12-lead ECG Delineation by Clinical Database

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ABSTRACT

Identifying characteristic points of 12-lead electrocardiograph (ECG) by computers is crucial to the development of computer assisted ECG interpreters, which are necessary for 12-lead ECG instruments as recommended by American College of Physicians and American Heart Association in 2003. However, most algorithms of ECG characteristic point detection are developed based on open accessed MIT/BIH arrhythmic database by one- or two-lead signal recording of 24-hour ECG monitoring holters instead of 12-lead ECG instruments. This is because the digital output of 12-lead ECG instruments was encrypted by ECG manufactures. In this study, we used a novel wavelet transform to delineate 12-lead ECG features including P wave, QRS complex, and T wave based on clinical used SCP-ECG by 12-lead ECG instruments, which were decoded by our previous research. The results indicated the following: (1) the average sensitivity of R wave is 99%,, the specificity is 99.9%; (2) the average sensitivity for J point is 97%,, the specificity is 99.9 %; (3) P wave and T wave can be delineated effectively with high sensitivity and specificity. It is believed that this type of more accurate assessment of national clinical 12-lead ECG data can facilitate more rapid development of 12-lead ECG interpreters made in Taiwan.

1: INTRODUCTIONS

The 12-lead ECG is a frequently used diagnostic tool in cardiac medicine. Most clinical diagnosis of 12-ECG is based on the morphology of ECG at limb leads and chest leads. Recent studies showed that the 12-lead ECG instruments equipped with computer-assisted interpreters can improve diagnostic errors [1-2]. In 2003, the American Heart Association and the American College of Physicians recommended the use of computer-assisted ECG interpreters for all 12-lead ECG instruments [3]. It is known that the detection of ECG characteristic points is the critical technology for the development of computer-assisted ECG interpreters. The real time algorithm, first developed by Pan and his associates [4], has been used to detect ECG features with traditional digital filtering technology. In 1995, Li and his associates [5] used a different approach and reported two major findings: (1) wavelet transform can be used to locate ECG characteristic points; (2) wavelet transform can have higher anti-noise ability in ECG processing than digital filters. Subsequently, many other studies on ECG feature detection using wavelet transform have adopted Li's theory to improve the ability to find ECG features [6-8]. Most of these researches [4-7] also used open accessed MIT/BIH ECG database [9] to develop their algorithms. Because the source of MIT/BIH database is from single- or two- lead 24-hour monitoring holters instead of 12-lead ECG, the morphology variability of ECG from the source of MIT/BIH ECG database is much less than real 12-lead ECG. To improve the problem of developing algorithms based on improper ECG source, we conducted this study to develop a more suitable algorithm of ECG feature detection using national clinical 12-lead SCP-ECG files which were decoded in our previous study [10]. In addition, this study also showed a new procedure that can improve the deficiency of wavelet transform on Q-point, J-point, T- and P- wave detection.

2: METHODS

The basic principle for detecting ECG characteristic points is that the coefficients of ECG wavelet transform at different scales can respond to specific locations of ECG features [5]. In this study, we used bior5.5 [11] as mother wavelet function and selected proper coefficients to delineate ECG features. The wavelet transform is shown by equation (1) and (2).

$$T_{m,n} = \int_{-\infty}^{\infty} ECG(t) * \Psi_{m,n}(t)dt \qquad (1)$$

$$\Psi_{m,n}(t) = \frac{1}{\sqrt{2^m}} \Psi\left(\frac{t - nb_0 2^m}{2^m}\right) \qquad (2)$$

Where $\Psi_{m,n}(t)$ represents mother wavelet function，$T_{m,n}$ represents coefficient of wavelet transform，m represents the scale of wavelet transform at frequency axis，nb_0 represents the shift at time axis。We used clinical SCP-ECG files of 12-lead ECG instruments to develop procedures of ECG feature detection. SCP, which is a standard for ECG communication protocol, was adopted by most European 12-lead ECG manufactures. The raw 12-lead

ECG signals were compressed at section 128 of SCP binary format. The bit-length, which was used to compress ECG, was decode in our previous study [10] shown in Table 1.

Table 1: Bit length for ECG signal compression in SCP-ECG files

Bit length	Negative values	Positive values
3	-2,-1	0,1
5	-4,-3	2,3
7	-12~-5	4~11
11	-140~-13	12~139
16	Below -141	Above 140

3: RESULTS

In the process of ECG delineation, R wave was identified at first, followed by Q and J points, T and P waves. In the procedure of R wave identification, the coefficients at scales 3 and 4 were selected and their multiplication was as the indicator of R wave. In Figure 1, the illustration of R wave identification was shown. The original ECG at lead V1 was shown at the top panel of Figure 1. The coefficients at scales 3 and 4 were shown at the second panel in Figure 1. The multiplication of coefficients at scales 3 and 4, as well as the multiplication above a pre-setting threshold selected as R wave indicator, were shown at the third panel. The exact location of R wave can be found at the neighborhood of the selected indicator. In Figure 1, the R wave can be identified correctly despite of baseline drift, which was commonly observed in ECG.

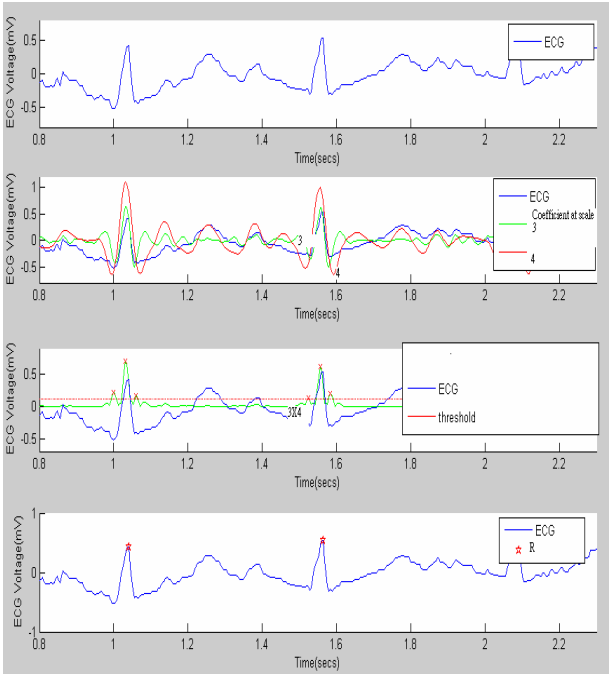

Figure 1: Illustration of R wave identification by lead V1 ECG with baseline wandering.

J point is much crucial than S point to clinical diagnosis of 12-lead ECG. It should be the first reflective point after S in normal ECG. We detected the J point instead of S point. The J point was determined at the third peak coefficient at scale 3 after R wave. The Q point was located at the coefficient with crossing zero value before R wave. In Figure 2A, a noise interfered ECG and its coefficient at scale 3 of wavelet were shown. The detection of Q and J points were indicated in Figure 2B.

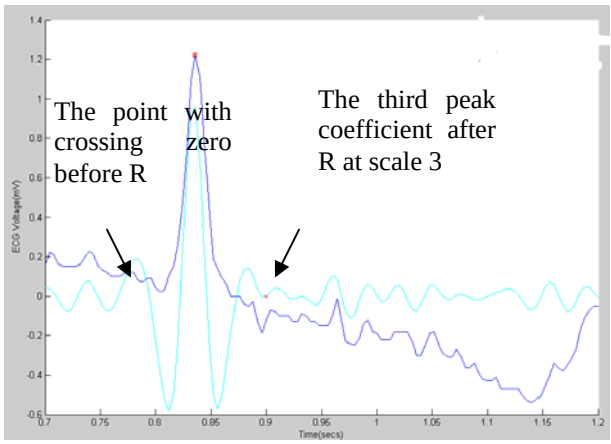

Figure 2A: Illustration of Q and J points detection by the coefficient at scale 3.

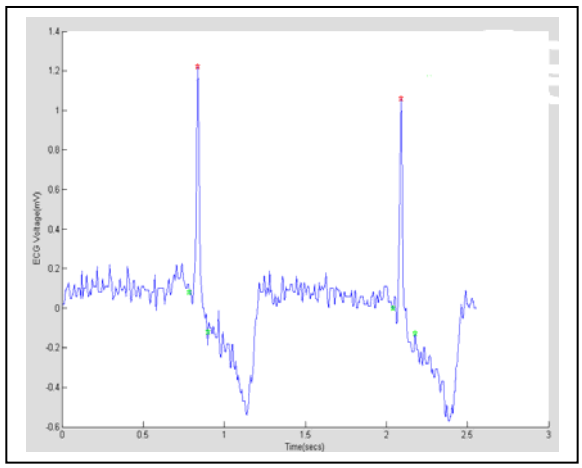

Figure 2B: Q and J point detection in lead V4 ECG.

By the multiplication of coefficients at scales 4 and 5, the peak of T wave (Tpeak) was determined by the absolute peak coefficient at scale 4, which was nearest to the multiplication. Once the T peak was located, the starting point of T (Ton) and the end point of T wave (Tend) were determined. The Ton was located on the right side of Tpeak and responded to the absolute peak coefficient at scale 5. Ton was found on the left side of T peak with the first coefficient crossing zero value at scale 4. In Figure 3, a standard 2.3 sec V4 lead in 12-lead ECG was shown. The T wave in Figure 3 was

inverted due to acute myocardial infarction and the T wave was interfered by relative high frequency noise. The T wave was delineated by identifying the locations of Ton, Tpeak, and Tend.

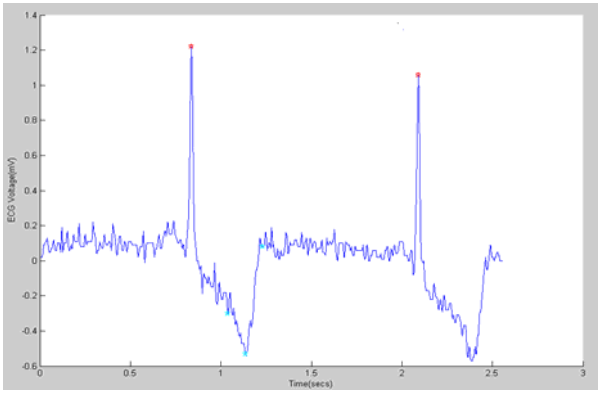

Figure 3 T wave delineation by the example of acute myocardial infarction.

By finding the peak of P wave (Ppeak), the end point of P wave (Pend), and the starting point of P wave (Pon), the P wave can be delineated. The Ppeak was determined by the absolute peak of the first derivate of coefficients at scale 4. The Pend was located on the right side of Ppeak with the crossing zero values at scale 4. The Pon can be found on the left side of Ppeak with the second crossing zero value at scale 4. In Figure 4A, the coefficients and the first derivative of coefficient of lead II ECG at scale 4 were shown. In Figure 4B, the delineated P wave was located by the proposed procedures as shown in Figure 4A.

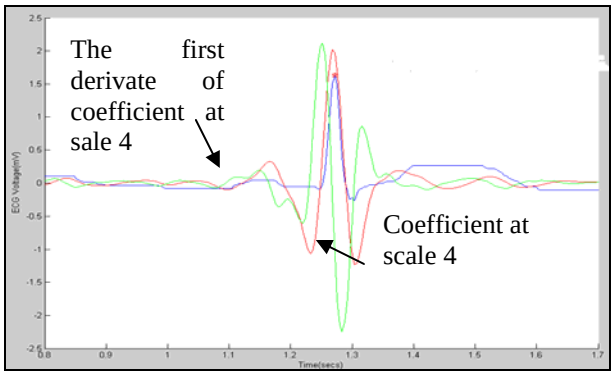

Figure 4A: The first derivate of coefficient at scale 4 was used to indicated the peak of P wave.

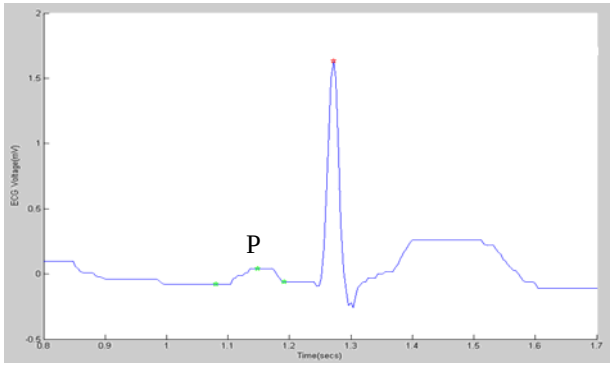

Figure 4B: P wave delineation by normal lead II ECG.

4: CONCLUSIONS

As shown in Tables 2A to 2E, this study showed that the sensitivity and specificity of ECG feature detection are high, especially on Q, J, T, and P detection as compared to other studies [5-7]. This study adopted three categories, including acute myocardial infarction (AMI), hyperkalemia, and normal ECG. The average sensitivity of R wave in these three categories is above 99%, and its average specificity is above 99.9%, as shown in Table 2A. As shown in Table 2B, the average sensitivity of Q point is about 97%, and its specificity is about 99.9%. The average sensitivity of J is about 97%, and its specificity is about 99.9%. The results showed that our study improved the accuracy of P and T wave feature detection as compared to Li's report [5]. With the methods proposed in this study, the asymmetric T wave and P wave can be detected more effectively. The sensitivity and specificity of P and T waves are shown in Tables 2D and 2E. In conclusion, we recommend the use of this type of more accurate assessment of national clinical 12-lead ECG data, which can facilitate more rapid development of 12-lead ECG interpreters made in Taiwan,

Table 2A Accuracy of R wave detection

	Sensitivity	Specificity (total=[Q]+[J]+[P]+[T])
AMI	(547/556)=98.4 %	(1961/1963)=99%
Hyper-kalemia	(879/889)=98.9 %	(3014/3014)=100%
normal	(364/364)=100 %	(1439/1439)=100%

Table 2B Accuracy of Q wave detection

	Sensitivity	Specificity (total=[R]+[J]+[P]+[T])
AMI	(536/556)=96.4 %	(1963/1963)=100%

Hyper-kalemia	(857/889)=96.4%	(3003/3014)=99%
normal	(360/364)=98.9%	(1349/1349)=100%

Table 2C Accuracy of J wave detection

	Sensitivity	Specificity (total=[R]+[Q]+[P]+[T])
AMI	(538/556)=96.7%	(1963/1963)=100%
Hyper-kalemia	(873/889)=98.2%	(3014/3014)=100%
normal	(351/364)=96.4%	(1349/1349)=100%

Table 2D Accuracy of T wave detection

		Sensitivity	Specificity (total=[R]+[Q]+[j]+[P*3]+[T*2])
AMI	T on	(463/500)=92.6%	(3489/3499)=99%
	T peak	(452/500)=91%	(3484/3499)=99%
	T end	(459/500)=91.8%	(3489/3499)=99%
Hyper-kalemia	T on	(773/806)=96%	(5564/5569)=99%
	T peak	(761/806)=94%	(5554/5569)=99%
	T end	(767/806)=95%	(5545/5569)=99%
normal	T on	(357/364)=98%	(2860/2861)=99%
	Tpeak	(356/364)=97.5%	(2853/2861)=99%

Table 2E Accuracy of P wave detection

		Sensitivity	Specificity (total=[R]+[Q]+[j]+[P*2]+[T*3])
AMI	P on	(318/351)=90.5%	(3866/3870)=99%
	P peak	(319/351)=90.8%	(3868/3870)=99%
	P end	(313/351)=89%	(3864/3870)=99%
Hyper-kalemia	P on	(386/430)=89.7%	(5944/5945)=99%
	P peak	(394/430)=91.6%	(5944/5945)=99%
	P end	(387/430)=90%	(5942/5945)=99%
normal	P on	(325/347)=93.3%	(2878/2878)=100%
	P peak	(325/347)=94%	(2878/2878)=100%
	P end	(323/347)=93%	(2877/2878)=99%

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