
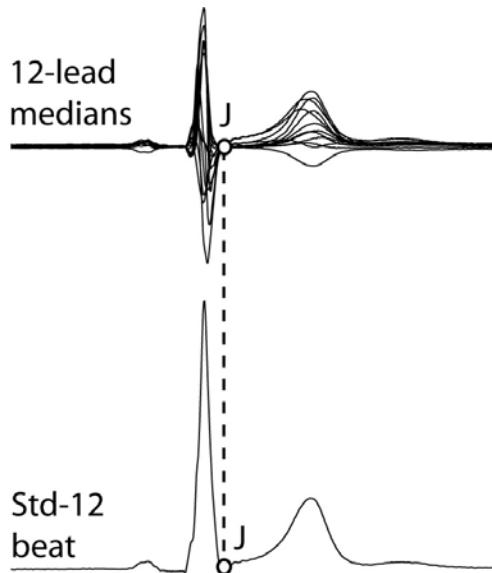
Figure 2. Illustration of the Std-12 algorithm for determining QRS duration. The minimum value following the QRS peak can be used to determine QRS offset. Similarly, the minimum value before the QRS peak can be used to determine QRS onset.

3.   Results

The average QRS durations in the ER- and ER+ groups are given in table 1.

When there is no early repolarization in an ECG, the Minnesota coded QRS durations and the Std-12 QRS durations are similar (both 101 ms). In contrast, when early repolarization is present in an ECG, the Minnesota coded QRS durations are significantly shorter compared to the Std-12 QRS durations (90 vs 99 ms).

Table 1. QRS durations in ECGs with early repolarization (ER+) and without (ER-) measured using Minnesota coding and the Std-12 J-point defined as the point of minimum standard deviation across leads.

	Minnesota QRS Mean±SD (ms)	Std-12 QRS Mean±SD (ms)	P-value
ER-	101±12	101±15	0.94
ER+	90±14 §	99±11	<0.01

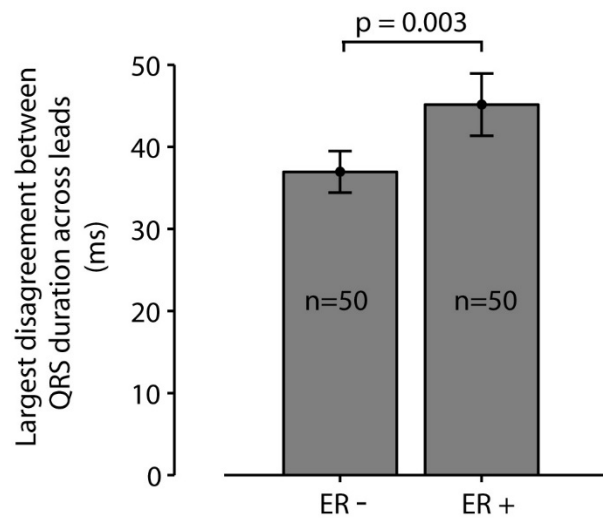§ Significantly different from Minnesota coded ER-, p<0.01.

Figure 3. Minnesota coding of the earliest J-point in each ECG lead will cause disagreement between QRS durations across leads. This disagreement is augmented when early repolarization is present (ER+).

Similarly, the Minnesota coded QRS durations in the ER- and ER+ groups are different (101 vs 90 ms, p<0.01) but there is no difference between the ER- and ER+ groups when the Std-12 QRS duration is used (101 vs 99 ms, p=0.5).

For Minnesota coded J-point locations (earliest J-point in each lead) the disagreement between shortest QRS duration in any lead and longest QRS duration in any lead was 37 ms on average in the ER- group and 45 ms in the ER+ group. Thus, when early repolarization is present in an ECG the disagreement between QRS durations across leads is significantly increased, p=0.003 (figure 3).

For subjects with ER present in the ECG, there were 41 cases where the lead determining QRS duration showed no ER (lead w/o ER), and 9 cases where the lead determining QRS duration did show ER (lead with ER). The 9 cases were visually inspected and found to be similar to the middle illustration of figure 1.

In the 'lead w/o ER' group, QRS duration was 88±14 ms (n=41) and in the 'lead with ER' group it was 100±14 ms (n=9). These groups are significantly different (p<0.05).

The 'lead with ER' group is similar to both the Std-12 QRS measure (p=0.92) and the Minnesota coded ER-subjects (p=0.75). The 'lead w/o ER' group is significantly different from both (p<<0.01 in both cases). Figure 4 shows a histogram of QRS durations obtained from ER- and ER+ subjects using Minnesota guidelines. For the ER+ group, 'leads with ER' and 'leads w/o ER' have been separated.
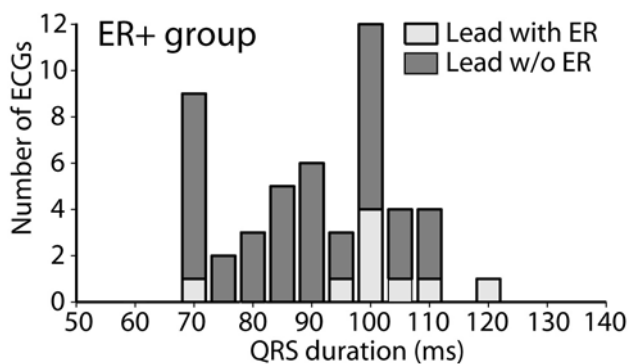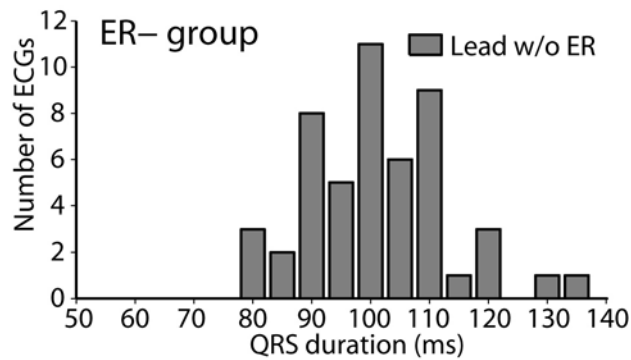
Figure 4. Top pane shows the distribution of Minnesota coded QRS durations in the ER- group. Bottom pane shows the same for ER+ group. In addition, the durations from leads with ER are light grey, and the durations from leads w/o ER is dark grey.

4. Discussion

The results presented in this study indicate, that although Minnesota coding is the most widely used coding system for ECGs, it does not handle cases of electrocardiographic ER well. As argued in the introduction, QRS duration should be similar to in ER- and ER+ groups; Minnesota coded QRS durations of the ER+ group is significantly different from the ER- group both statistically and clinically.

In line with the argument that QRS duration should be similar in the ER+ and ER- groups, using 'leads with ER' for determining QRS duration gives values similar to the ER- group. Hence, our results suggest that instead of using the earliest J-point for determining QRS duration, the latest J-point should always be used, both for

determining QRS duration and J-point (ST) elevation.

The developed Std-12 algorithm found QRS durations that were similar to the Minnesota coded QRS durations of the ER- group. It also found similar durations in the ER+ and ER- groups, regardless of the electrocardiographic presence of ER. The Std-12 algorithm appears to robustly determine the correct QRS duration. Larger studies are needed to verify both the recommendation of using the latest J-point, and the robustness and correctness of the developed algorithm.

Acknowledgements

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