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Blood pressure monitor with a position sensor for wrist placement to eliminate hydrostatic pressure effect on blood pressure measurement

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Abstract— **Accurate measurement of blood pressure at wrist requires the heart and wrist to be kept at the same level to avoid the effects of hydrostatic pressure. Although a blood pressure monitor with a position sensor that guides appropriate forearm angle without use of a chair and desk has already been proposed, a similar functioning device for measuring upper arm blood pressure with a chair and desk is needed. In this study, a calculation model was first used to explore design of such a system. The findings were then implemented into design of a new blood pressure monitor. Results of various methods were compared. The calculation model of the wrist level from arthrosis angles and interarticulars lengths was developed and considered using published anthropometric dimensions. It is compared with 33 volunteer persons' experimental results. The calculated difference of level was -4.1 to 7.9 (cm) with a fixed chair and desk. The experimental result was -3.0 to 5.5 (cm) at left wrist and -2.1 to 6.3(cm) at right wrist. The absolute difference level equals ±4.8 (mmHg) of blood pressure readings according to the calculated result. This meets the AAMI requirements for a blood pressure monitor. In the conclusion, the calculation model is able to effectively evaluate the difference between the heart and wrist level. Improving the method for maintaining wrist to heart level will improve wrist blood pressure measurement accuracy when also sitting in the chair at a desk. The leading angle of user's forearm using a position sensor is shown to work for this purpose.**

I. Introduction

Automated blood pressure monitors are widely used at home to assess the hypertension treatment. Blood pressure is usually measured at the upper arm or wrist. There are some anatomical differences at the wrist comparing with upper arm that affect blood pressure measurement [1]. Also, the wrist can move more extensively than upper arm. The difference level between the heart and measurement site leads to errors in measurement of blood pressure because of a difference in hydrostatic pressure [2]. Therefore, keeping the heart and wrist at the same level is important for accurate measurement of blood pressure at the wrist. Some blood pressure monitors with a position sensor have been proposed to improve the level of the wrist which is one of the factors [3,4]. These wrist blood pressure monitors measure the angle of forearm and guide the users to put wrists into a correct posture resting on their chest. However, some users prefer to measure blood pressure while sitting on a chair with their arm on the desk. Use of a desk might make measurement easier for elder people and others. In this study, a method to guide the angle of forearm posture for use with chair and desk was explored through a calculation model. The findings were then implemented into design of a new blood pressure monitor.

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II. Methods

A. Calculation Model

The difference between the heart and wrist level can be calculated from arthrosis angles and interarticulars lengths. The model used to calculate the difference is shown in Fig. 1 and is based on a person sitting on a chair with their elbow on a desk.

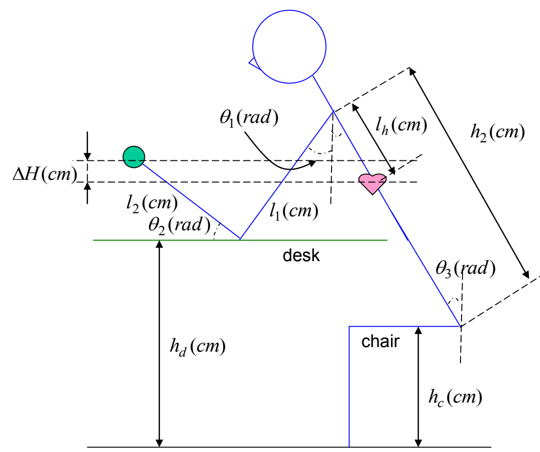

Figure 1. Schematic diagram of the model to calculate difference between the heart and wrist level with the chair and desk.

The anthropometric dimensions are shown with length of upper arm l_1, length of forearm l_2, length between heart and shoulder l_h and length of shoulder from chair h_2. The angle of joints are defined as angle of upper arm and vertical line θ_1, angle of forearm from desk θ_2 and angle of waist and vertical line θ_3. The difference between the heart and wrist level ΔH is given by:

$$\Delta H = l_1\cos\theta_1 - l_2\sin\theta_2 - l_h\cos\theta_3 \qquad (1)$$

The upper arm cuff to measure blood pressure is wrapped on the center of the upper arm because it is same level of the heart. We set that the heart level is same with center of upper arm. In other words, the readings of wrist blood pressure and upper arm blood pressure should be the same in this case. The difference between the upper arm cuff and wrist cuff affects the readings directly. The length between heart and shoulder l_h can be replaced using length of the upper arm as below:

$$l_h = l_1 / 2 \qquad (2)$$

The elbow must be on the desk in this condition. There are relationships between the anthropometric dimensions, the height of desk h_d, and the height of chair h_c with:

$$h_2\cos\theta_3 - (h_d - h_c) = l_1\cos\theta_1 \qquad (3)$$

Using those equations, the difference between the heart and wrist level can be calculated.

To calculate the level differences, the published arthrosis dimensions [5] were used. Data on arthrosis dimensions of 217 young men (18-29 years old), 204 young women, 50 elder men (over 60 years old) and 50 elder women are available. Twenty data points were excluded because they are not completed filling all the required data. Some of the parameters are defined as TABLE I. The angle of forearm from the desk θ_2 as a leading target is considered in a previous study [6] and defined as 29.5 degrees. The angle of waist and vertical line θ_3 could be taken in many cases. The minimum angle for each case was employed.

TABLE I. PARAMETERS FOR CALCULATION

	Parameters
Height of desk h_d	70 (cm)
Height of chair h_c	40 (cm)
Target Angle of forearm from desk θ_2	29.5 (degree)

B. Experiment

The wrist type blood pressure monitor, HEM-6310F (Omron Healthcare, Kyoto Japan) shown in Fig. 2 was newly designed and a 3-dimensional acceleration sensor was mounted on its print circuit board. Software to detect the angle of forearm was implemented and a blue light-emitting diode (LED) is turned on when it detects appropriate angle, 29.5±0.5 (degree). A chair and desk were prepared with respective heights of 70 (cm) and 40 (cm) the same height of the calculation model according to typical height of Japanese Industrial Standard.

A total of 16 men and 17 women volunteered for testing. They are using their own blood pressure devices at home or are people interested in blood pressure measurement. Four younger persons (20 – 30 years old) and 29 older persons (40 – 70 years old) are included as shown in Fig. 3. After measurement of anthropometric dimensions, they were asked to sit on the chair front of the desk while wearing the wrist type blood pressure monitor to measure. They adjusted the angle of their forearm until the blue LED became turned on. Then the difference level between the center of the upper arm and the upper and lower sides of wrist cuff, as well as the angle of the forearm were measured. The level of wrist is calculated as the average of the upper and lower sides of the wrist cuff as shown in Fig. 4. Measurements were made for the left wrist and right wrist twice respectively.

Figure 2. A picture of blood pressure monitor HEM-6310F with a position sensor. The blue LED which is placed the right side of the LCD is turned on when the sensor detects target angle.

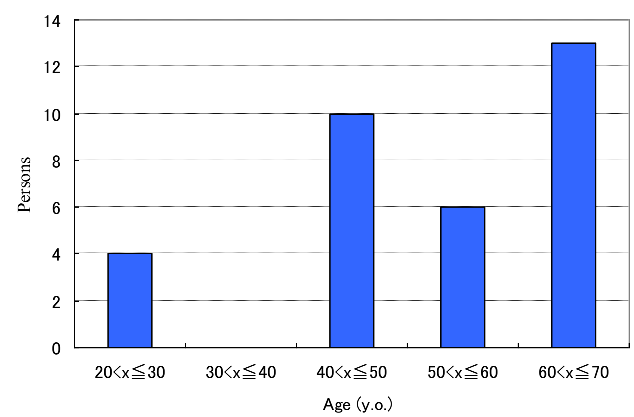

Figure 3. A dsitribution of age of volunteer persons. Four younger persons and 29 older persons are included.

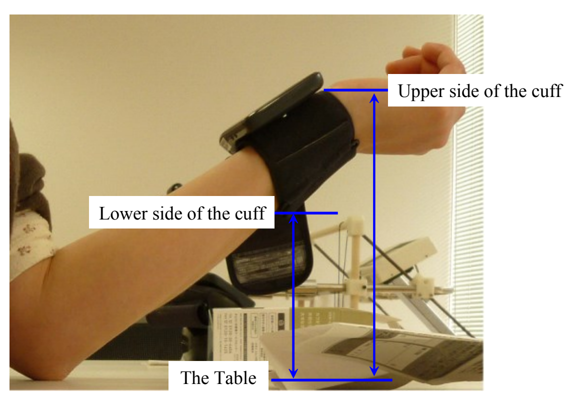

Figure 4. A picutre of the posture to measure and measurement points of wrist cuff.

This experiment was approved by the Experiment Review Committee of Omron Healthcare Co., Ltd.

III. RESULTS

The calculated result is shown in Fig. 5. The difference level was -4.1 to 7.9 (cm) with the fixed chair and desk.

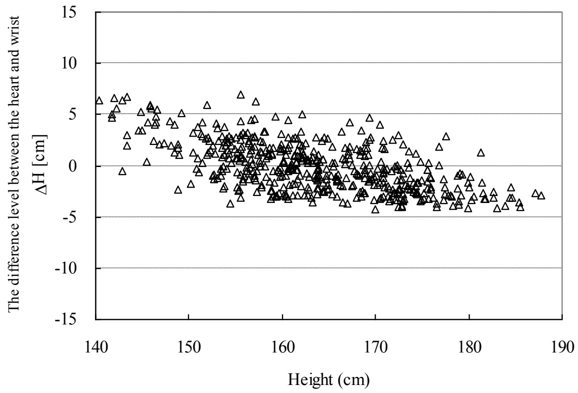

Figure 5. A scatter plot of 501 points for calculated result of difference between the heart and wrist level plotted each persons' height.The maximum difference was 7.9 (cm) and the minimum difference was -4.1 (cm).

The experimental result at the left wrist is shown in Fig. 6. The result was -3.0 to 5.5 (cm). The experimental result at the right wrist is shown in Fig. 7. The result was -2.1 to 6.3(cm). One data point was excluded due to mishandling. The case in which angle was 29.5±0.0 degree was selected from both experimental results as in a case of correct angle is shown in Fig. 8. The result was -1.4 to 5.0 (cm). All results are given in Table II.

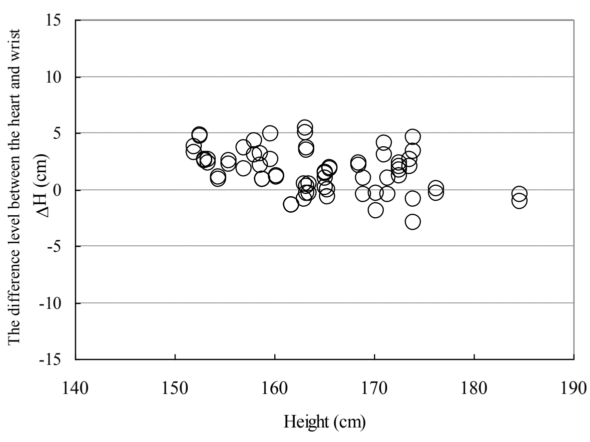

Figure 6. A scatter plot of 66 points for experimental result of the difference between the heart and left wrist level. The maximum difference was 5.5 (cm) and the minimum difference was -3.0 (cm).

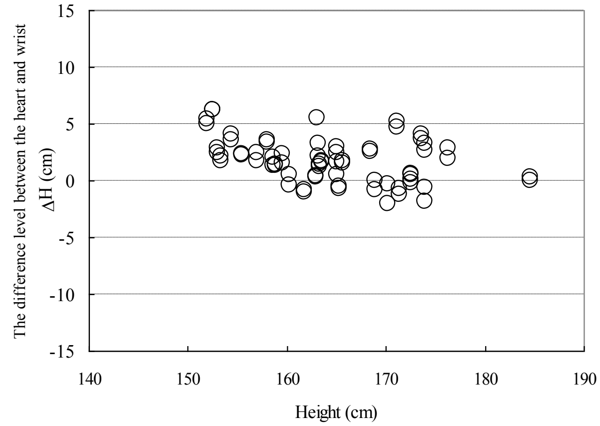

Figure 7. A scatter plot of 65 points for experimental result of the difference between the heart and right wrist level. The maximum difference was 6.3 (cm) and the minimum difference was -2.1 (cm).

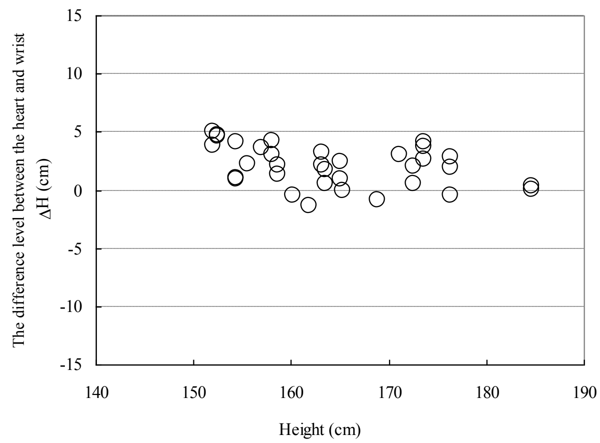

Figure 8. A scatter plot of 34 points for experimental result of the difference between the heart and wrist level in case of correct angle. The maximum difference was 5.0 (cm) and the minimum difference was -1.4 (cm).

TABLE II. CALCULATED AND EXPERIMENTAL RESULTS

	Difference between wrist and level of the heart (cm)			
	Calculated Model	***Left***	***Right***	***Correct Angle***
Average	0.0	1.6	1.8	2.1
Maximum	7.9	5.5	6.3	5.0
Minimum	-4.1	-3.0	-2.1	-1.4
Standard Deviation	2.44	1.90	1.96	1.75
N	501	66	65	34

IV. DISCUSSION

The ranges of both experimental results for the left wrist and right wrist are included in the calculated result. The standard deviations of both measurements are less than the standard deviation of the calculated result. It is suggested that the experimental results do not exceed from the result of the calculated model. The averages of experimental results are higher than the calculated results. This difference is caused when the angle of waist and a vertical line θ_3 is greater than a minimum value when the subject's backbone is not straight. This is a point to consider when apply the technique with real users. The calculation model can be used to evaluate this method at a straightened spinal posture.

The absolute range of difference was 12.0 (cm) in the calculated result. A difference level can be converted to an error reading of blood pressure according to the hydrostatic pressure [7]. The equivalent error reading of blood pressure is ±4.7 (mmHg) caused by the difference level between the heart and wrist. In the same manner standard deviation of the differences was 2.44 (cm) and 1.9 (mmHg) in blood pressure readings.

The AAMI requirements of blood pressure monitor accuracy are less than ±5.0 (mmHg) of the average and 8.0 (mmHg) of the standard deviation [8]. The height of the subject is not mentioned in the requirements so any combination should be possible. The error readings of blood pressure by level of the wrist will not exceed ±4.7 (mmHg) in the any combination subject height. This means that the average of error readings meets the ±5.0 (mmHg) of requirements. In the case of the standard deviation, the square sum of the standard deviations of difference level and basic performance should be less than the requirements. The standard deviation of error reading caused by different levels between the heart and wrist was 1.9 (mmHg). The standard deviations meet requirements when the standard deviation of basic performance is less than 7.77 (mmHg) in this case.

A desk and chair of fixed dimensions were employed in this study. People potentially select different sizes in their home. The difference level will decrease using the chair and desk for each person's best size. This device accepted a 0.5 (degree) difference with the target angle. This affects the leading performance less than 1.0 (cm) comparing with the selected correct angle cases.

There is a report to confirm improvement of total accuracy for other device with position sensor [9]. The position sensor is an important method for wrist blood pressure monitor accuracy.

V. CONCLUSION

A proper method for adjusting wrist to heart level will improve wrist blood pressure measurement accuracy while users are sitting in a chair at a desk. A calculation model to evaluate the difference between heart and wrist level was proposed and could be use for evaluation. The angle of the user's forearm using a position sensor will work for this purpose.

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