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Cuffless and Noninvasive Tonometry Mean Arterial Pressure Measurement by Physiological Characteristics and Applied Pressure

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***Abstract*— We developed a cuffless and noninvasive measurement technique of blood pressure using tonometric pressure sensor. With observation that the maximum value of a pulse pressure is not obtained at mean arterial pressure (MAP), we have figured out MAP based on the physiological characteristic including the elasticity of wrist tissue, the depth of blood vessel.**

Through an analysis of 198 clinic data, we have induced the regression equation of the MAP. The probability of the elasticity, depth and AP_M to explain MAP was 92.1%. The mean difference and the standard deviation between the MAP predicted from the regression equation and the MAP measured by commercial cuff type BP meter were -3.183 mmHg and 5.133 mmHg respectively. Comparing the results with the American National Standard for Electronic or Automated Sphygmomanometers, we can conclude that the results are quite reliable and promising.

Detecting only one part of the body and using only one device are quite advantageous over other BP measurement technique. Our technique makes new way for the cuffless BP measurement

I. INTRODUCTION

Blood pressure (BP) is a very important factor for detecting the state of patients who have a cardiovascular disease. The conventional noninvasive BP measurement using cuff is not appropriate for consistent patient care and monitoring. Figure 1 shows the general transit waveform characteristics of cuff pressure with superimposed Korotkoff (K) sounds and amplified cuff pressure oscillations. S_0 is the point at which cuff-pressure oscillations start to increase. A_S is the amplitude corresponding to auscultatory systolic blood pressure, and A_d is the amplitude corresponding to auscultatory diastolic blood pressure. A_m is the maximum oscillation amplitude that corresponds to mean blood pressure.

Recently, cuffless BP measurement techniques (based on pulse transit time [1], [2] and wavelet transform [3]) have been studied. Although the techniques have a potential capacity for predicting BP, they have a couple of drawback: the techniques have to measure multi-points of the body to predict BP and therefore patients could feel uncomfortable. Also, the conventional techniques need both the electrocardiogram (ECG) and the photoplethysmography (PPG) and consequently the accuracy of these techniques depends on that of two devices of ECG and PPG. Therefore, an improved technique which needs only one point of the body and one device is necessary. Recently, the tonometric method has been studied for BP measurement.

Theoretically, a pulse pressure should have a maximum value at MAP which is defined as the average blood pressure during a single cycle. However, the clinic data obtained through a wave analyzer using the tonometric method was not consistent with the theory: the max value of the pulse pressure was obtained at a pressure different from MAP. We predicted that the physiological characteristics including the elasticity of the wrist tissue and the depth of blood vessel would influence the difference between MAP and the applied pressure which has the maximum pulse pressure (AP_M) [4],[5]. The reason has not been clarified. With the reason, we can develop cuffless BP measurement using applied pressure on the radial artery. This study examines the relationship between the MAP and the AP_M based on our prediction about physiological characteristics.

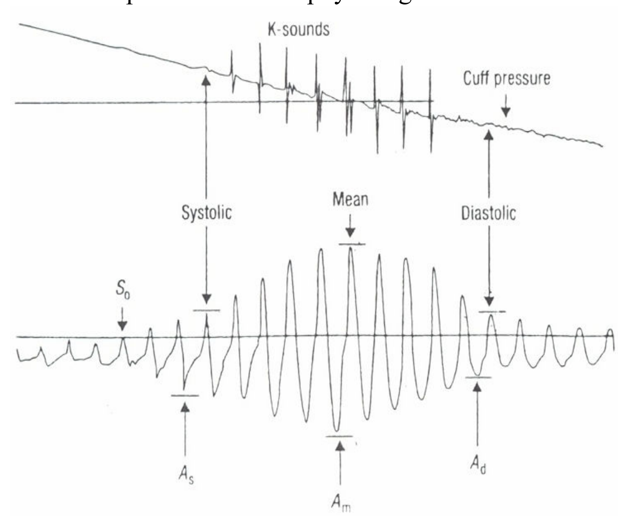


Fig. 1. The general transit waveform characteristics of cuff pressure with superimposed Korotkoff (K) sounds and amplified cuff pressure oscillations [6].

II. METHODOLOGY

A. Experiment for data collection

Forty-four healthy volunteers participated in this study.

TABLE I
NUMBER OF VOLUNTEERS RESPECT TO BMI, AGE AND SEX

BMI (kg/m^2)	20	20~24	24~30	30	
	5	20	18	1	
AGE (years)	20~30	30~40	40~50	50~60	60
	6	9	9	10	10
SEX	male		female		
	14		30		

First, systolic blood pressure (SBP) and diastolic blood pressure (DBP) were recorded on the left radial artery by commercial wrist type BP meter (OMRON R6, OMRON Corp.) with a cuff. We measured BP data five times for each volunteer and averaged it. With the average data, we calculated the mean arterial pressure (MAP), which was calculated by equation (1).

$$MAP = DBP + \frac{SBP - DBP}{3} \tag{1}$$

TABLE Ⅱ
MAXIMUM, MINIMUN, MEAN VALUES OF SBP, DBP AND MAP

	Max	Mean	Min
SBP(mmHg)	155	122.98	97
DBP(mmHg)	103	77.57	63
MAP(mmHg)	114.67	92.66	74.06

Figure 2 shows the box plot of SBP, DBP and MAP.

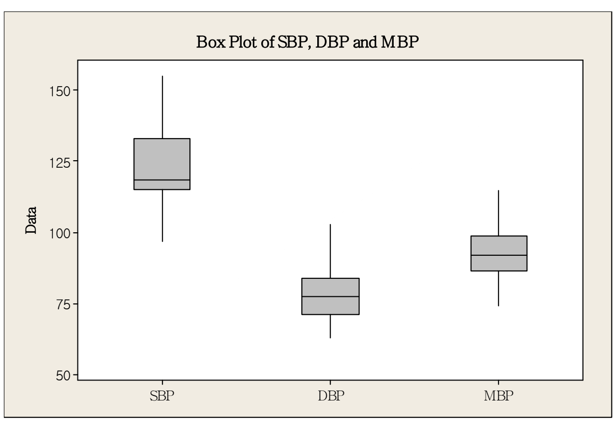


Fig. 2. Box Plot of SBP, DBP and MAP

Second, we applied pressure on the radial artery and recorded the pressure detected by 3-D MAC (DAEYOMEDI, Co., LTD.). As shown in Figure 3, 3-D MAC is a device detecting pressure on the radial artery with tonometric pressure sensor. It is operated by step motor and has a 3 axial robot finger moving front and rear, left and right, and up and down. The robot finger automatically scans the vessel in the arm and then records the pressure of the radial artery.

Fig. 3. Pulse pressure of radial artery measurement by 3-D MAC

We measured three regions (Figure 4) of the left radial artery of forty-four volunteers and three regions of the right radial artery of thirty-two volunteers. Therefore we could get 288 data and we used 198 data for regression line and 40 data for comparison between measured MAP and predicted MAP. And the measurement was done by five steps which were defined according to the applied pressure. We applied five different pressures on the same spot and we did these five steps for 6 different regions of each volunteer.

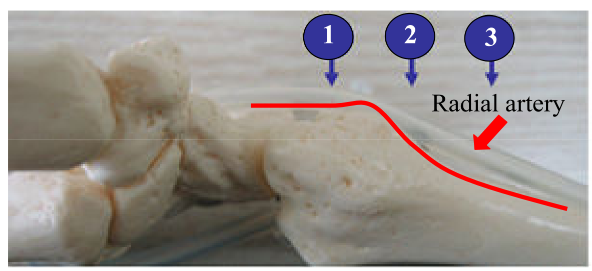


Fig. 4. Three regions (1, 2, 3) of radial artery measured in this study.

Figure 5 shows waveform of pulse pressure according to five steps. Five colors are used to index each step.

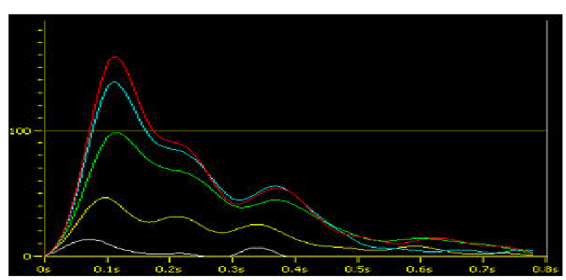


Fig. 5. Waveform of pulse pressure according to 5 steps. 5 colors are used to index each step.

After getting data, we draw the tendency graph and defined the pressure which had maximum amplitude of waveform as a maximum applied pressure (AP_M) as shown in Figure 6.

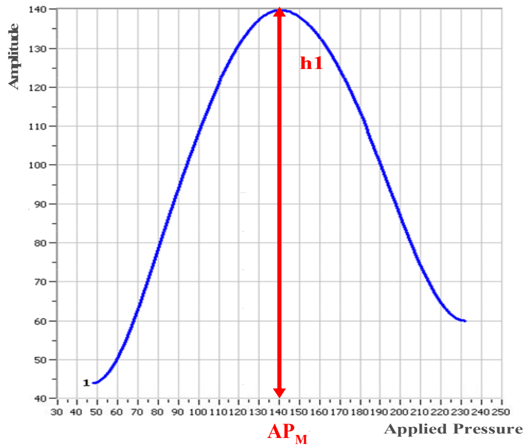


Fig. 6. Tendency Graph. h1 means the maximum value of pulse pressure and AP_M means the applied pressure at h1

.Figure 7 shows that the AP_M of six different regions of one person was not same. To find out the reason of the difference between MAP and AP_M, we extracted the depth information with which we could get the maximum value of the pulse pressure and the coefficient of elasticity of wrist tissue

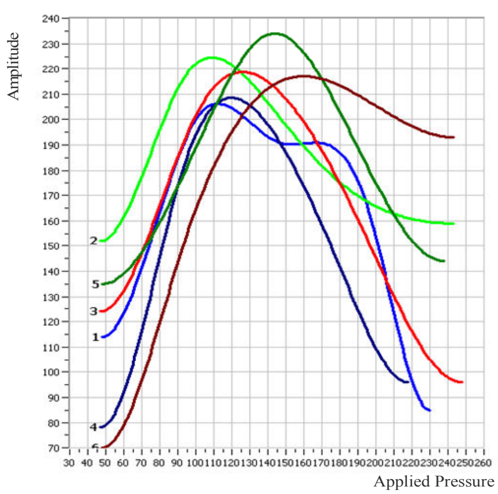


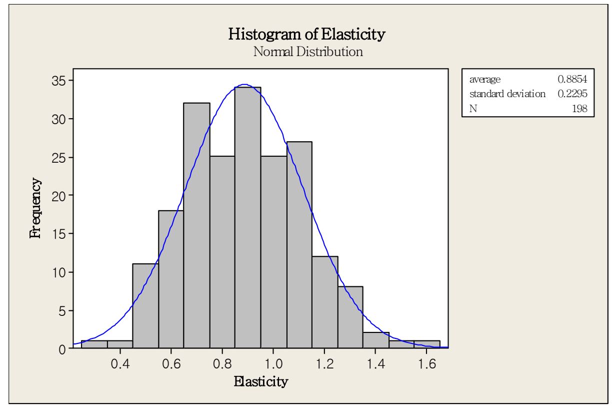
Fig. 7. Pulse pressure of 6 region of same person

B. Data analysis

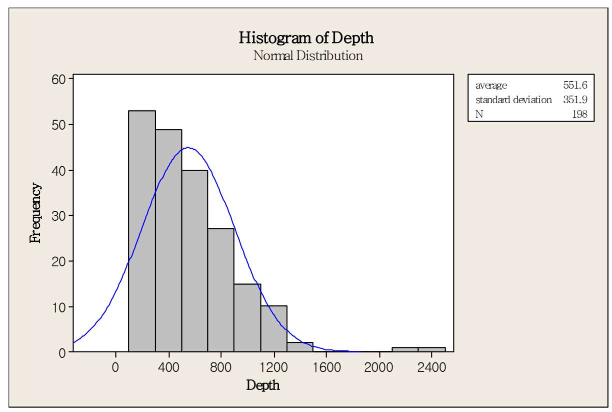
We used MINITAP 14 which is comprehensive statistical and graphical analysis software for data analysis. And MINITAP 14 is widely known for its comprehensive collection of methods, reliability, and unsurpassed ease-of-use. Therefore we decided analyze clinic data through MINITAP 14.

We draw tendency graph with five data to get the real AP_M.

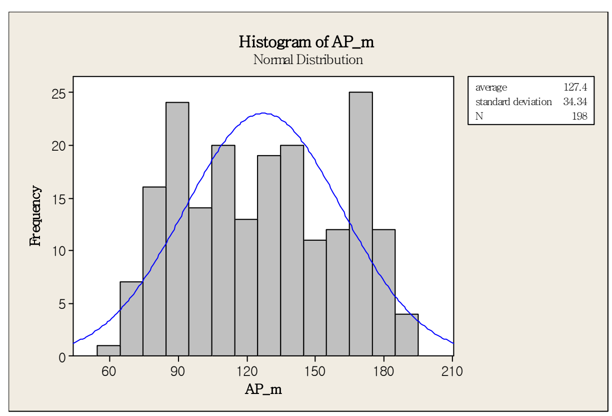
Figure 8 shows histogram of elasticity, depth of blood_vessel and AP_M. This histogram tells us that the collected data were normally distributed.



(a)



(b)



(c)

Fig. 8. Histogram of Elasticity, Depth and MAP
(a)Normal distribution of Elasticity (b) Normal distribution of Depth (c) Normal distribution of AP_M

III. Results

Using MINITAP to analyze 198 data, we got a regression equation (p = 0.00). Equation (2) shows the final regression equation.

$$MAP = 73.2 + 4.03 \times EC - 0.0078\,D + 0.169\,AP_M \quad (2)$$

where EC is defined as the elasticity of the wrist tissue and D is depth of the blood vessel. The probability of the elasticity, depth and AP_M to explain MAP was 92.1%.

Table Ⅲ shows that the comparison between the MAP measured by commercial wrist type cuff BP meter and the MAP predicted by the regression equation.

TABLE Ⅲ
COMPARING THE MEASURED AND PREDICTED MAP

Mean Difference (mmHg)	Standard Deviation (mmHg)
-3.183	5.133

According to the American National Standard for Electronic or Automated Sphygmomanometers, the mean difference (MD) should be ± 5mmHg or less with a standard deviation (SD) of 8mmHg or less [7]. Hence, the results of the MD and SD shown in table indicate that the MAP measurement through the regression equation is quite promising.

IV. Discussion

The MAP measurement technique based on the pressure of radial artery was developed. For further development, the elasticity of the wrist tissue, the depth of blood vessel should be measured more precisely. Also the influence of tension of blood vessel and stenosis of blood vessel should be considered.

We are in process of measuring the depth of blood vessel, tension of blood vessel and stenosis of blood vessel using different modalities. Using an artificial heart simulator, we made the pulse wave considerably similar that of human and this will be used to find out various influences of blood vessel on pulse wave.

Even though we succeeded in predicting MAP, we could not calculate the exact value of BP because the tonometric pressure sensor only gives waveform information but not an absolute value

Therefore appropriate calibration is needed to get the value of BP. Conventional calibration methods, however, use cuff to calibrate information in the waveform [8]. Because our objective is to get the values of BP with only tonometric pressure sensors and because BP measurement using cuff is not appropriate for the continuous BP monitoring, we will make a new calibration method not using cuff. We plan experiments for the new calibration on the basis of characteristic of wrist tissue and tension of blood vessel.

And to get a more precise regression equation, nonlinear factors of the regression equation should be derived too.

V. Conclusion

We developed cuffless BP measurement technique. Preliminary results suggest that the regression equation obtained though this technique is quite promising and reliable. Detecting only one part of the body and using only one device are quite advantageous over other BP measurement technique. Our technique makes new way for the cuffless BP measurement.

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