Improvement of the Accuracy of Wrist Noninvasive Blood Pressure Measurement Using Multiple Bio-signals

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Abstract - The blood pressure measuring equipment, which is being supplied and used most widely by being recognized convenience and accuracy now generally, is oscillometric blood pressure monitor. However, a change in blood pressure is basically influenced by diverse elements such as each individual's physiological status and physical condition. Thus, the measurement of blood pressure, which used single element called oscillation in blood pressure of being conveyed to cuff, is not considered on physiological elements such as cardiovascular system status and blood vessel stiffness index, and on external elements, thereby being quite in error. Accordingly, this study detected diverse bio-signals and body informations in each individual as the measurement subject such as ECG, PPG, and Korotkoff Sound in order to enhance convenience and accuracy of measuring blood pressure in the complex measurement equipment, thereby having extracted regression method for compensation in error of oscillometric blood pressure measurement on the wrist, and having improved accuracy of measuring blood pressure. To verify a method of improving accuracy, the blood pressure value in each of SBP, DBP, MAP was acquired through 4-stage experimental procedure targeting totally 51 subjects. Prior to experiment, the subjects were divided into two groups such as the experimental group for extracting regression method and the control group for verifying regression method. Its error was analyzed by comparing the reference blood pressure value, which was obtained through the auscultatory method, and the oscillometric blood pressure value on the wrist. To reduce the detected error, the blood pressure compensation regression method was calculated through multiple linear regression analysis on elements of blood pressure, individual body information, PTT, HR, K-Sound PSD change. Verification was carried out on improving significance and accuracy by applying the regression method to the data of control group. In the experimental results, as a result of confirming error on the reference blood pressure value in SBP, DBP, and MAP, which were acquired through applying regression method, the results of -0.47 ± 7.45 mmHg, -0.23 ± 7.13 mmHg, 0.06 ± 6.39 mmHg could be obtained. This is not only the numerical value of satisfying the sphygmomanometer reference of AAMI, but also shows the lower result than the numerical value in SBP : -2.5 ± 12.2 mmHg, DBP : -7.5 ± 8.4 mmHg, which is the mean error in the experimental results of Brame's research for verifying accuracy of Omron RX-M, which shows relatively high accuracy among wrist sphygmomanometers. Thus, the blood pressure compensation could be confirmed to be made within significant level.

Key Words : Wrist NiBP, Auscultatory method, Multi parameter, BP Compensation, Vascular status

1. Introduction

With the development in modern society and the improvement in quality of life, an interest in health and medical care increases in the whole society. Thus, the changes for offering preventive medical service are being shown in order to early detect and prevent a disease in daily life such as home, school, and company, with

escaping from just curing disease. In addition to this, even the monitoring equipments were developed from health monitoring through measuring single parameter, thereby being developed into the complex measurement equipment available for synthetic diagnosis, which is more accurate and has high reliability, through multiple element detection. However, in the face of a partial change in medical service and environment, it is the tendency of being continuously increased the mortality caused by cardiovascular disease and the incidence of hypertension, which is potential risk factor of cardiovascular disease. the hypertension curing ratio is remaining in 20 % level of patients with incidence. Thus, necessity of continuous monitoring on blood pressure is being emphasized[1].

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According to the emphasis on necessity of monitoring blood pressure, diverse automated electronic blood pressure monitors were developed for measuring blood pressure. The majority of equipments use oscillometric method, which extracts blood pressure by analyzing blood flow oscillation that is vibration component of blood pressure cuff according to flow pulsation. However, oscillometric blood pressure monitor detects blood pressure by analyzing only one blood flow oscillation component. Thus, there is a problem about accuracy because of cuff size and failing to be considered on diverse physiological factors, which have influence upon the vessel stiffness(vascular status) and blood pressure of each subject[2].

Accordingly, this study detected the representing element of the vascular status through analyzing diverse bio-signals such as ECG(electrocardiogram), PPG(photoplethysmography), and blood flow oscillation, which are basic elements of measuring in the complex equipment such as patient monitoring system or complex measurement terminal in E-Health Care. In addition, diverse elements were detected that have influence upon blood pressure through measuring additional bio-signal such as korotkoff sound that is a factor of detecting the blood pressure by the auscultatory method, and an individual's body information. This was carried out multiple linear regression analysis. To secure universality in the aspect of a measurer's convenience and E-Health Care, a new method was suggested for improving the accuracy of measuring blood pressure on the wrist.

2. Main Subject

2.1 Problems about the existing electronic blood pressure monitors

According to the emphasis on importance of periodic blood pressure measurement, diverse methods were researched. However, the electronic blood pressure monitor, which is used mainly by being recognized convenience and accuracy in measurement, is oscillometric blood pressure monitor. As these of numerous oscillometric automated blood pressure monitors were developed, the standard for its accuracy was arranged. The typical standard includes AAMI(Association for the Advancement of Medical Instrumentation) and BHS(British Hypertension Society) protocol. In case of AAMI protocol, the specification is passed only when satisfying the mean error in under 5 mmHg and the standard deviation in under ± 8 mmHg in 85 % of the measurement scope in 20-250 mmHg[3]. In case of BHS protocol, the specification is satisfied only when being over grade B by dividing the accuracy grade into A~D[4].

Table 1 BHS Protocol

Grade	Absolute difference between standard and test device		
	≤ 5	≤ 10	≤ 15
A	60%	85%	95%
B	50%	75%	90%
C	40%	65%	85%
D	Worse than C		

Oscillometric blood pressure measurement doesn't measure blood pressure directly, thereby having error in measuring blood pressure. Its cause can be divided largely into two kinds such as the error in detecting the maximum peak of blood flow oscillation, and the non-consideration on physiological factor of having influence upon blood pressure. Oscillometric method detects SBP(systolic blood pressure) and DBP(diastolic blood pressure) through application in specific ratio with presuming that the pressure at the point of having the maximum amplitude possessed by blood flow oscillation as MAP(mean arterial pressure). However, the blood flow oscillation component has many cases that the point of being the maximum in amplitude is shown as plateau in a flat highland shape, not as one sharp point. Explicit definition is obscure on which point will be set for MAP within this pressure scope, thereby bringing about error in measurement[5]. Also, blood pressure is detected through analyzing single element called blood flow oscillation. Thus, diverse elements, which influence the vascular status and blood pressure, are not considered, resulting in the occurrence of considerable error in measuring blood pressure in patients with atherosclerosis, and in the elderly groups whose blood vessel elastic index drops. In case of using the fixed characteristic ratio, the measurement error in 10-15% is being clarified to likely occur[6]. Many equipments, which were produced by diverse companies, are satisfying the specification of AAMI or BHS, but are not the satisfactory level. Also, even the equipment, which fail to meet the clinical specification in grade A of BHS, reach lots of numbers.

Types of electronic blood pressure measurement without using oscillometric method include korotkoff sound method, PWV(pulse wave velocity) method, and finapres method ect. However, these blood pressure measurement methods have considerable errors in detecting blood pressure because they prescribing blood pressure as single element in sound, velocity, and time. Therefore, it is necessary that suggestion of new blood pressure measurement method in consideration of a change in physiological elements related to a change in blood pressure of the cardiovascular system status in each individual as a measurer.

2.2 The elements of influencing blood pressure

Blood pressure, which represents for the status of cardiovascular system, which is a Closed Loop form, is greatly influenced by diverse changes of cardiovascular system such as changes of physiological functions and vascular status. Among those things, the main elements are vessel peripheral resistance, heart rate, and stroke volume. A change of blood pressure results from a cardiac output, which is a volume of blood ejected from the heart pre minute, and from a change of vessel peripheral resistance. Normal blood pressure is maintained by the balanced relationship between cardiac output and blood vessel. Accordingly, being able to measure the cardiac output and the variation of vessel peripheral resistance as the equation(1), even the variation in blood pressure can be measured.

$$\text{Blood pressure} \propto \text{Cardiac output} \times \text{Peripheral vascular resistance} \quad (1)$$

The status of vascular system(vessel peripheral resistance, blood viscosity), which is the major element of influencing blood pressure, can be evaluated through analyzing PPG signal component, which is created by a change in blood around the peripheral vessels according the closed loop characteristic of cardiovascular system. Also, blood flow volume can be indicated as equation(2) by Hagen-Poiseuilles's Law(HPL)[7].

$$V = \frac{\pi r^4}{8\eta l} \Delta P \quad (2)$$

$$R = \frac{8\eta l}{\pi r^4} \quad (3)$$

Where equation(2) and (3), ΔP is the difference of pressure, r is the radius of tube, η is the viscosity of fluid, and l is the length of tube. Equation(2) can be expressed in the form of resistance like equation(3) by using relationship among pressure, volume, and resistance. Blood flow and vessel resistance can be known to be direct proportion and inverse proportion, respectively, to four squared of a radius in blood vessel. Therefore, these two variables will be more influenced by a change in diameter of vessel, rather than length in vessel, difference in pressure, or a change in viscosity. This change in diameter is considerably influenced by vessel peripheral resistance component. Also, fluid model, which flows in cylinder flexible tube, is expressed as equation(4) and (5). Equation(6) is called as Moen-Korteweg method, and is used in indicating PWV[8]. Where equation(4), (5), and (6), C_o is the wave velocity, h is the thickness of vessel wall, E is the elastic coefficient, r_1 is the inner radius of

vessel, r_2 is outer radius of vessel, p is the density of blood, Δp is the change of inner pressure, and Δr_2 is the change of outer radius.

$$\frac{\alpha^2 p}{\alpha z^2} = \frac{1}{(hE/2\alpha p)} \frac{\alpha^2 p}{\alpha t^2} = \frac{1}{C_o^2} \frac{\alpha^2 p}{\alpha t^2} \quad (4)$$

$$C_o = \sqrt{\frac{hE}{2r_1 p}} \quad (5)$$

$$E = \Delta P \left(\frac{r_2}{\Delta r_2} \right) \quad (6)$$

Based on this ground, a research was progressed on evaluating the vascular status by using PTT(pulse transit time) and PWV. Oxford research team suggested the result that PTT has inverse proportion to blood pressure as a result of comparatively researching with PTT by using finapres method, which is non-invasive blood-flow measurement method[9]. Also, even a research on evaluating vascular system by using the secondary differentiation of PPG signal is being progressed in diverse fields[10].

Even in addition to physiological internal mechanism, diverse factors exist that have influence upon blood pressure, such as measurement time and temperature, age, gender, and obesity level. Even among those things, age and obesity level seem to have direct connection with a change in blood pressure. In a change of blood pressure depending on to age, a case of systolic blood pressure increases according to a rise in age. A case of DBP shows a rise according to a rise in age, and then indicates again the reducing aspect before and after 50 years old[11]. Also, as obesity is already a risk factor of adult disease, it is involved in several diseases. Especially, it possesses very great weight along with age as a risk factor of hypertension[12]. Indexes of judging obesity include weight, BMI(body mass index), and total human body fluids measurement. Among these things, what is simple in a method and is used widely is BMI. As a method of someone's weight in relation to height, it shows very high correlation with the total body fat in a human body[13]. Also, even the judgment of obesity is also available through detecting body fat and lean body mass ratio by measuring body impedance.

2.3 Design of the measurement system

Fig. (1) is showing the system scheme of experiment for improving the accuracy of the wrist oscillometric blood pressure measurement. The measurement system can be divided into the reference blood pressure measurement equipment by auscultation, data acquisition hardware that made myself for measuring the wrist oscillometric blood pressure and multiple bio-signals, data

acquisition system for gathering and storing data, and data analysis equipment.

Fig. 1 Equipments of Measurement for Clinical Trials

2.3.1 Measurement of reference blood pressure value

The most accurate reference blood pressure measurement method is a direct method of inserting catheter into blood vessel. However, due to the aspect of risk and cost, this study measured the reference blood pressure by using the auscultatory method with the use of Mercury Sphygmomanometer, which is a gold standard of indirect blood pressure measurement, not direct measurement method. In case of auscultatory method, it is a method of relying upon a measurer's sense, thereby being existed errors in observation. These errors in observation is classified into the systematic error, which is interrupted listening to korotkoff sound by observer's lack of concentration and by instrumental insufficiency, the terminal digit preference, in which an observer selects the last-digit number of the measurement value as the number of being preferred, and the observer prejudice or bias of occurring, by which an observer predicts the measurement value based on the prior record of the measurement subject.

To minimize the above error, as for the reference blood pressure value measurement, mean data value of two measurement data was suggested as the reference blood pressure value as far as a case is concerned that the difference in data simultaneously measured by two observers satisfies the condition within 10mmHg, by which the trained observers according to the recommendation of SP10 in AAMI performs the auscultatory method simultaneously in the mutually closed status. Also, the data when over 90% of the whole data satisfies 5 mmHg scope was recognized as effective data. When difference in two measured blood pressure values deviate from the effective scope, the re-measurement was progressed after the passage of 5 minutes by considering the recovery time of the vascular system[3]. In the measurement of reference blood pressure value, three trained nurses, who belong to Won-ju Christian hospital, Yonsei University, performed a role of two observers and

one supervisor. To minimize systematic error by equipment, the efficiency of measurement was enhanced by using stethoscope(3M Littmann Cardiology III), which is available for simultaneous auscultation. To minimize inaccuracy of sphygmomanometer, Yamasu model.600 mercury sphygmomanometer was used.

2.3.2 Data acquisition

Fig. (2) indicates the whole scheme of data acquisition system. The data acquisition system can be divided into the data acquisition part, which is composed of sensor part for detecting bio-signals, and analog hardware for detecting the acquired data from sensor with electric signal, and into the data analysis part for analyzing the acquired data. The acquired signal through sensor was detected the desired bio-signals after passing through the primary data processing through analog hardware. The detected signal through hardware became ADC by Powerlab(ML880, AD Instrument, Australia) and was changed into a text form, thereby having been analyzed through Windows-based LabVIEW(LabVIEW 8.6, National Instrument, USA).

Fig. 2 Data Acquisition System

2.3.2.1 The hardware for data acquisition

The sensor part for acquiring data was composed of the blood pressure cuff for measuring blood pressure on the wrist, microphone for detecting korotkoff sound, hand-grip type electrode for detecting ECG, and sensor for detecting PPG. Hardware for electric conversion of data, which was obtained through sensor, is composed of NiBP, ECG and PPG measurement system according to each of measurement data. NiBP measurement system measured the wrist blood pressure and the oscillation signal by using wrist-type cuff. A change in korotkoff sound on the wrist was measured by making mike in the form of stethoscope. In the measurement of pressure signal, P-2000 501G pressure sensor was used. The transformation equation on pressure of voltage is as equation(7) that is extracted by the regression analysis of voltage and pressure. Through the secondary lowpass filtering in 10Hz of the signal, which was obtained

through pressure sensor, DC component, which was removed noise, was extracted. Through the primary highpass filtering in 0.5Hz and amplifying the signal, the blood flow oscillation component was detected. Equation(7) was detected by regression method about the relation of the pressure and voltage for P-2000 pressure sensor. Where equation(7), $Y(p)$ is pressure and $X(p)$ is voltage.

$$Y(p) = 94.31X(p) - 31.77 \quad (7)$$

In detecting korotkoff sound, the condenser microphone (CMS-58, BSE, Korea) was used that has broad frequency scope and flat frequency characteristic. A change of korotkoff sound was detected from radial artery, by making microphone in a form of stethoscope for acquire the clearer sound. Also, the influence of noise around was minimized by using and connecting shielding cable from microphone to hardware. To make division in signal clear by detecting signal of korotkoff sound in a sharp form, the bandpass filtering in 10-100 Hz was performed[14].

ECG measurement system was formed in order to be available for detecting ECG signal on both hands by making three electrodes of RA, LA, RL in a hand-grip form in order to increase convenience of measurement. Electrode, which was used in measuring signal, was used Cr2+ coated electrode that has good conductivity and is excellent in bio-compatibility. Analog hardware was designed in order to be available for the simultaneous measurement with body impedance. ECG signal was detected through differential amplification in the measured signal on both hands through electrode. To remove high-frequency noises and to eliminate baseline wandering, the secondary bandpass filtering was performed in order to have passband in 0.1-130 Hz. Through amplification, ECG signal in LEAD I was detected.

Also, Body-Impedance component was detected simultaneously with detecting ECG by sharing and using the measurement electrode of ECG and Bio-Impedance. The impedance measurement system minimized the impedance influence according to frequency by adopting Tetra Polar Electrode Method in constant current method easy for limitation to electric current, which is approved to the measurement subject[15]. Impedance inside a human body was measured by approving the constant current source in sine wave to a human body. The constant current, which is used at this time, needs to be within intensity and frequency scope, which doesn't cause response to any bio-tissue. Accordingly, the frequency in 50 kHz and the electric current in 500 uA were used, which belong to the scope of giving no harm to a human

body because of having no response to cell tissue, and which are the scope of being much used in measuring general Body-Impedance, in the relationship between stimulus strength and stimulus time.

Also, to measure PPG signal necessary for detecting PTT and PWV, the system was designed by referring to Webster's Pulse Oximeter System[16]. PPG sensor was used the sensor(oxi-pulse RA01, Hurev, Korea), which is composed of PD(photo detector) of having infrared LED(Light Emitting Diode) in 890nm wavelength and the response frequency centering on 900nm. The signal, which was detected by PD, extracted AC component in PPG by performing the secondary highpass filtering in 0.5 Hz and the secondary lowpass filtering in 20 Hz. The electric current, which is supplied to LED, was made consistent through LED drive. The amplification factor in the analog signal processing circuit was maintained consistently.

2.3.2.2 Data acquisition system

To acquire the bio-signals that is measured in module, Powerlab was used. Powerlab is available for simultaneous measurement, selective record, and storage on 16 channel, and is easy for changing the acquired data into text form, thereby being excellent in compatibility with the analysis program. In the experiment, the signals in ECG, Body Impedance, PPG AC, PPG DC, Pressure, Oscillation, and Korotkoff Sound were collected with 1000 samples/s. Fig. 3 shows the results of having collected data by using Chart 5, which is data acquisition software of Powerlab provided by AD Instrument company.

Fig. 3 Powerlab Chart 5 Data Acquisition Software

2.3.2.3 Data analysis software

The analysis of data, which was changed into a form of text through Powerlab, was performed by using LabVIEW 8.6. Fig. 4 is a flow chart of the analysis software for detecting data. In the analysis of blood pressure signal, the pressure at the maximum amplitude point in blood flow oscillation component was detected with MAP by using the maximum amplitude algorithm.

SBP and DBP were detected by reading pressure at the point of being detected when applying the characteristic ratio in 0.55, 0.82 to the maximum amplitude in each of blood flow oscillation. As for the analysis of korotkoff sound, a change of PSD(Power Spectrum Density) component in each beat section was extracted by classifying and performing FFT in korotkoff sound according to each beat of the heart. K_max(maximum point) was defined as the point that its size is maximum in a change of PSD. K_rip(rapidly increasing point) was defined as the time at the point that a rise in PSD is the biggest among data before K_max. K_rdp(rapidly decreasing point) was defined as the time at the point that reduction in PSD is the biggest among data after K_max. The time between each of points was defined as K_max-rip, K_rdp-max, K_rdp-rip. In detecting PTT, the time was detected between peak points in each signal by using ECG and PPG signal. In detecting peak of ECG, it was detected by highlighting the R-peak point through difference from the original signal by using median filtering. In case of PPG signal, the inflection point was detected at the peak through differentiation. Also, a case of signal that time between two peaks is over 1s was excluded by being judged to be error.

Fig. 4 Data Analysis Software Flow Chart

2.4 Experiment

2.4.1 The Subjects

The experiment was carried out targeting totally 51 adults(33 men, 18 women, age in 40.86 ± 24.642). Before experiment, all the subjects were educated simply on

experiment, and prepared the agreement of research participation. In selecting subjects, hypertension, cardiac disease, the appearance of chronic disease, and the appearance of smoking were confirmed and recorded through questionnaire before experiment. For inducing stability in blood flow and vascular status, the subjects were prohibited from food except water, smoking, and excessive exercise before 4 hours of experiment[17]. Also, the compensation regression equations were extracted and verified by dividing the whole experimental subjects into the experimental group with 36 people and the control group with 15 people.

Table 2 Personal Information Descriptive statistics

	Experimental Group				
	N	Mini mum	Maxi mum	Mean	Std. Dev
age	36	20.0	92.0	42.92	26.824
height	36	138.0	187.5	166.37	10.862
weight	36	39.8	98.8	66.08	16.388
arm length	36	59.0	81.6	73.19	5.405
arm circumference	36	20.0	35.1	26.70	4.075
Valid N(list)	36				

	Control Group				
	N	Mini mum	Maxi mum	Mean	Std. Dev
age	15	20.0	86.0	35.93	18.250
height	15	149.0	181.3	167.07	10.148
weight	15	44.6	91.7	70.77	15.752
arm length	15	65.0	81.5	73.88	5.517
arm circumference	15	20.2	31.7	27.73	3.061
Valid N(list)	15				

2.4.2 The Method

Prior to measurement, the agreement related to experiment was prepared by considering pain or uncomfortable, risk by the cuff pressure which may occur during the experimental process. Experimental subjects' basic personal matters and body information were measured and recorded. The subjects, who were completed the preparation for experiment, were asked to take a rest for 10 minutes with leaning on comfortably to sit down on the chair with attaching electrode and cuff for stability in the status of cardiovascular system. The use of cushion led to making it the same for the subject's heart height position and the blood-pressure cuff height position[18]. Also, both hands were positioned the electrode for measuring ECG and Body-Impedance. On the index finger of the left hand was positioned the nipper-type PPG sensor. The cuff for measuring the reference blood pressure was positioned on the brachial of the left arm. On the wrist of the right arm was positioned the wrist cuff and microphone for measuring the wrist blood pressure. The whole experimental process was progressed as Fig. 5. The experimental subjects

were maintained the comfortable condition. Thus, a sudden change in blood pressure was minimized. When the inducement of stable condition through taking a rest for 10 minutes was finished, Bio-Signals in ECG, PPG, Body-Impedance were measured for 2 minutes. The measurement of blood pressure was progressed in a situation that the experimental subjects lean on comfortably to sit down on a chair. Blood pressure shows a frequent change according to a change of time. Thus, measurement for 3 minutes was progressed by measuring the reference blood pressure value and measuring the wrist blood pressure at the same time. When the reference blood pressure value deviates from margin of error, the re-measurement was performed after taking a rest for 5 minutes. In Fig. 6, the actual experimental environment is suggested.

Fig. 5 The Steps of Clinical Trial

Fig. 6 Clinical trial Model

3. The Experimental Results

Targeting totally 51 subjects, this study acquired blood pressure value in each of SBP, DBP, MAP through 4-stage experimental procedure. The verification of compensation blood pressure by measuring multiple bio-signals was progressed as the following process. First, its error is analyzed by comparing the auscultatory blood pressure value, which was acquired by using mercury sphygmomanometer that was used as the measurement method of the reference blood pressure value in this experiment, and the blood pressure value, which was acquired in the manufactured wrist electronic sphygmomanometer. Second, suggesting a feasibility as

the element of blood pressure compensation by carrying out correlation analysis on elements such as blood pressure, individual body information, PTT, HR, and a change in Korotkoff sound density ect. Third, through multiple linear regression analysis with the compensation elements and the reference blood pressure value on 36 data for the experimental group, the regression method is calculated. Finally, the new blood-pressure compensation method is verified by carrying out statistical analysis on error before and after compensation of blood pressure through applying the compensation regression equation to 15 data for the control group.

3.1 The Error rate in the wrist blood pressure and the reference blood pressure value

The measurement error in the wrist blood pressure and the reference blood pressure value was obtained by reducing the reference blood pressure value from the wrist blood pressure measurement value. At this time, in case of MAP, the direct measurement is impossible with auscultatory method. Thus, MAP was calculated and compared by using equation(8). Table 3 shows descriptive statistics in SBP, DBP and MAP. The oscillometric blood pressure on the wrist can be known to show the higher value as a whole than the reference blood pressure value.

$$MAP = DBP + \frac{SBP - DBP}{3} \quad (8)$$

Table 3 The Differences between Wrist BP and Reference BP

	N	Minimum	Maximum	Mean	Std. Err
Err_SBP_raw	51	6.0	44.0	23.35	8.747
Err_DBP_raw	51	-14.0	44.0	17.06	10.360
Err_MAP_raw	51	-5.0	44.0	18.14	10.965
Valid N(list)	51				

3.2 Extraction the regression equations for compensation of error rate

The statistical processing in data for this study was progressed by using SPSS 17.0 statistically analytical tool. All the statistical significant level was set for $p < 0.05$, and was established in order to be significant within the confidence interval of 95%. Prior to multiple linear regression analysis on experiment, the elements were primarily extracted that have high correlation with blood pressure, through analyzing Bivariate Correlation Coefficient of confirming correlation between each of elements and blood pressure. To select only independent variable that has no dependency among the extracted elements, multi-collinearity was verified. Through verifying multi-collinearity, the elements of having mutual dependency were excluded. It acquired regression models

and regression equations on SBP, DBP and MAP by progressing multiple linear regression analysis through backward elimination by applying the selected independent variables. The acquired regression models are as equation (9), (10), and (11). In the equation (9), (10), and (11), MAP is the oscillometric mean arterial pressure, SBP is oscillometric systolic blood pressure, $K_{\max-rip}$ is the time gap between korotkoff sound maximum PSD point and rapidly increasing point, Arm_c is the upper arm circumference, and Gender is applied that man is number 1, and woman is number 2. In the detected regression models, the oscillometric wrist blood pressure values, which show direct correlation with auscultatory blood pressure, are all over t-value 9, thereby having been able to confirm to have the greatest contribution. In addition, the bio-signal data could be confirmed to have been used as compensation data.

$$MAP_{comp} = 0.647MAP - 4.615Gender - 0.806K_{\max-rip} + 37.545 \quad (9)$$

$$SBP_{comp} = 0.827SBP - 0.194Age + 1.641Arm_c - 1.091BMI - 23.892 \quad (10)$$

$$DBP_{comp} = 0.585MAP - 4.594Gender - 1.127K_{\max-rip} + 34.611 \quad (11)$$

Table 4 Multi-Regression Analysis Results of MAP

Mo del	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.933 ^a	0.870	0.858	6.6125

a. Predictors : (Constant), Sex, MAP, Kmax-rip
b. Dependent Variable : R_MAP

Table 5 Multi-Regression Analysis Results of SBP

Mo del	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.915 ^a	0.838	0.817	8.4493

a. Predictors : (Constant), Age, Arm_c , BMI, SBP
b. Dependent Variable : R_SBP

Table 6 Multi-Regression Analysis Results of DBP

Mo del	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.910 ^a	0.828	0.812	7.5421

a. Predictors : (Constant), Gender, MAP, Kmax-rip
b. Dependent Variable : R_DBP

3.3 Confirmation of error in blood pressure compensation

To verify on regression method that was detected through multiple linear regression analysis on the experimental group with 36 people, the verification was made on error-rate compensation method of the wrist blood pressure measurement through applying multiple bio-signal and body information by applying the regression method to data of the control group with 15 people.

Fig. 7 Reference BP Vs. Compensation BP

Fig. 7 indicates scatter diagram in the reference blood pressure value and the compensation blood pressure on each of SBP, DBP and MAP for the control group. Through the point distribution of scatter diagram, it can be confirmed visually to be existed significance between each of compensation blood pressure and reference blood pressure value. Also, in table 7, the contents are suggested on the mean and the standard deviation in error between reference blood pressure value and compensation blood pressure. The mean and the standard deviation of the error in the numerical value, which was suggested in table 7, can be confirmed to be within mean : ± 5 mmHg, standard deviation : ± 8 mmHg as the standard for AAMI. Through this, the compensation regression equations in significant level can be known to have been detected.

Table 7 The Differences between Reference and Wrist BP of Control Group

	N	Minimum	Maximum	Mean	Std. Err
Err_SBP_comp	15	-12.0	9.0	-0.27	6.464
Err_DBP_comp	15	-14.0	9.0	-2.13	7.491
Err_MAP_comp	15	-15.0	12.0	-0.87	7.140
Valid N(list)	15				

Table 8 is being shown the results that carried out descriptive statistical analysis on error rate of blood pressure before and after compensation on the whole subjects' data. Error before compensation is obtained by reducing the reference blood pressure value from the wrist blood pressure. Error after compensation is obtained by reducing the reference blood pressure value from the compensated wrist blood pressure. The mean distribution in blood pressure before compensation is all over 5 mmHg. Thus, all can be known to be measured more highly than the reference blood pressure value on SBP, DBP and MAP. Blood pressure after compensation was reduced the mean to about ± 1 mmHg, thereby being able to be confirmed that effective compensation was performed. Examining the standard deviation in error rate, the deviation before compensation is about ± 10 mmHg, thereby failing to reach the reference specification of sphygmomanometer. However, the standard deviation after compensation could be confirmed to be all included within ± 8 mmHg.

Table 8 The Error Rate for the whole subjects

	N	Minimu m	Maximu um	Mean	Std. Err
Err_SBP_raw	51	6.0	44.0	23.35	8.787
Err_SBP_comp	51	-14.0	19.0	-0.47	7.452
Err_DBP_raw	51	-14.0	44.0	17.06	10.360
Err_DBP_comp	51	-18.0	13.0	-0.24	7.137
Err_MAP_raw	51	-5.0	44.0	18.14	10.965
Err_MAP_comp	51	-12.0	15.0	0.06	6.392
Valid N(list)	51				

Fig. 8 is being suggested visually the results before and after error compensation of SBP, DBP and MAP. The points, which were marked with blue circle in the distribution chart, indicate data distribution before compensation. Points, which were marked with red color, indicate data distribution after compensation. The line, which was presented with the width, is indicating the mean in error rate. Through the mean value and the dispersion distribution of data centering on the mean value, the error rate in blood pressure can be confirmed visually to have been improved.

Fig. 8 The Differences between reference and wrist BP(O : Before, * : After)

4. Conclusion

This study aimed to improve the convenience and accuracy of periodic blood pressure measurement at home and in daily life, which is the basis of diagnosing hypertension. A study was progressed on improving accuracy of blood pressure measurement method on the wrist. As for the demand of the masses for the more convenient and accurate measurement equipment, the oscillometric blood pressure monitor is satisfying most of conditions. However, blood flow oscillation signal is sensitive to diverse measurement conditions and to a change in a measurer's physical status. Thus, error of measurement may occur. Due to uncertainty in correct definition and characteristic ratio on the point of maximum amplitude in blood flow oscillation, error in

each equipment is high. Accordingly, this study suggested the blood pressure measurement method on the wrist for the more convenient and accurate blood pressure measurement. To compensate high error rate in the wrist blood pressure measurement, the aim is to reduce error in blood pressure measurement by reflecting a change in blood-vessel characteristic of each individual through measuring multiple bio-signals.

Targeting 51 experimental subjects(33 men, 18 women, age in 40.86 ± 24.642), it simultaneously measured the reference blood pressure value through mercury sphygmomanometer and the wrist blood pressure through electrical equipment. The compensation regression equations were detected through multiple linear regression analysis by using the acquired blood pressure data, multiple bio-signal, and body information in each individual of experimental subjects. By applying this, the error in blood pressure was compensated. The error between the compensated blood pressure and the reference blood pressure value showed distribution in 0.06 ± 6.392 mmHg in case of MAP, -0.47 ± 7.452 mmHg in case of SBP, and -0.24 ± 7.14 mmHg in case of DBP. Thus, its value could be confirmed to be significant.

Through this study, multiple bio-signal and subjects' body information were confirmed to offer error compensation element of electronic sphygmomanometer. It suggested a method available for enhancing convenience and significance of detecting blood pressure in the equipment available for complex measurement. If a future research on complex measurement equipments is progressed compensation and verification on body fat percentage conversion along with verification on numerous experimental subjects, is improved accuracy and significance of detecting SV(stroke volume) through measuring impedance cardiogram, and is integrated properly into one system, the more accurate blood pressure compensation will be made.

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