HOME MEASUREMENT OF BLOOD PRESSURE: PRESENT PROBLEMS AND PERSPECTIVE IMPROVEMENTS

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Abstract

The most frequently performed health test is the measurement of blood pressure. Popularity of home measurement increased substantially with the introduction of inexpensive automatic instruments to the market. Accurate measurement of blood pressure is important for diagnosis and management of hypertension. Inaccuracies of measurement with automatic oscillometric instruments are caused by wrong size cuff and by errors in algorithmic measurement. The authors developed several perspective improvements in the measurement of systolic pressure. An experimental system for acquisition and processing of arterial pressure pulses facilitated the development of these methods. More accurate measurement of the systolic pressure was achieved with a dual-cuff method. A new method of wrist-cuff pulse analysis facilitated estimation of hemodynamics. Estimation of hemodynamics simultaneously with measurement of blood pressure provides the physician with more complete picture of the type of hypertension and it facilitates better diagnosis and management. An inexpensive commercial instrument based on the methods developed by the authors could be used by the patient in home care.

Keywords

blood pressure, home measurement, oscillometric method, empiric algorithms, experimental system, hemodynamics of hypertension

Introduction

High blood pressure (BP) is today one of the most frequent health problems. Measurement of BP is the most frequently performed health test. It belongs to the family of the so-called "vital signs". Blood pressure measurement is also increasingly performed in the home [1]. Manual home BP measurement was performed before the introduction of inexpensive automatic BP monitors. The method is the same as that performed in doctor's office by a healthcare worker. A sphygmomanometer and a stethoscope are usually used. A sphygmomanometer consists of an inflatable cuff and a pressure meter. A mercury pressure gauge used to be prevalent but it is no longer used because of the toxicity of mercury. The person performing BP measurement should be acquainted with correct methodology. Measurement errors caused by wrong cuff size, too slow or too fast cuff deflation, wrong stethoscope placement or digit preference are all well known problems [2].

A substantial expansion of home BP monitoring came with the introduction of the automatic, inexpensive BP monitors. More frequent are also ambulatory BP monitors. The reason for their use is the white coat hypertension or resistant hypertension. The patient wears the monitor for 24 hours and the monitor automatically measures BP at predetermined intervals and the results are stored in the monitor for later evaluation by the physician. The white coat syndrome manifests itself by higher BP in the doctor's office than at home. Resistant hypertension is high BP in the office and at home even after the introduction of drug treatment. Home BP monitoring provides useful information to the physician and to the patient. Most home monitors on the market are automatic, with an arm cuff. Wrist home monitors are gaining popularity. There advantage is small size, low power consumption, and they can usually be used even on very obese people. The disadvantage is that the wrist must be kept at the level of the heart during measurement.

Specific problems with accuracy of BP monitors

All BP monitors should pass validation tests. Several validation tests with varying sophistication are in existence [3, 4]. Validations require large number of volunteers with wide range of ages, blood pressures and arm sizes. Validation protocols themselves are not perfect. A study published in 2002 showed that BP monitors can sometimes pass validation protocol and still be systematically inaccurate for certain patients [5]. It is also important to point out that the validations are voluntary. It is likely, that majority of BP monitors, especially the home monitors, have never been validated.

Accurate BP measurement is important for diagnosis and management of hypertension. Even relatively small errors in measurement can cause misdiagnosis or a change in management [2]. Ideally, all monitors should measure BP equally accurately. Actual situation is, unfortunately, different. Differences exist among monitors of different manufacturers and even among different models of the same manufacturers. These differences could be even larger for home monitors. Home monitors are sold at substantially lower price than professional monitors. Low cost monitors are not as rugged and their pressure sensors cannot be calibrated.

Problems with cuff size

“Ideal” BP cuff should have the length of 80% and width of 40% of the arm or wrist circumference [6]. The cuff length is the length of the cuff’s bladder. Marks [7] concluded that error of BP measurement can be decreased with the cuff width of 46% of arm circumference. A cuff too small causes erroneously high BP and a cuff too large causes lower BP measurements. The errors with narrow cuff are usually larger than errors with a large cuff [7]. According to recommendation of British Hypertension Society, the adult cuff size should be 12 x 26 cm and the large size 12 x 40 cm [8]. American Hypertension society recommends 16 x 30 cm for standard adults and 16 x 42 cm for large adults. Wrist monitors are sold with the cuff sizes of about 6 x 11 cm. According to the “40 % circumference” formula, the wrist cuff is suitable for only 15 cm and smaller wrist circumferences.

It can be concluded that there must be errors of BP measurement with wrong sizes of cuffs. A study of wrist cuffs [9] showed that the 6 cm wrist cuff width is not correct for wrist monitors and that a larger cuff size could contribute to a better accuracy and reliability of the wrist monitors. Fig. 1 shows the wrist cuffs used in the study. Published studies of wrist monitors usually show that that wrist monitors are not suitable for situations where accurate BP measurement is important [10].

Fig. 1: Wrist cuffs for BP measurement – 10 cm wide (blue cuff) and 6 cm wide (gray cuff).

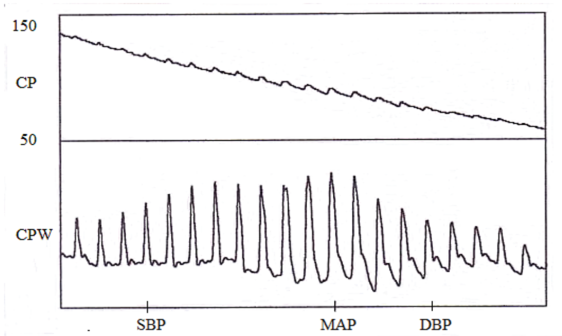

Fig. 2: Graphic representation of cuff pressure (CP) and cuff pressure waveforms (CPW) during a gradual cuff deflation.

Problems with the oscillometric method of BP determination

The so called oscillometric method of BP determination is employed by a large majority of automatic BP monitors. The method was introduced in the 1970’s of the 20th century and it quickly gained in popularity. The method evaluates pressure pulse amplitudes elicited in the cuff [11]. An external sensor was eliminated at the cost of diminished accuracy of the monitor. The accuracy problems cannot be easily defined. Fig. 2 illuminates these problems. Cuff pressures (CP) and cuff pressure waveforms (CPW) can be identified during the entire cuff pressure deflation procedure. The CPWs appear at CPs above the point of SBP, they continue to increase in amplitude until they reach the point of MAP (mean arterial pressure), and then their amplitudes decrease until the end of the procedure well past the point of DBP. The points of SBP and DBP cannot be easily identified. The oscillometric method relies on CPW amplitude ratios or on other amplitude changes. According to Geddes [12], the SBP is at the point where CP at SBP is 50% of maximal amplitude and

DBP is at 80% on the descending slope. The values of 50% and 80% were statistically derived from comparisons with the series of manual BP measurements. Some published critical studies pointed to accuracy problems caused by decreased arterial compliance [13] or by altered hemodynamics [14]. Published literature sometimes describes the oscillometric method completely erroneously. For example, Borow [15] claims that the Dinamap instrument defines SBP as the point where the CPW amplitudes start increasing and the DBP as the point where the CPWs stop decreasing or disappear. It is obvious from Fig. 2 that Borow's claim is false. Automatic BP measurement with the oscillometric method is not considered reliable and accurate by experts [16] and the manual BP measurement is still the „gold standard".

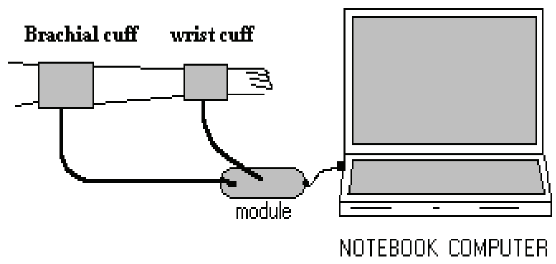

Fig. 3: Dual cuff system with two cuffs, a module and a notebook.

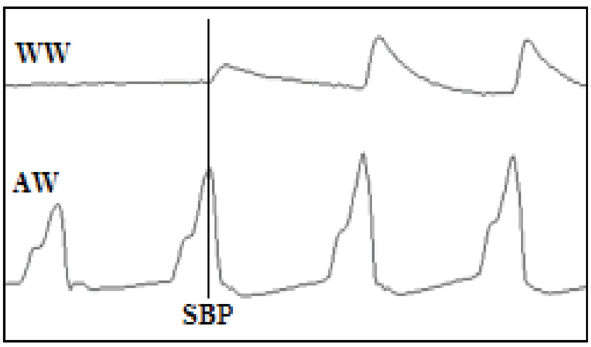

Fig. 4: Wrist cuff waveforms (WW) and arm cuff waveforms (AW) during cuff deflation near the level of SBP.

Perspective improvements of automatic BP measurement

Improved accuracy of BP measurement is clearly desirable. One such method was developed by the authors of this article. The method employs two cuffs. The dual-cuff system components are shown in Fig. 3. The arm (brachial) cuff functions as a „standard" cuff and the wrist cuff emulates a stethoscope. The wrist cuff is pre-inflated to approximately DBP level. The arm cuff is inflated to a pressure higher than the expected SBP level and then it is gradually lowered. When the arm cuff pressure is at SBP level, arterial pulsations start penetrating past the cuff and they appear in the preinflated wrist cuff. The first pulse appearing in the wrist cuff corresponds to the SBP pressure in the arm cuff. This process can be followed in Fig. 4.

The dual-cuff system improves accuracy of SBP determination and it also allows automatic determination of hemodynamics. The system for determination of BP and hemodynamics was described previously [17,18]. Arterial waveforms elicited in the wrist cuff are used to compute stroke volume (SV). Cardiac output (CO) is computed from SV and heart rate (HR). Total peripheral resistance (TPR) and systemic arterial compliance (SAC) are estimated from previously computed variables. The resulting hemodynamic variables are displayed on the computer screen numerically and graphically in the form of a graphic „quadrant" (Fig. 5).

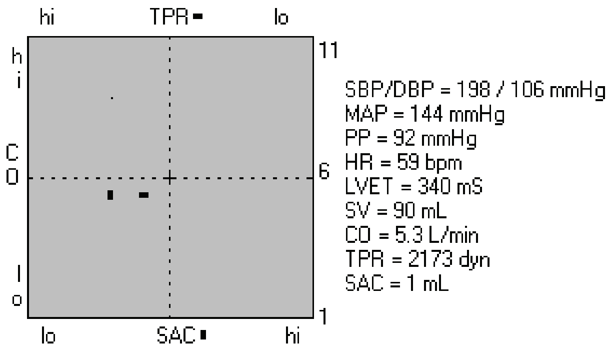

Fig. 5: Numerical and graphic quadrant results of a BP and hemodynamics test.

The quadrant shows the relationship of CO, TPR and SAC. TPR and SAC are represented by small rectangles that move vertically with changes of CO and horizontally according their own values. Higher value of SAP and lowe TPR value move the rectangles to the right. The right side of the quadrant is the „good" side and the left side reprezent the abnormal or „bad" values. Results of a test in Figure 5 show abnormal values of a test performed on a hypertensive subject.

Discussion

Home monitoring of BP is performed frequently and its value are widely recognized [1]. Accuracy problems, however, still exist. Differences between home and office BP measurement can cause erroneous conclusions about the existence of hypertension or about its seriousness. The need to measure BP accurately even in the home is obvious. The errors caused by wrong size cuff or incorrect cuff placement are well known and they can be removed by patient training. The errors caused by the instrument are more difficult to recognize and correct. The errors can be caused by an inaccurate pressure sensor or shortcomings of software algorithms. The oscillometric monitors have „built-in“ inaccuracies that are variable [19] and cannot be removed. There is no standard oscillometric algorithm and commercial algorithms are kept secret by the manufacturers. It is difficult to determine when and how errors in measurement occur. The above introduced improvements could contribute to the improvements in accuracy. Perspectively important may be the determination of BP and hemodynamics by a quick and inexpensive method. It has been known for a long time that hypertension is basically a hemodynamic abnormality [20].

A number of studies [21, 22] showed the utility of hemodynamic measurement in the management of resistant hypertension. The dual-cuff system described above could be made much more compact and inexpensive for home use. Application of two cuffs is a simple task that can be performed easily by any individual in the home. Fig. 6 shows the dual-cuff system in operation.

Fig. 5: The dual-cuff system in operation.

Conclusion

Accurate BP measurement is important during home monitoring for correct diagnosis and management of hypertension. The inexpensive BP monitors on the market frequently do not meet accurate measurement and reliability requirements. A simplified, commercial version of the dual-cuff system described above could improve accuracy of BP measurement and provide additional hemodynamic information, namely CO, TPR and SAC.

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