Volume 2008 ELECTROSCOPE Number III
Applied Electronics 2008

# The effect of wrist cuff width on oscillometric blood pressure waveforms

J. Jilek[1], M. Stork[2]
[1] Carditech, Culver City, California, USA.
[2] Katedra aplikované elektroniky a telekomunikací, Fakulta elektrotechnická, ZČU v Plzni, Univerzitní 26, Plzeň
E-mail : jilekj@usa.net, stork@kae.zcu.cz

**Abstract**:
Accuracy of blood pressure (BP) measurement with any method is affected by cuff size. Narrow cuff overestimates BP and wide cuff underestimates BP. Wrist cuff oscillometric BP monitors typically use narrow cuffs with bladders about 6 cm wide. The segment of the radial artery compressed by the wrist cuff presents a hydraulic resistance (Rc) to blood flow during BP measurement. Narrow cuff presents smaller Rc than wide cuff. Changes in Rc alter the amplitude envelope of oscillometric waveforms. Narrow cuff allows blood flow under the cuff and into the hand sooner than wide cuff. The objective of this study was to demonstrate that narrow cuff alters the amplitude envelope in a manner that results in increased BP values when characteristic ratio algorithm is used. A specialized experimental system was used to acquire wrist oscillometric BP data from a narrow (6 cm) cuff and from a wide (10 cm) cuff. Data were acquired from 10 volunteers in sitting position. The results confirmed the objective of the study. All narrow cuff BPs were higher than either the reference BPs or wide cuff BPs. Wide cuff algorithmic BPs were similar to the reference BPs. Wider wrist cuffs appear to be desirable for improved accuracy and reliability of wrist BP monitors.

## INTRODUCTION

A major factor affecting accuracy of blood pressure (BP) measurement with any type of BP instrument is cuff size [1]. The “ideal” cuff should have bladder length 80% of arm circumference and bladder width equal to 40% of arm circumference [2]. A recent study [3] concluded that measurement error is minimized with a cuff width of 46% of arm circumference. Typically, a cuff too small (under-cuffing) will overestimate blood pressure and a cuff too large (over-cuffing) will underestimate blood pressure. Under-cuffing errors are larger than over-cuffing errors [2]. Wrist cuff monitors have the cuff permanently attached to the enclosure and different cuff sizes are not available. Wrist cuff bladder is usually about 6 cm wide, but some are as narrow as 5 cm. According to the “40% “ width formula, wrist cuff width of 6 cm is suitable for wrist circumferences of 15 cm or smaller. According to the “46%” width formula, 6 cm wrist cuff corresponds to only 13 cm of wrist circumference.

The segment of the radial artery compressed by the wrist cuff presents a hydraulic resistance to blood flow (Fig 1). According to Poiseuille’s law, hydraulic resistance (R) is expressed in the equation.

$$R = (8\,\eta\, l) / (\pi\, r^4) \qquad (1)$$

where $\eta$ is blood viscosity, $l$ is the length of the segment compressed by the cuff, and r is the radius of the artery under the cuff. The cuff width is approximately equal to $l$. It follows from the equation that the cuff width changes the hydraulic resistance (Rc). Wider cuff increases Rc and narrower cuff decreases Rc. Hydraulic resistance of the cuff segment is in series with vascular resistance of the hand (Rh) (Fig 1). Rc decreases during gradual cuff deflation procedure as the radius of the compressed segment increases.

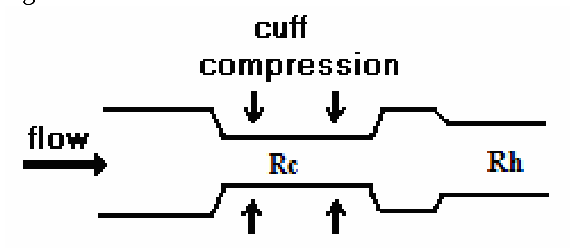


Figure 1. Schematic of radial artery compression by wrist cuff. Rc is the resistance to blood flow exhibited by the compressed segment of the artery and Rh is the resistance of the hand’s vasculature.

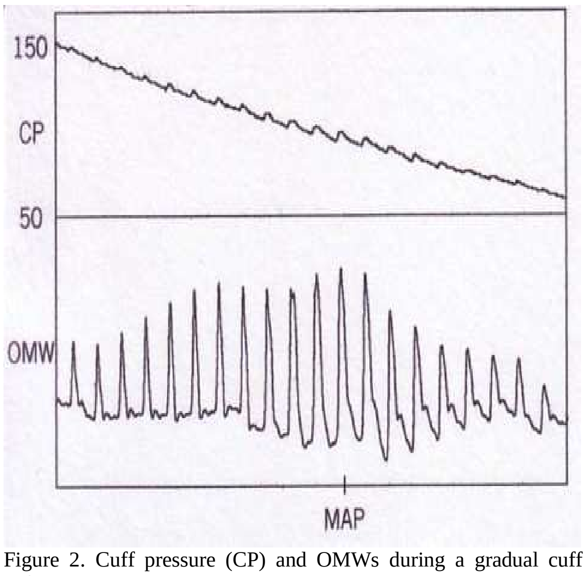


Figure 2. Cuff pressure (CP) and OMWs during a gradual cuff deflation. MAP is mean arterial pressure.

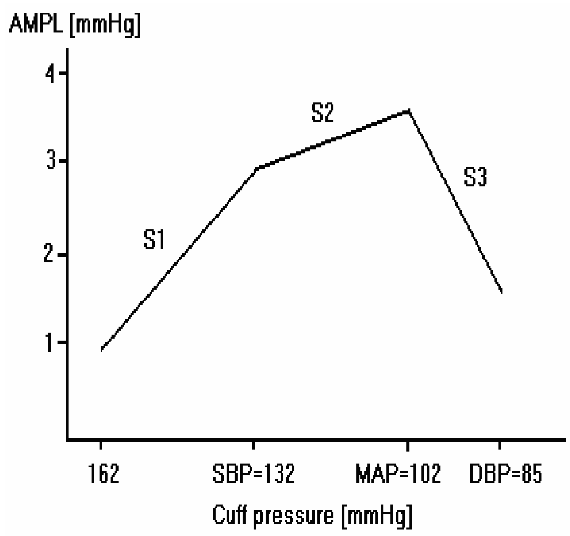


Figure 3. Graph of OMW amplitude (AMPL) envelope during a gradual cuff deflation. S1, S2, S3 are the slopes of three segments of the OMW envelope.

Arterial pulsations evoke oscillometric waveforms (OMWs) in the cuff during gradual cuff deflation [4]. Figure 2 shows cuff pressures (CP) and OMWs during gradual cuff deflation. The OMW amplitudes increase with decreasing cuff pressure until they reach the point of mean arterial pressure (MAP) and then they decrease until the end of the procedure. Figure 3 shows the graph of a typical OMW amplitude envelope. The envelope slopes S1, S2, and S3 represent three segments of the cuff deflation procedure [5]. S1 is the slope from the beginning of the procedure to the systolic pressure (SBP) reference point, S2 is the slope from the SBP reference point to the mean pressure reference point (MAP), and S3 is the slope from MAP to the diastolic pressure reference point (DBP).

Changes in hydraulic resistance Rc alter the OMW amplitude envelope during gradual cuff deflation. Changes in Rh also alter the OMW amplitude envelope, but main concern of this study is wrist cuff width. Wider cuff presents higher Rc to the blood flow under the cuff and the result is increased slope S2. Narrow cuff allows blood flow under the cuff and into the hand sooner than wide cuff. Korotkoff sounds or blood flow pulse are detected earlier and the result are higher BPs with narrow cuff (under-cuffing). Oscillometric method is affected by slope alterations and also by early flow detection. Various algorithms have been used to determine oscillometric pressures. Some algorithms have been published, but commercial algorithms are typically kept secret by the manufacturers. Published algorithms differ in their approaches. Some algorithms use OMW amplitude ratios while other algorithms use changes in the OMW amplitude envelope slope or sudden changes in OMW amplitudes. These algorithms have been developed empirically for the lack of physiological theory of oscillometric BP measurement [5]. One popular algorithm [6] uses the cuff pressure at 50% of maximal OMW amplitude (OMWmax) as the point of SBP and 80% of OMWmax to determine DBP. This type of algorithm is called “characteristic ratio” algorithm and it was developed empirically. S2 is the slope important for the determination of SBP and S3 is used to determine DBP with characteristic ratio algorithm.

The objective of this study was to demonstrate that narrow (6cm) cuff shifts the OMW amplitude envelope to the left of the wide cuff envelope. Narrow cuff also decreases the slope S2. The resulting BP values with the narrow cuff should be higher than with the wide cuff. The “50%” and “80%” algorithms were used to show the effect of cuff width on the determination of oscillometric blood pressures.

## METHODS

A specialized experimental system for acquisition and evaluation of cuff pressures and oscillometric waveforms was used in the study. The system (Figure 4) consists of a notebook computer, a module with pneumatic and electronic circuits and two detachable cuffs. The notebook controls all pneumatic and electronic functions of the system via USB interface. Specialized software performs acquisition of waveforms and corresponding cuff pressures, waveform display, and computations of waveform amplitudes and derived variables. The system is capable of evaluating either standard single cuff pressures or dual-cuff pressures. Dual-cuff BP measurement is more accurate. Dual-cuff method uses the wrist cuff as blood flow pulse sensing device in a manner similar, but not identical, to a stethoscope as used in the traditional BP measurement.

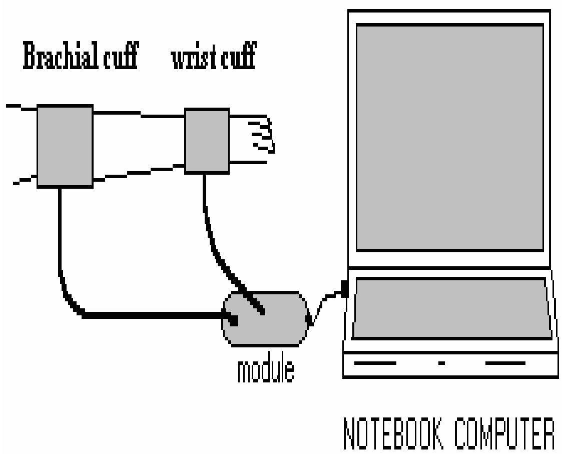


Figure 4. The system for acquisition and evaluation of oscillometric waveforms.

Commercial cuffs were used in this study. A wrist cuff 6 cm wide and a 10 cm wide cuff were used. A standard brachial cuff 12 cm wide was used to obtain reference BP values. Reference SBP value was obtained first with the system in dual-cuff mode. After a 30 sec pause, one wrist test with the 6 cm cuff was followed (after 1 min pause) with one wrist test with the 10 cm cuff. Ten volunteers were tested in the sitting position with the cuff positioned at heart level. Mean wrist circumference was 17 cm. The values of MAP were determined as cuff pressure at the point of maximum OMW amplitude. Software routine developed by the authors was used to compute the MAP values. The values of SBP and DBP were calculated as follows: the amplitude value of OMW at 50% of maximal amplitude was referenced to cuff pressure as SBP. The amplitude value at 80% of maximum amplitude was referenced to cuff pressure as DBP.

## RESULTS

Results of the study are tabulated in Table 1. All algorithmic values (SBP-50%, DBP-80%) for SBP, MAP and DBP were increased when 6 cm cuff was used. Mean 6 cm cuff SBP was increased by 11%, mean MAP increased by 12.5% and mean DBP increased by 12%. The values for 10 cm cuff were similar to the reference BP values.

Table 1. Mean values of reference BPs and algorithmic (SBP-50%, DBP- 80%) values with 6 cm and 10 cm wrist cuffs. All values are in millimeters of mercury.

| n=10 | SBP | MAP | DBP |
|---|---|---|---|
| Ref. BP | 127 | 96 | 80 |
| 6 cm cuff | 141 | 108 | 90 |
| 10 cm cuff | 125 | 95 | 80 |

## DISCUSSION

The results confirm the objective of this study. The values of SBP, MAP, and DBP are higher with narrow (6 cm) cuff than reference BP values or the BP values obtained with wide (10 cm) cuff. 10 cm cuff BP values are close to the reference BP values. This pattern points to under-cuffing as the cause of overestimation of blood pressures with the 6 cm cuff.

Two factors appear to cause BP overestimation with narrow cuffs. Decreased hydraulic resistance of the narrow cuff is one factor and the second factor is earlier start of blood flow under the narrow cuff. Decreased Rc decreases the slope S2 and earlier blood flow under the cuff shifts the OMW amplitude envelope to the left, thereby increasing algorithmic BP values. Higher oscillometric, algorithmic BP values with narrow cuffs are consistent with reports on under-cuffing where auscultation methods are used [3].

In order to obtain more accurate results, algorithmic methods different from the 50% and 80% characteristic ratio method need to be employed in wrist BP monitors. The nature of such algorithms has not been published and commercial algorithms are kept secret. Narrow cuffs used in wrist devices may be partly responsible for less accurate and unreliable BP measurements reported in literature [7, 8, 9]. Another factor altering the OMW amplitude envelope in the wrist devices is blood flow in the hand. Hand cooling experiments conducted by one of the authors [5] demonstrated that decreased blood flow in the hand altered the S2 slope of the OMW amplitude envelope.

## CONCLUSION

This study investigated the influence of wrist cuff width on OMW amplitude envelope and concluded that narrow wrist cuff contributes to the decreased accuracy and reliability of BP measurement with wrist BP monitors. Wider wrist cuff appears to be desirable for more accurate and reliable BP measurement. Characteristic ratio algorithms could then be used in wrist BP monitors with wider cuffs. More research of wrist cuff BP methods is desirable.

## ACKNOWGLEDMENT

Milan Stork's participation in preparing this paper has been supported by Department of Applied Electronics and Telecommunications University of West Bohemia, Plzen, Czech Republic and GACR project No. 102/07/0147.

## REFERENCES

[1] Jones DW, Appel LJ, Sheps SG, Rocccella EJ, Lenfant C. Measuring Blood Pressure Accurately. JAMA 2003;289:1027-1030

[2] Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, et al. Recommendations for lood Pressure Measurement in Humans and Experimental Animals. Part 1:Blood Pressure Measurement in Humans. Hypertension 2005;45:142-161.

[3] Marks LA, Groch A. Optimizing cuff width for noninvasive measurement of blood pressure. Blood Press Monit. 2000;5:153-156.

[4] Jilek J, Fukushima T. Oscillometric blood pressure measurement: The methodology, some observations, and suggestions. Biomed Instrum Technol. 2005;39:237-241.

[5] Jilek J, Fukushima T. Blood Flow Under Wrist Cuff, in Hand Alters Oscillometric Waveforms During Blood Pressure Measurement. Biomed Instrum Technol. 2007;41:238-243.

[6] Geddes LA, Voelz M, Combs C, Reiner D, Babbs CF. Characterization of the oscillometric method for measuring indirect blood pressure. Ann Biomed Eng. 1982;10:271-280.

[7] Kikuya M, Chonan K, Imay Y, Goto E, Ishii M. Accuracy and reliability of wrist-cuff devices for self-measurement of blood pressures. J Hypertens 2002;20:573-578.

[8] Weber F, Erbel R, Schafers R, Philipp T. Wrist measurement of blood pressure: some critical remarks to oscillometry. Kidney & Blood Pressure Research 1999;22:161-165.

[9] Wielemborek-Musial K, Jegier A. Value of blood pressure of adults depending on method of measurement. Pol Arch Med Wewn 2006;115:529-34.