

COMPARISON OF TWO METHODS FOR REMOVING BASELINE WANDER IN THE ECG

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Abstract

The purpose of this study was to compare the cubic spline method with a multi-pole, null-phase digital filters in their ability to correct for baseline wander on 69 ECG segments with both normal and abnormal rhythms. A single-pole 0.05 Hz filter as recommended by the 1975 AHA Report was also included in this study for comparison. A null-phase, 6-pole filter with a cut-off between 0.75 and 1.0 Hz can attenuate low frequency noise (i.e. correct baseline) as well as the cubic spline. However, such a filter will introduce minor changes in the original signal, especially in the presence of a long RR interval. The cubic spline is very dependent upon an accurate determination of QRS onset. The single-pole, 0.05 Hz filter does very little to attenuate low frequency noise.

Introduction

In order to suppress the effects of noise, esp. muscle noise, many digital ECG algorithms use a representative PQRS complex epitomized from a statistical combination (mean, mode, etc.) of many beats. A major difficulty with such algorithms is that baseline wander can produce artefactual ST displacements, leading to false diagnoses of ischemia or injury. Some electrocardiographs attempt to suppress baseline wander with high pass filters which introduce phase nonlinearities and consequent ST displacements. By applying a digital filter to the data forwards and backwards, one can eliminate these phase nonlinearities.

A different method of baseline correction, which is widely used, involves estimating the baseline with a cubic spline and subtracting it from the raw ECG signal. The purpose of this study was to compare the cubic spline method with multi-pole, null-phase digital filters in their ability to correct for baseline wander. A single-pole 0.05 Hz filter as

recommended by the 1975 AHA Report was also included in this study for comparison.

Materials and Materials

The raw ECG data consisted of 3-channel ECGs - 5 seconds of each of the 12-Standard leads and 10 seconds of XYZ leads, digitized at 250 12-bit samples per second per lead. The raw data were first filtered to suppress high frequency noise and low frequency baseline wander, thereby producing "clean" ECGs. These ECGs contained 3 cases of atrial fibrillation, one of which also had multifocal PVCs, and 1 normal sinus rhythm with LVH and T wave changes.

An artificial baseline wander was constructed using a combination of sine and cosine waves at 0.30 and 0.25 Hz, respectively, typical of respiratory frequencies; the amplitudes of the sine and cosine waves were fixed at 250 and 200 microvolts respectively. Thus the root mean square value (RMS) of this low frequency noise was about 320 microvolts. This artificial baseline wander or low frequency noise was then added to the "clean" ECG signal to form the test data.

Baseline correction methods including the cubic spline and various high pass filters were applied to the test data to form "restored" ECGs. A measure of the total residual difference after applying the correction method was the root mean square difference (RMSD) of the restored ECG minus the clean ECG.

Some of the total residual difference was made up of minor changes of the clean data by the baseline correction method itself. Hence, the baseline correction method was also applied to the clean ECG and the resulting minor changes were measured as root mean square values (RMSV). This RMSV was subtracted from total residual RMSD in order to estimate the root mean square error (RMSE) of the low frequency noise which the baseline correction method passed.

These methods were applied to each lead of the 12 standard leads and to 5 second

T A B L E 1

Hertz	Single-pole 0.05	F I L T E R S				CUBIC SPLINE ---
		Null-phase, 0.50	6-pole 0.75	1.00	1.20	
Total Residual Difference (RMSD)	297.1	129.3	75.4	61.1	58.4	23.5
Minor Change (RMSV)	22.8	34.1	38.8	43.5	47.8	0.0
LF Noise Passed (RMSE)	274.3	95.2	36.6	17.6	10.6	23.5
LF Noise Passed (%) (100 X RMSE/RMS) *	85.7	29.7	11.4	5.5	3.3	7.3
* RMS of total added LF Noise = 320.2 microvolts						

sequential segments of each of the XYZ leads. Three ECG segments were excluded because of multiple spike artifacts; thus a total of 69 segments were extracted from four ECGs.

Results

Figure 1 shows clean ECG data (lead V5) in a case with atrial fibrillation and PVCs. (The ordinate is in millivolts and the abscissa is in sample points with 1250 samples = 5 seconds of data). Figure 2 shows the test ECG data with the low frequency noise (baseline wander) added. Figure 3 shows application of the null-phase, 6-pole, 1.0 Hz filter to the test data. Figure 4 shows application of

the cubic spline correction to the test data. Figure 5 shows the result of applying the single-pole, 0.05 Hz high pass filter to the test data. Figure 6 shows the time course of the artificial noise and the time course of the residual noise after application of the baseline correction methods in Figures 3, 4, and 5.

Table 1 shows the total residual RMSD, the minor change RMSV, and the RMSE and percent of low frequency noise passed for each correction method. The methods include: the single-pole 0.05 Hz high pass filter; null-phase, 6-pole filters at 0.5, 0.75, 1.0, and 1.2 Hz; and the cubic spline. The results in Table 1 represent mean values over 69 ECG segments.

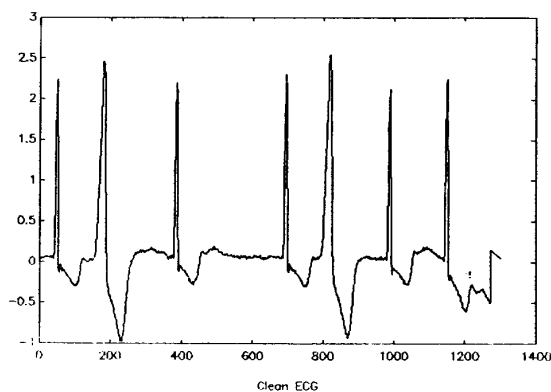


FIGURE 1

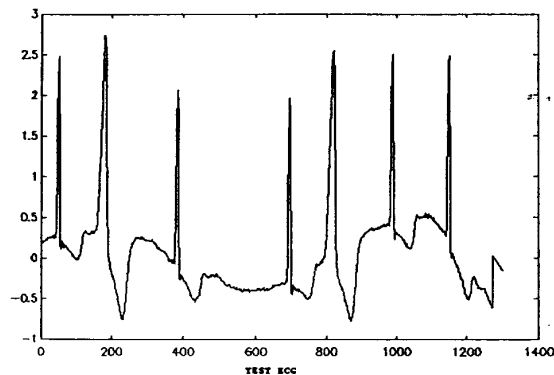


FIGURE 2

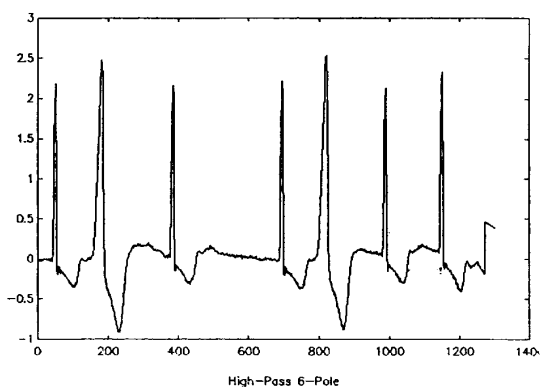


FIGURE 3

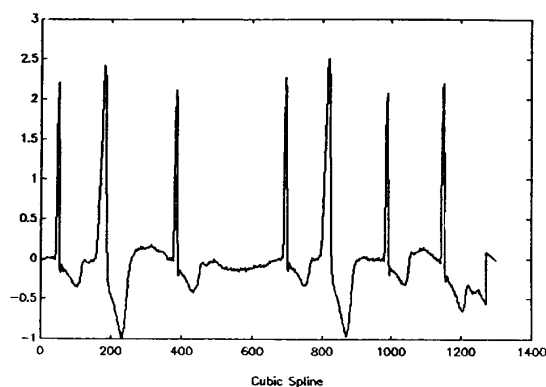


FIGURE 4

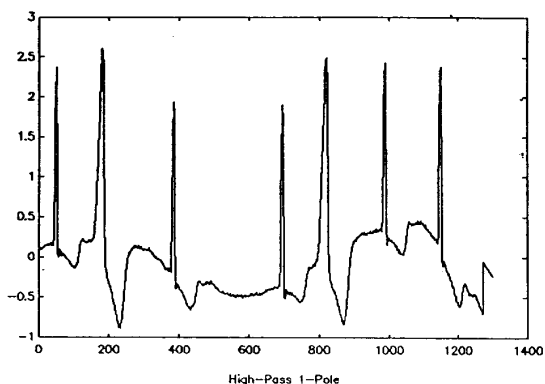


FIGURE 5

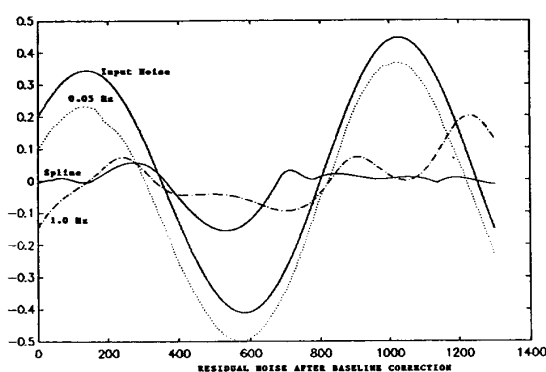


FIGURE 6

Discussion

The cubic spline method represents a nonlinear, adaptive filter for which a definite spectral diagram cannot be drawn; it depends upon a reliable method of estimating baseline points. It is assumed that the best estimator is a point just before the QRS onset, but this assumption may break down in some circumstances, such as PVC on T. Furthermore, determination of QRS waves may be confounded by the presence of spike artifacts.

The null-phase, 6-pole filter does not depend upon these assumptions. However, it is possible that one might wish to optimize the cut-off level for a given heart rate, which would require only simple QRS detection. The minor changes in the clean ECG introduced by the digital

filters occur in the instance of wide RR intervals, resulting in a small part of the signal having some power in the region of the cut-off or below. Clearly raising the cut-off will increase this power as can be seen in Table 1. Nevertheless, on visual inspection these changes do not appear to affect baseline or ST segments significantly.

The null-phase filters and the cubic spline method produce restored tracings which look very similar as shown by comparing Figure 3 with Figure 4. The single-pole, 0.05 Hz filter does very little to attenuate low frequency noise as shown by the example in Figures 2, 5, and 6 and by the average over 69 ECG segments as shown in Table 1; the null-phase, multi-pole filters and the cubic spline perform much better.

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