Improvement of the Diagnostic Accuracy in Computer-Assisted Differential Diagnosis for Wide QRS Premature Complexes

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The differential diagnosis of wide QRS premature contractions is often inaccurate in most ECG machines with automatic computer-assisted diagnosis. The purpose of the present study was to improve the accuracy of the automated differential diagnosis between premature ventricular contractions (PVC) and supraventricular contractions with aberrant conduction (A-PSC). The study investigated 180 consecutive electrocardiograms (ECGs) with wide QRS premature contractions picked up from 3,723 in the ECG database. A new algorithm, Detection of Wide QRS Complex $\bar{\omega}$ Second Derivative $\bar{\omega}$ Absolute Value $\bar{\omega}$ Smoothing $\bar{\omega}$ T Wave Subtraction $\bar{\omega}$ P’ Detection, was compared with a conventional QRS morphology algorithm and P’ algorithm without T wave subtraction. The rate of false positives was reduced step by step (22.3% in the conventional algorithm, 7.8% in the P’ without T subtraction algorithm and 3.0% in the P’ with T subtraction algorithm), resulting in a marked increase in diagnostic accuracy for A-PSC from 77.2% to 90.6% and 95.0%, respectively. In a general population with external samples, the newest algorithm showed 77.8% sensitivity, 99% specificity, and 98.9% accuracy for diagnosis of A-PSC. The new algorithm for differential diagnosis of wide QRS complexes is simple, reliable, and easy to apply to most 12-lead ECG machines with computer-assisted automatic diagnosis. (Circ J 2003; 67: 1036–1040)

Key Words: Computer-assisted diagnosis; Electrocardiogram; Supraventricular premature contraction; Ventricular premature contraction; Wide QRS premature complexes

Because the therapeutic strategies for ventricular and supraventricular arrhythmias are frequently different, accurate differential diagnosis between these 2 types of arrhythmias is quite important! However, despite a long history of computer-assisted diagnosis of electrocardiograms (ECGs)2–5 the accuracy of automatic diagnosis for wide QRS premature complexes is not always good. The algorithm for this differential diagnosis itself is not established yet in some of the widely used electrocardiographic recorders with computer-assisted diagnostics.

The fact that many practitioners rely solely on the computer diagnosis may lead to serious problems in clinical practice6. The purpose of the present study was to improve the accuracy of automated differential diagnosis of premature ventricular contractions (PVC) versus premature supraventricular contractions with aberrant conduction (A-PSC).

Methods

Patients

We first studied 180 consecutive patients with wide QRS premature contractions on their 12-lead ECG from our 3,723 ECG database as ‘internal samples’ for the present study. The tentative diagnosis (without using our new algorithms) was ‘PVC’ in all patients; however, 14 cases were diagnosed as A-PSC by expert cardiologists. They confirmed the remaining 166 patients as having PVC. We used their opinion as the gold standard in the following analysis.

We also tested our system using 296 ECG samples of wide QRS premature complexes obtained from a different hospital. Finally, we analyzed another 1,345 ECGs from routine medical check-ups as an ‘external sample’ for the objective evaluation of our diagnostic algorithm.

Strategies for the Computer Diagnosis of A-PSC

First Step: Conventional QRS Algorithm Before the present study, we did not have an algorithm to diagnose A-PSC in our 12-lead ECG recorder with automatic computer diagnosis (NEC Kartizer system, Tokyo, Japan). Our first step was to make a diagnosis of A-PSC and then we made a diagnostic algorithm using the morphologic characteristics of the QRS configuration, as shown in Table 1: widening of the QRS duration, right bundle branch block pattern, a greater deformity of QRS morphology in the shorter coupling interval of premature complexes and a non-compensation.

Table 1  Conventional QRS Algorithm

<table>
<thead>
<tr>
<th>Condition</th>
<th>Diagnosis</th>
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<tbody>
<tr>
<td>Wide QRS complex $&gt; 100 \text{ms}$</td>
<td>A-PSC</td>
</tr>
<tr>
<td>RSR’ or rsR’ or qR pattern in V1 or V2</td>
<td>A-PSC</td>
</tr>
<tr>
<td>R &lt; R’ in V1 or V2</td>
<td>A-PSC</td>
</tr>
<tr>
<td>No AF, no WPW, no RBBB</td>
<td>PVC</td>
</tr>
<tr>
<td>Multiform with variable coupling (uniform with variable coupling and multiform with fixed coupling excluded)</td>
<td>A-PSC</td>
</tr>
</tbody>
</table>

AF, atrial fibrillation; WPW, Wolff-Parkinson-White syndrome; RBBB, right bundle branch block.
satory pause. Patients with atrial fibrillation, Wolff-Parkinson-White syndrome or right bundle branch block were excluded. Also, premature complexes that had a uniform QRS morphology with variable coupling and multiform QRS morphology with fixed coupling were excluded.

**Second Step: P' Algorithm** Next we composed an ectopic P wave (P') detection algorithm in addition to the conventional one. In order to correctly detect P', we selected leads II, III, and V1. The signals from each lead were amplified, converted to digital data (sampling frequency: 250 Hz), and passed through a digital processing filter that was designed to amplify the P' components and to attenuate noise elements. The filtered signals for these 3 leads were combined into a single signal for detecting P'. P' was defined as a small deflection just before the premature QRS complex.

The digital data processing methods used are described.

1. Original signals from lead II, III, and V1 (Fig 1) are differentiated into second derivatives according to the following formula (Fig 2).

\[ D(n) = E(n-5) + E(n+5) - 2E(n) \]

where \( E(n) \) is electrical potential at time \( t=n \) (t(n−1)−

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**Fig 1.** Original ECG. The second beat is a premature supraventricular contraction with aberrant ventricular conduction. The first and the third beats are sinus beats.

**Fig 2.** All electrical signals from leads II, III, and V1 were differentiated to their second derivatives.

**Fig 3.** Absolute values of secondarily differentiated signals. All negative components of the 3 leads in Fig 2 were converted to their absolute value and summed into 1 signal.
t(n) = t(n+1) - t(n) = 4 ms.

2. The secondarily differentiated signals are converted into absolute values and are added to each other (Fig 3).

A(n) = |DII(n)| + |DIII(n)| + |DV1(n)|

3. The signals are executed using a 10-point smoothing filter through the following formula (Fig 4).

W(n) = (A(n) + A(n+1) + ... + A(n+9))/10

4. Then we searched for a low-amplitude peak that satisfied the following criteria as a candidate for the P wave.

W(n-1) ≤ W(n) ≥ W(n+1) and W(n-5) ≤ W(n) ≥ W(n+5)

**Third Step: New P' Algorithm**

P' is sometimes superimposed on the preceding T wave. To differentiate the P' from the T wave, the digitized signal derived from the normal T wave was subtracted from the beat under examination. Then, the P' detection algorithm was applied to the residual signal.

**Statistical Analysis**

Chi-square test was used to compare the diagnostic accuracy between conditions; p<0.05 was considered statistically significant.

**Results**

**Diagnostic Accuracy of A-PSC Using Conventional QRS Morphology Criteria**

As shown in Table 2, changing the definitions of the QRS morphology resulted in different diagnostic accuracy. The condition where RsR' and R<R' or qR of the QRS morphology showed the highest sensitivity and relatively good diagnostic accuracy still had a high rate of false positives.

**Diagnostic Accuracy Using P' and New P' Algorithm**

We next applied our new algorithm for the detection of the ectopic P wave for the diagnosis of A-PSC. As shown in Table 3, the rate of false positives was reduced to 7.8%, resulting in a marked elevation of diagnostic accuracy to over 90%, even without T-wave subtraction (p<0.005). Moreover, the application of the new P' algorithm with T-wave subtraction resulted in a significantly lower rate of false positives (3.0%) and much higher diagnostic accuracy (95.0%) (p<0.005). Fig 5 shows the steps in the process of reducing the false positives.

**Evaluation of the New P' Algorithm Using External Samples With Wide QRS Premature Complexes**

To evaluate the validity of our new P' algorithm, we tested it using 296 ECG samples with wide QRS premature complexes obtained from a different hospital (Table 4) and found it gave a high sensitivity, specificity, and diagnostic accuracy.

**Evaluation of the New P' Algorithm Using Another Set of External Samples**

We next tested our new P' algorithm using field ECGs from routine medical check-ups, which included not only wide QRS premature complexes but also various other abnormal findings. As shown in Table 5, the sensitivity, specificity, and diagnostic accuracy for A-PSC remained high.
Discussion

Recognition of Ectopic P Waves in the Differential Diagnosis of Wide QRS Premature Complexes

The differential diagnosis between PVC and premature supraventricular contraction with aberrant conduction essentially depends upon whether an ectopic P wave exists or not. However, some of the widely used electrocardiography machines do not have an algorithm for ectopic P wave detection in their computer-assisted automatic diagnosis system, even though the diagnostic performance for morphologic abnormalities has improved significantly. As shown in the present study, the accuracy of diagnosing an A-PSC based solely on QRS morphology criteria is not adequate in the clinical setting. Some of the ventricular premature complexes have been misdiagnosed as A-PSC because their QRS morphology was quite similar. Thus, the rate of false positive diagnoses was high, resulting in low specificity and diagnostic accuracy.

Two studies about the detection of ectopic P waves have...
been reported. Sippensgroenewegen et al have reported the usefulness of spatial analysis using 62-lead QRST subtraction system10 and Clavier et al have applied a wavelet analysis on it.11 Both emphasized the high diagnostic accuracy, but their systems were fairly complicated to apply to routine ECG analysis. There have not been any reported studies that used second derivatives to detect ectopic P waves.

When we introduced an ectopic P wave detection algorithm, the rate of false positive markedly decreased, and the specificity and diagnostic accuracy increased dramatically. Using only this alteration to the algorithm, we still had 7.8% false positive cases, which were caused by misreading a preceding T wave as an ectopic P wave, mostly because of postural changes or mechanical artifacts (Fig 5A,B). To improve this situation, we developed a new algorithm that allowed the preceding T wave to be subtracted while leaving dominant the normal T wave component. The residuals after this procedure must have the signal from the ectopic P wave, if it is there, making it possible to more accurately diagnose an A-PSC. When the complex is a PVC, the residual signal must reveal no P wave component (Fig 5C).

### Validation of the New P' Detection Algorithm

Because we composed the new P' detection algorithm using same ECG data as that for the QRS morphology algorithm, we next needed to confirm its accuracy by using external samples. In the analysis of ECGs with wide QRS premature complexes recorded at another hospital as an external sample, the sensitivity, specificity, and diagnostic accuracy of our new algorithm were almost equivalent to the results with the internal sample, and were thought sufficiently high for use in the clinical setting. However, the results showed a 4.5% false positive rate, which was related to misdiagnosis of the complexes as premature supraventricular contractions with aberrant ventricular conduction. It is thought that, in such cases, the residual signal after subtraction of the dominant T wave revealed some component that resembled an ectopic P wave, probably because of an artifact or a multiformal ventricular contraction.12 This is a major limitation of the present method, because our system has no way of compensating for multiformal PVC or mechanical noise on low-quality ECGs. In addition, low amplitude of the ectopic P wave sometimes resulted in a false negative. Further improvement is needed to deal with these problems.

### Usefulness as a Screening in the Medical Check-up

Using our new P' algorithm, high sensitivity with high specificity were obtained in both the internal and external samples, resulting in high diagnostic accuracy. Because there are few abnormal ECGs at routine medical check-ups, a sensitivity of approximately 80% with over 90% specificity for the diagnosis of A-PSC should be satisfactory.13 In fact, our data using ECGs from routine medical check-ups showed very high diagnostic accuracy for A-PSC.

### Conclusion

Our new algorithm for differential diagnosis of wide QRS complexes is simple, reliable, and easy to apply to most 12-lead ECG machines with computer-assisted automatic diagnosis.

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### References