Wrist Cuff Method Determines Diastolic Pressure in Dual Cuff Blood Pressure System

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Abstract – **Single cuff noninvasive blood pressure (BP) measurements performed manually or automatically are subject to errors. We developed an experimental system that uses two cuffs in order to improve accuracy of noninvasive BP measurement. This study concentrated on a novel determination of diastolic BP using wrist cuff pulse waveforms and arm cuff pressures. The method was compared with the oscillometric method using the British Hypertension Society agreement grading system. The resulting grade was B- "good agreement". The wrist cuff method may prove to be better than single cuff methods because it is based on physiological principles.**

Keywords - Blood pressure, systolic blood pressure, mean arterial pressure, diastolic pressure, oscillometric method, dual cuff system, wrist cuff method

I. INTRODUCTION

Manual method for blood pressure (BP) measurement is still the most widely used method but it is being replaced by automatic BP monitors. The manual method uses a sphygmomanometer and a stethoscope. Systolic and diastolic pressures are determined from Korotkoff sounds and cuff pressures. The systolic pressure (SBP) is the cuff pressure at the point of first appearance of Korotkoff sounds. The diastolic pressure (DBP) is the point of the disappearance of Korotkoff sounds. The manual method cannot determine mean arterial pressure (MAP).

Automatic blood pressure monitors are fast becoming the most popular method in the hospital, the clinic, and the home. The early automatic monitors emulated the manual sphygmomanometry. They used contact microphones or ultrasonic transducers in place of stethoscopes. Difficulties with accurate transducer placement and with signal processing lead to the development of the oscillometric method that eliminated the need for an external transducer. The method evaluates amplitudes of arterial pulsations in the cuff. The oscillometric method can determine SBP, MAP and DBP, but only the MAP is based on a physiological principle of vascular unloading.

Most of the monitors used today employ single cuff oscillometric method. The oscillometric method has accuracy problems that have been described in literature [1]. The problems with single cuff oscillometric methods have led to the development of systems with more than one cuff. A system with three special cuffs [2] used pulse delay technique. A system with two cuffs [3] used an arm cuff and a forearm cuff of the same size.

We developed an experimental dual cuff system for the determination of blood pressures and hemodynamics that uses an arm cuff and a wrist cuff. The early version of the system was described previously [4]. The arm cuff functions as an occluding cuff in a manner identical to the manual BP method or an automatic method. The arm cuff is inflated to a pressure higher than expected SBP and then the pressure is gradually lowered until the end of deflation procedure. Arterial pulsations in the arm cuff are acquired simultaneously with the cuff pressure. The wrist cuff is pre-inflated at the beginning of a BP test to a value approximately equal to the expected DBP value and the cuff pressure is held at that value until the end of the test.

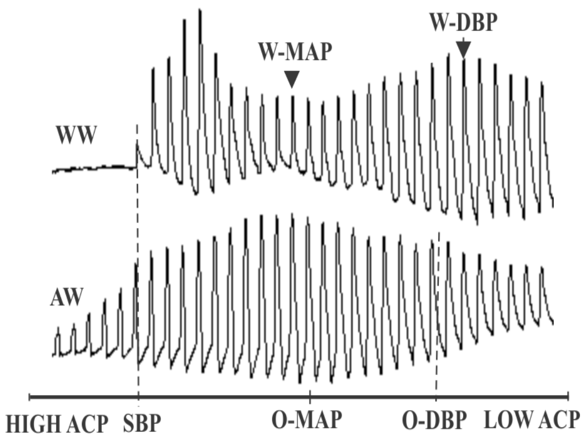

Figure 1. Gradual cuff deflation segment of a BP test. ACP is arm cuff pressure, WW is wrist cuff waveforms, AW is arm cuff waveforms, W-MAP is wrist mean pressure, O-MAP is oscillometric mean pressure, W-DBP is wrist cuff DBP, and O-DBP is oscillometric DBP. Length of segment is 25 sec.

The radial artery pulses are acquired from the pre-inflated wrist cuff in a manner similar to a stethoscope in the manual BP method. The early version of the

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system used the wrist cuff waveforms only for the determination of SBP. The system used in this study is capable of determining SBP, MAP and DBP. Figure 1 shows wrist-cuff pulse waveforms (WW) and arm cuff pulse waveforms (AW). During gradual arm cuff pressure (ACP) lowering from high ACP several BP points can be determined.

The point of SBP is determined as the onset of WW waveforms. The wrist mean arterial pressure (W-MAP) is determined as the point of the minimum WW amplitude. The oscillometric MAP (O-MAP) is determined as the point of maximum AW amplitude. With further decrease of ACP the WW amplitudes increase and the AW amplitudes decrease. When the WW amplitudes no longer increase the point of DBP is reached. The point of oscillometric diastolic pressure (O-DBP) is determined using the ratio-metric method. The ratio-metric method was introduced by Geddes [5]. According to Geddes, SBP corresponds to the point of 50% of the maximal AW amplitude (the point of O-MAP) and O-DBP corresponds to the point of 80% of the maximal AW amplitude. The points of O-MAP and O-DBP can be observed in Figure 1.

Figure 2 shows detailed segment of WW and AW waveforms acquired during gradual arm cuff deflation. The WW amplitudes gradually increase until they reach the W-DBP point. From W-DBP point on the brachial artery is free of partial occlusion and the WW amplitudes plateau.

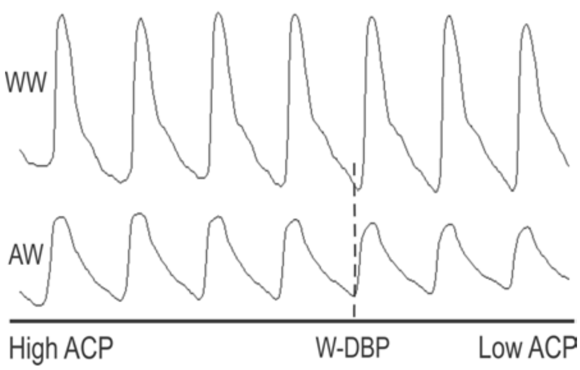

Figure 2. Detailed segment near W-DBP point. WW are wrist cuff waveforms, AW are arm cuff waveforms, ACP is arm cuff pressure, and W-DBP is wrist method DBP point. Length of segment is 7.5 sec

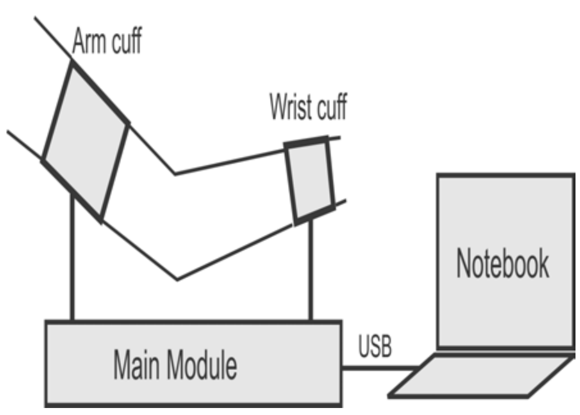

Figure 3. The dual cuff system configuration.

The main hypotheses of this study are that the point of W-DBP (Figure 2) is reached when the WW amplitudes no longer increase from the W-MAP point to the end of BP test. This phenomenon is related to blood flow under the arm cuff.

II. METHODS

The dual cuff system used in this study (Figure 3) consists of two cuffs (arm and wrist) a module and a notebook computer.

Block diagram of the main module with cuffs is in Figure 4. The two pneumatic and analog circuits for the cuffs are similar. Two air pumps inflate the cuffs and the cuff deflation is controlled by the valves. Piezoelectric pressure transducers (pr.xducr) provide analog signal that is amplified, filtered, and separated into two channels. One channel provides cuff pressure and the other channel provides amplified cuff-pressure waveforms. The resulting four analog signals are digitized in the submodule. Analog-to-digital conversion is 12-bit, 85 conversions/ sec operation. The digitized data are converted into USB format and made available to the notebook. The notebook contains special software that controls the main module's and the sub-module's functions and receives four channels of digitized data. Only pressures in the cuffs are monitored during inflation of the cuffs. When wrist cuff pre-inflation pressure is reached the wrist cuff pump is turned off and the deflate valve is kept closed. When arm cuff inflate pressure is reached the arm cuff pump is turned off and the valve is open for gradual deflation. At the end of a BP test both valves are in fast deflate mode. The cuff pressures and corresponding waveforms are then processed and the values of SBP, O-MAP, W-MAP, O-DBP, and W-DBP are displayed.

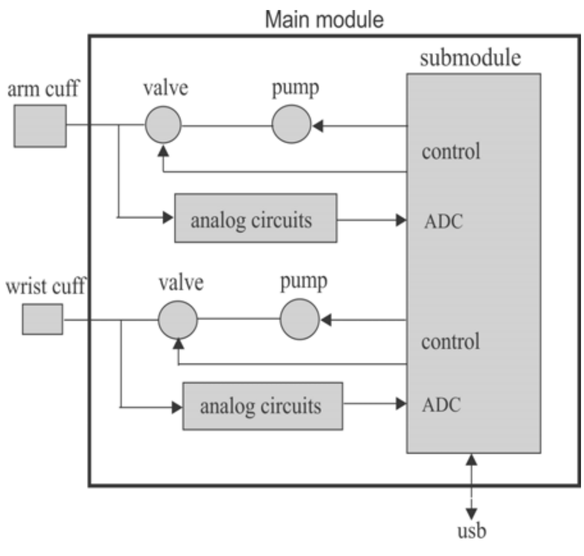

Figure 4. Block diagram of the dual cuff system's main module and the cuffs. The submodule contains analog-to-digital conversion, control circuit, and USB interface.

We designed the specialized software as Windows-based multifunction system that performs data acquisition processing functions and data storage. The function used in this study is the “Dual cuff”. The dual cuff function uses an arm cuff and a wrist cuff. Both cuffs in this study were commercial Omron cuffs. The arm cuff is an adult cuff 14 cm wide and the wrist cuff is 6 cm wide cuff. During the Dual cuff test the arm cuff is inflated to a pressure higher than expected SBP and the wrist cuff is inflated to the approximate level of DBP. The wrist cuff pressure is not critical but the pressure close to DBP level provides the best signal to noise ratio.

III. Results

Fifty BP tests were obtained from volunteers in the sitting position, age 40-79. Five sets of data were computed from the acquired cuff waveforms and pressures. Mean values and ranges of the computed variables are in Table 1. The W-SBP values were computed with a software routine based on first appearance of WW (Figure 1). The values of oscillometric MAP (O-MAP) were computed with a software routine that determines the peak value of AW amplitudes (Figure 1). The values of wrist MAP (W-MAP) were computed with a software routine that determines minimum value of WW amplitudes in the middle segment of gradual cuff deflation (Figure 1). The values of oscillometric DBP (O-DBP) were computed using ratio-metric method with the amplitude ratio of 0.76. The values of wrist DBP (W-DBP) were computed with software routine that determined the point of beginning of the WW amplitudes plateau (Figure 2). The mean values were computed with Microsoft Excel software.

The results in Table 1 show SBP mean value of 138 mmHg and range 114-195. The mean SBP is just short of hypertension value of 140 mmHg. We purposely used an older group of volunteers because older individuals have higher prevalence of hypertension. Hypertension is of greater interest to clinicians and researchers than normotension. The difference between mean value of W-DBP 80 mmHg and mean O-DBP value 84 mmHg is 4 mmHg.

TABLE I. Mean values, standard deviations and ranges of the five sets of computed values. All values are in mmHg. N=50

Pressures	Mean	SD	Range
W-SBP	138	15.6	114-195
W-MAP	106	11.7	88-124
O-MAP	103	16	81-153
W-DBP	80	7.8	66-104
O-DBP	84	9.6	66-102

IV. Discussion

Because we did not have the opportunity to obtain direct BP measurements, we compared the W-DBP method with the O-DBP method. For detailed comparison of W-DBP and O-DBP we used grading system of agreement developed by the British Hypertension Society (BHS) for comparison of BP devices [6]. The result is shown in Table 2. The grade of agreement is B (good agreement). The category of differences larger than 9 and smaller than 15 mmHg has eight difference values. Seven out of the eight difference values have corresponding SBP values higher than 140 mmHg, which qualify those tests as hypertension (HTN). Oscillometric devices have been shown to exhibit larger measurement errors when BP values are higher than 140/90 mmHg or[7].

Thirty two percent of the fifty tests in this study had BP values that qualified them as Isolated Systolic Hypertension (ISH). ISH is characterized by SBP value higher than 140 mmHg and DBP value lower than 90 mmHg. All eight differences in the category of differences larger than 9 and smaller than 15 mmHg had the values of W-DBP lower then the O-DBP values. They also had SBP values higher than 140 mmHg and W-DBP values lower than 90 mmHg.

TABLE II. BHS grading of agreement between O-DBP and W-DBP. N=50

Differences	< 5 mm Hg	< 10 mm Hg	< 15 mmHg	Grade
O-DBP vs W-DBP	52 %	78%	100%	B (good)

The prevalence of ISH is much higher in individuals older than 60 years. All volunteers in our ISH group were over 60 years old. ISH is frequently associated with decreased arterial compliance. Decreased arterial compliance has been associated with increased errors in oscillometric BP devices [8]. It is therefore reasonable to conclude that the W-DBP values may be more accurate than the O-DBP values. Another factor in favor of the W-DBP method is the fact that it is based on physiological principles whereas the O-DBP method is based on statistical estimates.

The W-DBP method described in this study is the last of three studies that described the novel wrist cuff methods for improved noninvasive determination of blood pressures. The first study [9] described the determination of SBP, the second study [10] concentrated on the determination of MAP (W-MAP), and the present study concentrated on the determination of DBP (W-DBP). We have also used wrist cuff waveforms for experimental determination of hemodynamics [11] and for other applications [12, 13].

V. Conclusion

The results in this study indicate that the wrist cuff method for the determination of DBP in dual cuff system may be sufficiently accurate to replace the oscillometric method. It is, however, prudent to consider our results and conclusions preliminary. Further studies are necessary to validate this study.

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