Novel Method of Automatic Auscultation for Blood Pressure Measurement Using Pulses in Cuff Pressure and Korotkoff Sound

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Abstract

In the NIBP (Non-Invasive Blood Pressure) measurement, we need well trained observer and there are differences in reading values between observers. We suggest new automated auscultation algorithms to select the proper epoch of K-sound for each heart beat. The sound for each epoch is converted into frequency domain and total power was calculated. We decided SBP(Systolic Blood Pressure) point when there was abrupt jump from the baseline. DBP (Diastolic blood pressure) was decided when there was the biggest drop in total power of successive beats. For the validation of our suggested method, human observer assessed SBP/DBP according to EHS (European Hypertension Society) recommendation. The mean differences between the automatic method and traditional auscultation method were 2.0 mmHg for SBP and 3.1 mmHg for DBP. We also took the paired t-test with the two results, and there was no statistically significant difference between these two methods.

1. Introduction

In clinics and home, there are many kinds of the automatic BP (Blood Pressure) measurement devices. The gold standard of NIBP is the auscultation method by human observer. To validate the accuracy of automatic BP measurement device, one has to compare its measurement value with the assessed value by well trained human observer [1]. Regardless of its scientific background, the good BP device should give similar values with auscultation method using K-sound. This study is the implementation result of the automatic assessment of SBP and DBP from the K-sound which is recorded during sphygmomanometery.

There have been some methods for automatic assessment of K-sound [2, 3]. Most of the algorithms use power spectrum analysis technique to detect appearance and disappearance of K-sound. For this purpose, to select proper time epoch of heart beat is critical. Tango®+ [4] utilizes R peak timing from electrocardiogram for selection of systolic period of each heart beat. This system needs additional device which can supply the timing of R peak. In this study, we suggest new technique to detect systolic period using the cuff pressure waveform analysis.

2. Methods

2.1. Measurement and playback system

As all the other system for automated K-sound BP measurement device, the cuff and microphone is placed around the brachial artery as shown in figure 1. In our system, piezoelectric type microphone (TSD 108, BIOPAC Co. Ltd., USA), air pressure sensor, amplifier and analog-to-digital converter (BIOPAC Co. Ltd., USA) are used. The size of the cuff is 16cm x 30cm. The cuff is inflated enough to block the artery and deflated with the speed of 2~3mmHg/second. The sound wave from the microphone and cuff pressure wave are digitized at the sampling rate of 1000 Hz.

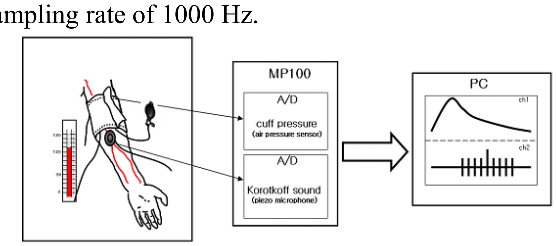

Figure 1. Measurement system configuration

The subjects were between 22 to 32 years old, who have no experience of cardiovascular disease. For each subject, 10 times of measurement were done from the early in the morning and late in the night to achieve various data.

After recording two signals, the manual assessment was done with the custom-made playback software. Using the sound card and headphone in PC, the observer can play back the recorded Sphygmomanometry as shown in figure 2. The observer followed the guidelines of EHS. In playing back software, when the observer feels uncertainty, he/she can listen to the sound repeatedly. The manually assessed values are used as reference values those are compared with automatically assessed SBP and DBP values.

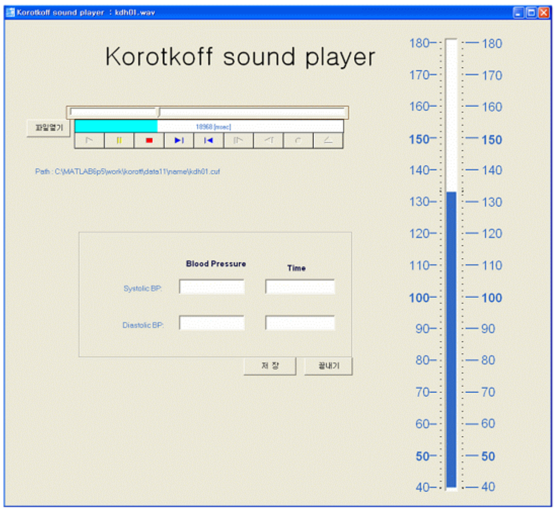

Figure 2. The playback software for recorded sphygmomanometry. When the observer press play button, PC plays the recorded sound and show the pressure value as bar graph.

2.2. Signal processing for automatic assessment of SBP and DBP

The major part of the algorithm is to detect the appearance/disappearance timing of K-sound while deflating cuff slowly. The major flow of algorithm is shown in figure 3.

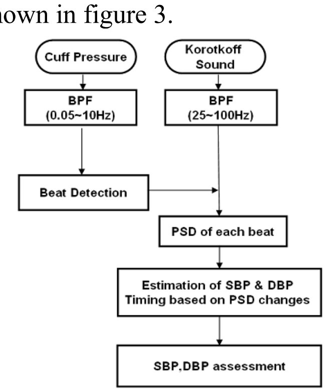

Figure 3. Flow of signal processing to assess SBP/DBP automatically.

At first, the sound wave should be segmented into each epoch for the algorithm to recognize whether there is K-sound or not. For this purpose, we applied band pass filter to cuff pressure signal (6^{th} order butterworth filter, the pass band 0.05~10Hz). Then the small oscillation can be detected as shown in the second row of figure 4. After localize the peaks, we selected time epoch of systolic period for each beat, where we will do spectral analysis for sound signal.

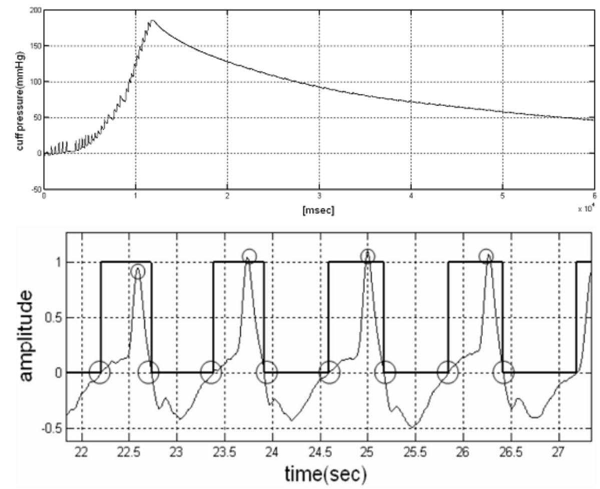

Figure 4. Cuff pressure analysis to select systolic period. Upper plot is typical cuff pressure, the lower graph is the band pass filtered signal to localize systolic period between zero crossings.

The circles in upper graph in figure 5 represents the systolic periods. Even though K-sound exists between SBP and DBP, the oscillometric component in cuff pressure exists from higher pressure than SBP to lower pressure than DBP. From these series of systolic epochs, the epoch when the K-sound appears means that the cuff pressure is SBP. The epoch when the K-sound disappears means that the cuff pressure is DBP.

In normal case, there are 30 to 40 systolic epochs. It depends on the deflating speed and heart rate. After collecting systolic periods, the sound wave was filtered with 8^{th} order chebychev filter between 25 and 100 Hz where most of the energy in the K-sound exists. After filtering, the total power values are calculated to assess whether there is audible K-sound or not. The figure 5 shows one example. When there was no audible sound, the total power spectrum value is very low. When the phase 1 begins, the observer can start to hear the K-sound and the total power has higher value than the previous systolic epoch. For DBP, from 24^{th} beat, the power is decreased a lot as shown in figure 5.

Figure 6 shows total power of 40 beats while deflating the cuff. Even though one can figure out clearly whether the power is higher than the lower values, we need robust algorithm to recognize the K-sound appearance and disappearance point. For this purpose, we applied the algorithm to find the maximum different beat as equation 1. P_i means the total power of i-th beat, M is the index of maximal power beat, P_S (P_D) means beat for SBP (DBP).

$$P_S = Max\,[\,|\log P_i - \log P_{i-1}|\,],\ i < M$$
$$P_D = Max[\,|\log P_i - \log P_{i+1}|\,],\ i < M \quad (1)$$

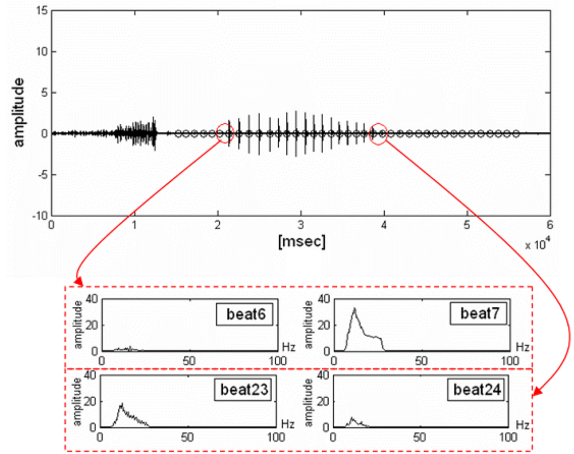

Figure 5. Analysis of sound wave, Circles in upper curves means the series systolic periods while deflating. The four power spectrum wave shows the appearance and disappearance of the K-sound.

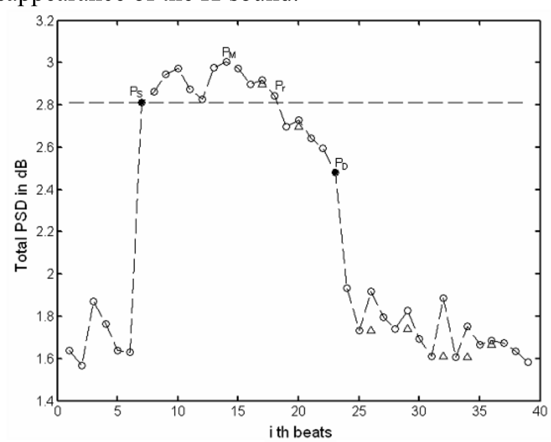

Figure 6. Series of total power of systolic periods for 40 beats while deflating the cuff. SBP is recognized as the maximal increasing beat of power from previous beat. DBP is recognized as maximal decreasing beat.

After selecting beats for SBP (DBP), by finding the cuff pressure of beat for SBP (DBP), the algorithm can assess SBP (DBP). This procedure was shown in figure 7. By comparing the values from automatic analysis with the manually assessed values, we checked the accuracy of the suggested algorithm.

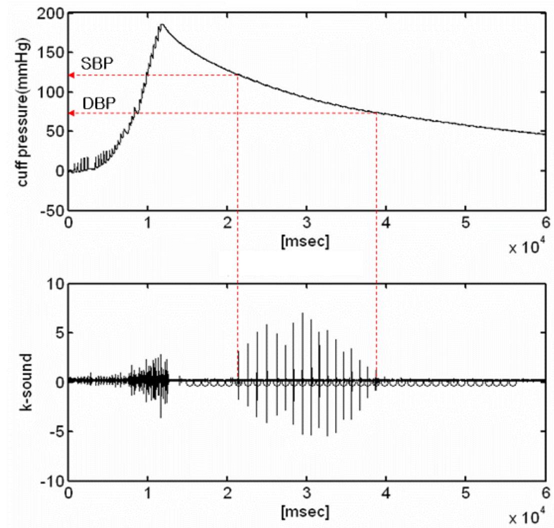

Figure 7. Assessment of SBP and DBP based on the K-sound analysis.

3. Results

Figure 8 and figure 9 show bland-Altman plot [5] of the comparison result. 'A' means conventional assessment method of NIBP measurement using K-sound. 'B' means automatic assessment method in this study. 90% of data are located in | A – B | < 5mmHg, 97% of data is in the range of | A – B | < 10mmHg for SBP assessment. For DBP, 86% and 93% are located in ±5, ±10mmHg respectively.

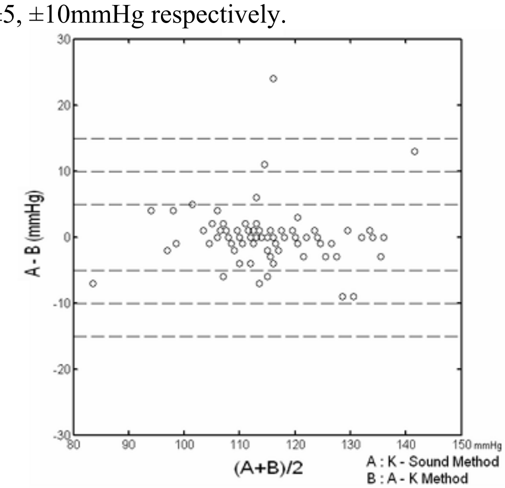

Figure 8. Bland-Altman plot of SBP between conventional method and automated method.

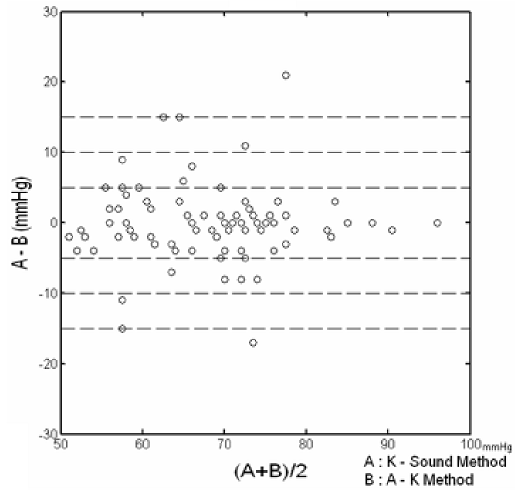

Figure 9. Bland-Altman plot of DBP

Table 1 shows the difference of each measurement in the form of mean and standard deviation. In the table, 'K sound' represents for conventional method and 'Auto K' means suggested method. According to this result, the suggested algorithm shows the higher performance in SBP than in DBP.

Table 1. The difference between conventional auscultation method and automated assessment method of K-sound.

	| K Sound – Auto K. |	
	mean	sd
SBP	2.03mmHg	3.29 mmHg
DBP	3.12 mmHg	3.98 mmHg

To check the significance of the statement that the suggested method is compatible with the conventional method, we performed paired t-test. According to the result in table 2, the suggested assessment method is not different from the conventional method significantly.

Table 2. Accuracy estimation of automated BP assessment using paired t-test.

	K Sound	Auto K.	p-value
	mean±sd	mean±sd	
SBP	114.82±9.32	114.71±9.37	P<0.778
DBP	67.57±9.32	67.77±9.34	P<0.695

4. Discussion and conclusions

In this paper new automated assessment method is suggested to measure SBP and DBP using the K-sound. In standard auscultation method to measure BP, the influence by the noise of environment and inter/intra observer variability of assessment are disadvantages. To develop automated assessment algorithm is useful for accurate and consistent measurement. In new algorithm, the valid epoch of sound is segmented based on the systolic oscillation of cuff pressure. The decision of appearance and disappearance of K-sound was made using the total power of these systolic epochs. The comparison between new method and conventional method shows these two methods are not different.

For further study, the accuracy in DBP should be enhanced. In this study, we considered only the total power of the sound. In phase 4 and 5, there seems to be some spectral changes. By analyzing the spectra, we expect to increase the accuracy in DBP. Also the critical validation shall be done according to the guidelines from EHS [1].

Acknowledgements

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