Extraction of Buried P Waves from Printed Electrocardiograms

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Background: Morphologic identification of ectopic P-waves from surface ECGs can be challenging, particularly when the P-wave is buried in the QRST wave complex. Because ECGs are often available on paper and not digitally, we developed a method of subtracting the T-wave from the buried P-wave complex on paper ECGs.

Methods: To validate our system, an atrial extrastimulus was introduced during and following the T-wave. The ECGs were scanned and then transformed from an image format to a digital format. A computer algorithm digitally subtracted a QRST with no buried P-wave from one with a buried P-wave, thus resulting in an extracted P-wave. The extracted P-waves were compared to the nonburied P-wave by determining correlation coefficients and by visual grading by two independent reviewers.

Results: Visual grading comparing the buried P-wave with the exposed paced P-wave was 94%. The median correlation coefficient was 85%.

Conclusions: An ectopic atrial P-wave obscured by a coincident QRST wave complex can be accurately derived from printed ECG using this PC-based system. Addition of this technique to the existing methods may aid in the localization and ablation of ectopic atrial foci.

A.N.E. 2005;10(2):142–145

atrial premature contractions; electrocardiography; QRST subtraction

Atrial premature contractions (APCs) have been shown to be associated with the onset of atrial fibrillation.[1,2] The morphology and timing of the APC from a standard 12-lead surface ECG can indicate the gross position of the ectopy and so guide further electrophysiological studies and treatment.[3–5] However, the nature of APCs is such that they often occur during the repolarization phase of the ventricles and thus "overlap" with the T wave from the preceding beat.[6] Therefore, the true morphology of an APC is obscured by the overlapping T wave and so a method must be devised to extract the true APC morphology for further examination. Since most ECGs are recorded on paper, we developed a PC-based system in which printed surface electrograms are converted to a digital format and the obscured P wave is extracted from the electrograms by subtracting out the QRST complex. The advantage of this system is the potential wide spread availability as it requires inexpensive hardware and can be used to extract APCs from printed ECGs.

METHODS

Standard 12-lead surface ECG recordings from 21 patients who underwent premature atrial pacing during diagnostic electrophysiologic study were recorded. Each patient had given informed consent and received conscious sedation during the study. Six French quadripolar electrode catheters (Bard Electrophysiology, Lowell, MA) were placed at the high right atrium, His-bundle, and right ventricular apex using fluoroscopic guidance. Atrial pacing was delivered at twice the atrial-pacing threshold to ensure consistent capture. Each patient

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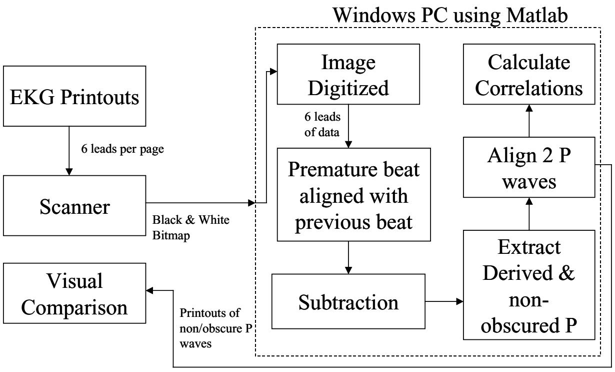

Figure 1. This block diagram depicts the digitization, extraction, and comparison procedure.

underwent regular atrial pacing at a cycle length long enough to ensure each paced P wave occurred completely after the preceding T wave. Atrial premature paced beat was delivered. Three groups of the regular/prematurely paced beats were delivered at progressively decreasing coupling intervals (Fig. 1).

The electrocardiograms were then printed on standard letter (8 × 11 inch) sized paper with six leads per page. The leads were separated on paper so that none of the leads would overlap. Each page showed one group of regularly paced beats followed by one prematurely paced beat. The printed sheets were then scanned into a Windows PC at 600 DPI and saved as black and white bitmap files. The bitmaps were then loaded into a program that we developed utilizing Matlab software (Matlab version 5.0, Mathworks, Natick, MA). The black and white bitmap describes the scanned ECG leads as matrices of 1′s and 0′s. The software algorithm translated the pictorial bitmap file (the 1′s and 0′s) into a real digital signal (a matrix of signal magnitude vs time) where the sampling rate is directly related to the resolution of the bitmap.

Now the signals are plotted six leads at a time in a window. The overlapping P and T complexes (Fig. 2) are aligned with the nonoverlapped P wave so that the nonoverlapped T wave could be subtracted from an overlapped T/P wave. The resulting derived P wave was then extracted and saved (Fig. 3).

In order to evaluate our system, we compared the extracted P waves with the corresponding non-obscured P waves by determining the correlation coefficient of the two waveforms (Fig. 4) and by having two blinded readers visually grade them as well.

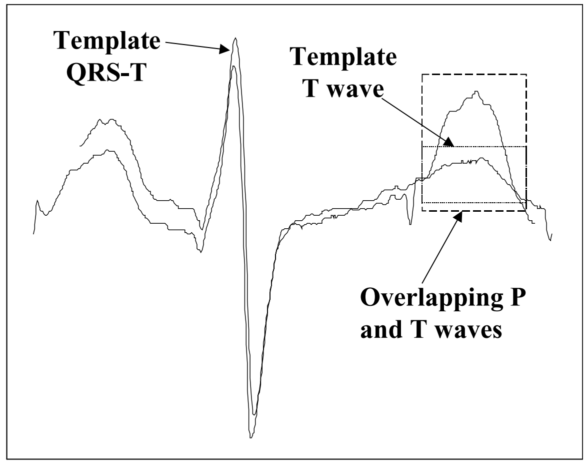

Figure 2. This representative plot shows the alignment of two QRST complexes (with respective overlapped and nonoverlapped P and T waves) prior to subtraction.

RESULTS

Our system′s derived P waves correlated well with the non-obscured P waves, having a median correlation coefficient of 84 ± 1% (100 being perfectly correlated) (Table 1). The readers visually graded 94% of the P waves as matching. Although the median correlation coefficient was high, there were some outliers that were very poorly correlated (Fig. 3). Several leads had the poorest median

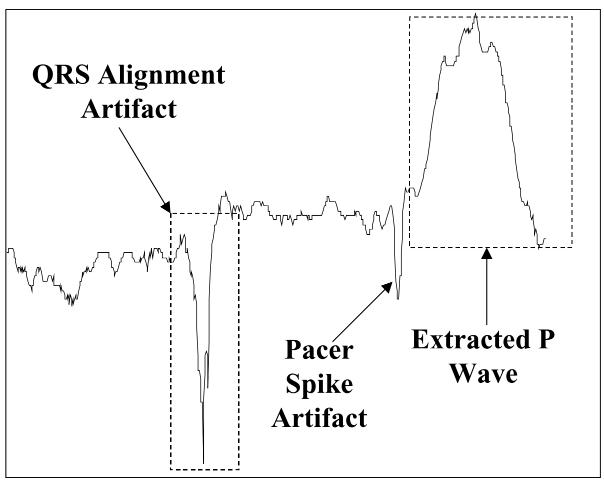

Figure 3. This representative plot shows the initial results of the alignment and subtraction algorithm.

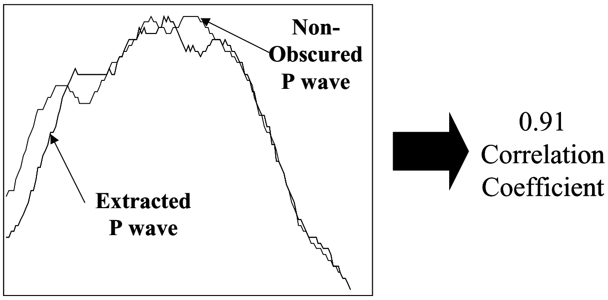

Figure 4. This representative plot shows the superposition of two corresponding nonobscured and extracted P-waves. There was 91% correlation between the two P-waves in this example.

correlations of lead I: 81 ± 3, V4: 82 ± 5, V5: 79 ± 5, and V6: 81 ± 6 (Table 1). Visual inspection revealed that these leads had the lowest amplitude overall.

DISCUSSION

This study has shown that a simple PC-based program can be used to digitize paper surface ECGs and successfully extract obscured P waves as evaluated both visually and quantitatively. Our study is the first one to evaluate the technique of QRST subtraction in digitized paper ECGs. The method we have shown requires only 12 leads and only 1 beat was necessary for use as a template.

Prior studies have shown that P wave morphology may be used to localize the site of atrial origin. Thomas Lewis showed in the early 20th century in animal models that atrial pacing in different regions results in distinct P wave morphologies. Mirowski has demonstrated that a "dome and dart" configuration is typically related to left atrial activation.[7] SippensGroenewegen et al. related an atlas of body surface integrals maps to sites of right atrial arrhythmias.[4] Yamane et al. showed that pacing at different pulmonary veins produced P waves with distinctive characteristics.[8]

Other studies have evaluated techniques to isolate obscured P waves from the QRST complex. Slocum et al. used a QRST subtraction algorithm that subtracted a mean QRST complex in patients with ventricular tachycardia to reveal the presence of atrial activity and to evaluate for atrioventricular dissociation.[9] SippensGroenewegen et al. used a 62-lead ECG system to record the ECG of patients during atrial pacing or atrial tachyarrhythmias. A QRST template was then subtracted revealing the underlying obscured P waves. Visual and mathematical comparisons showed a correlation coefficient of 0.88 ± 0.07 in the atrial-pacing group and 0.94 ± 0.05 in the atrial arrhythmia group.[10] Choi et al. evaluated the ability of QRST subtraction to expose an ectopic atrial beat that could then be compared to a previously generated pacemap catalog to determine based on the correlation coefficient where the source of the ectopic atrial beat may be.[6] In this study, comparing the exposed ectopic beat to the pacemap catalog resulted in a correlation with the successful ablation site in 84% of ectopic beats.[6]

Using QRST subtraction is a feasible and potentially useful method to help localize atrial ectopy. This method may be useful clinically to efficiently plan procedures and may help reduce time mapping areas of the atrium that are less likely to be the focus of ectopic activity, this may minimize the procedure time or help the clinician decide to proceed with transseptal puncture if needed. Using QRST subtraction on printed paper ECGs is additionally attractive since most spontaneous ectopic beats and arrhythmias occur outside the EP lab. This method of using a previously recorded and printed ECG may have unique advantages for patients with multiple infrequent arrhythmias compared to body surface mapping.

Table 1. Correlation Coefficient Versus Visual Grading per ECG Lead

ECG Lead	Correlation Coefficient (%)	Visual Grading (%)
I	81 ± 3	100
II	92 ± 5	100
III	85 ± 3	96
aVR	90 ± 3	96
aVL	67 ± 5	96
aVF	89 ± 4	89
V1	80 ± 5	93
V2	84 ± 5	89
V3	88 ± 6	93
V4	82 ± 5	93
V5	79 ± 5	93
V6	81 ± 6	93
Overall	84 ± 1	94

Study Limitations

The primary limitation of our method is that it depends on the ECG. The method does not currently adjust for overlapping leads. Currently, a user

adjusts the alignment of QRST complexes prior to subtraction and also adjusts the alignment of the obscured and non-obscured P-waves when correlating the two. It is unclear whether automatic alignment would result in a superior result. We did not examine extraction of P waves at different pacing sites such as the left atrium. Potentially, extracted P wave morphologies with pacing from different sites might be compared. In addition, we did not try to vary the time the paced P-wave occurs in the QRST complex, there may be differences in the correlation coefficient based on the timing of the paced P-wave. Correlation results in leads with low P-wave voltage were poor. This could be expected as the low amplitude original signal with the added variability of several alignment and subtraction steps results in a low signal-to-noise ratio in the resulting wave segment. Improvement could result through increasing the hardware sampling gain when capturing the original signal and, as discussed above, increasing the resolution of the printed ECG. Visual grading of the results showed a better relationship between the extracted and non-obscured P wave. There may be better algorithms than correlation waveform analysis that may compensate for some of the limitations described above.

CONCLUSION

This system provides a useful, simple tool to extract APCs from paper surface ECGs using PC-based software. The derived P-wave may be useful in estimating the localization of the origin of atrial activation.

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