Series Editor: Bernard Karnath, MD

Sources of Error in Blood Pressure Measurement

Bernard Karnath, MD

Blood pressure measurement, a routine feature of every clinical visit, is an important component of the diagnostic evaluation for hypertension. Nearly one fourth of the US adult population has hypertension[1]; it is the most frequent diagnosis encountered in ambulatory care visits.[2] The Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure defines hypertension as a systolic blood pressure of 140 mm Hg or greater or a diastolic blood pressure of 90 mm Hg or greater, as measured at each of 2 or more visits after an initial screening visit.[3] Blood pressure should be measured according to a standardized method that is in line with the American Heart Association's recommendations (**Table 1**).[4]

Reliance on automated blood pressure measuring devices may lead to inaccurate readings in the presence of arrhythmias.[5] Indirect measurement of blood pressure by the auscultatory method is the most widely accepted technique. The mercury sphygmomanometer remains the most commonly used instrument for indirect blood pressure measurement. However, direct intra-arterial measurement is considered the gold-standard method for determining blood pressure. This article reviews the history behind the development of methods to determine blood pressure and discusses potential sources of error in measurement.

HISTORICAL PERSPECTIVE

Stephen Hales conducted the first direct measurement of blood pressure in 1714 (**Figure 1**). Hales conducted his blood pressure studies on animals.[6,7]

> In December I caused a mare to be tied down alive on her back… having laid open the left carotid artery, I inserted a brass pipe whose bore was 1/6 of an inch in diameter. The blood rose in the tube 8 feet 3 inches above the level of the left ventricle of the heart.[6]

METHODS OF BLOOD PRESSURE MEASUREMENT

Indirect
Auscultation of Korotkoff sounds by using a mercury sphygmomanometer (gold standard) or an aneroid sphygmomanometer

Direct
Intra-arterial measurement

However, it was not practical to carry out direct intra-arterial measurement of blood pressure on a routine basis (and it still is not today, even with more advanced technologies for performing the procedure). In 1896, the development of the sphygmomanometer by Scipione Riva-Rocci (**Figure 2**) provided an indirect method for measuring blood pressure.[8]

Russian physician Nicolai Korotkoff (**Figure 3**) described in 1905 a modified version of the method made possible by the Riva-Rocci sphygmomanometer.[8–12] The blood pressure cuff was originally promoted as a tool to measure systolic blood pressure by the obliteration of the radial pulse. Palpation of the point at which the radial pulse was obliterated allowed for determination of the systolic blood pressure. In contrast, Korotkoff proposed listening for the appearance and disappearance of sounds to mark systolic and diastolic pressures.

> The cuff of Riva-Rocci is placed on the middle third of the upper arm; the pressure within the cuff is quickly raised up to complete cessation of

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Table 1. Recommendations for Blood Pressure Measurement

1. Seat the patient with his or her arm supported in such a manner that the midpoint of the upper arm is at the level of the heart.
2. Select an appropriately sized cuff. The cuff bladder should encircle 80% of the arm in adults and 100% of the arm in children younger than 13 years.
3. Wrap the cuff around the bare upper arm, centering the bladder over the brachial artery. The lower edge of the cuff should be 2 cm above the antecubital fossa.
4. The cuff should be inflated while palpating the radial pulse to approximate systolic blood pressure, which is the point at which the radial pulse disappears.
5. The bell of the stethoscope should be placed just above and medial to the antecubital fossa.
6. The cuff should be inflated to a pressure 20 to 30 mm Hg above the point at which the radial pulse disappears.
7. The cuff should be deflated at a rate of 2 mm Hg per second.
8. The systolic blood pressure is recorded at the appearance of Korotkoff sounds (phase I).*
9. The diastolic blood pressure is recorded at the disappearance of Korotkoff sounds (phase V) in adults and the muffling of sounds (phase IV) in children.*
10. Repeat the procedure in the opposite arm.

NOTE: points 1 through 9 adapted from Perloff et al.[4]

*See Table 2 in this article.

Figure 1. Stephen Hales in 1714. Reprinted from Hall WD. Stephen Hales: Theologian, botanist, physiologist, discoverer of hemodynamics. Clin Cardiol 1987;10:488 with permission from Clinical Cardiology Publishing Company, Inc, and/or the Foundation for Advances in Medicine and Science, Inc.

> circulation below the cuff.... It follows that the manometric figure at which the first tone appears corresponds to the maximal blood pressure.... The time of the cessation of sounds indicates the free passage of the pulse wave.... It follows that the manometric figure at this time corresponds to the minimal blood pressure.[11]

Goodman and Howell in 1911 recommended the division of the changing sounds into 5 distinct phases, and physicians subsequently determined diastolic blood pressure according to either the point of muffling of sounds or the disappearance of sounds (**Table 2**).[12]

DIRECT VERSUS INDIRECT MEASUREMENTS OF BLOOD PRESSURE

As previously stated, direct intra-arterial measurement is considered the gold-standard method for the measurement of blood pressure. A study by Chyun compared intra-arterial (direct) and auscultatory (indirect) readings in 14 intensive care unit patients and found that the auscultatory method overestimated the systolic and diastolic blood pressures.[13] Furthermore, use of the phase IV Korotkoff sounds (Table 2) as an indicator of diastolic blood pressure can overestimate readings by as much as 20 mm Hg as well.[13] Direct intra-arterial measurement of blood pressure is often used to monitor critically ill patients.

SOURCES OF ERROR IN MEASUREMENT

Several critical steps in measuring blood pressure are selection of an appropriately sized cuff, cuff placement, proper placement of the bell of the stethoscope, appropriate cuff deflation rate, and auscultation of appropriate Korotkoff sounds. Sources of error in blood pressure measurement include improper technique, observer bias, and faulty equipment. In addition, the presence of clinical conditions such as atrial fibrillation can lead to a high degree of interobserver variability.

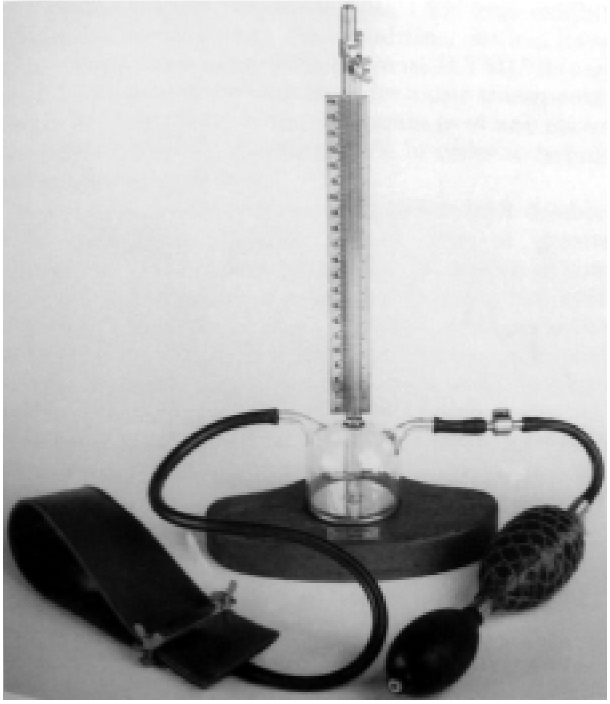

Figure 2. The Riva-Rocci sphygmomanometer. Reprinted with permission from Brown WC, O'Brien ET, Semple PF. The sphygmomanometer of Riva-Rocci 1896–1996. J Hum Hypertens 1996;10:723–4.

Figure 3. Nicolai Korotkoff. Reprinted with permission from Segall HN. N. C. Korotkoff—1874–1920—Pioneer vascular surgeon. Am Heart J 1976;91:816–8.

Technique

McKay and colleagues evaluated physicians for common errors in blood pressure measurement technique, which included use of an inappropriately sized cuff, failure to allow a rest period before measurement, not measuring blood pressure in both arms, and failure to palpate maximal systolic blood pressure before auscultation.[14,15] Furthermore, fewer than 20% of physicians followed a proper cuff deflation rate of 2 mm Hg per second.[14,15] Rapid cuff deflation leads to underestimates of systolic pressure and overestimates of diastolic blood pressure.[16] Also, cuff size can affect blood pressure readings. A blood pressure cuff that is too small can lead to overestimates of systolic and diastolic pressures; a cuff that is too large can lead to underestimates of these pressures.[16]

Blood pressure should be measured with the patient in a sitting position. The patient should be seated with his or her arm supported in such a manner that the midpoint of the upper arm is at the level of the heart. Failure to follow these procedures can lead to falsely elevated blood pressure measurements if the midpoint of the upper arm is lower than the heart level and even higher measurements if the midpoint is above the heart level.[16]

Korotkoff sounds are low frequency sounds and are therefore heard more clearly with the bell of the stethoscope. A study by Prineas and Jacobs evaluated the differences between blood pressure readings obtained with the bell of the stethoscope and those obtained with the diaphragm.[17] The results of the study showed that when the bell of the stethoscope was placed over the brachial artery, a higher systolic and lower diastolic reading was obtained than when the diaphragm was placed over the antecubital fossa.[17] The results of the study also suggested that Korotkoff sounds are detected earlier and disappear later when the bell of the stethoscope is placed over the brachial artery, as suggested by the American Heart Association.

Observer Bias

A study by Neufeld and Johnson evaluating 26 physicians with regard to their abilities to measure blood pressure found standard deviations of 3.5 and 5.7 mm Hg for systolic and diastolic blood pressures, respectively.[18] The higher degree of standard deviation for diastolic blood pressure was attributed to observer bias in using phase IV Korotkoff sounds as the indicator for diastolic blood pressure. Phase V Korotkoff sounds are the preferred measuring point for diastolic blood pressure measurement in adults. As previously mentioned, use of phase IV Korotkoff sounds has been shown to overestimate

Table 2. Phases of Korotkoff Sounds

Phase	Characteristics
I	First appearance of low-frequency tapping sounds
II	Softer and longer sounds
III	Crisper and louder sounds
IV	Muffled and softer sounds
V	Complete disappearance of sounds

diastolic blood pressure by as much as 20 mm Hg when compared with intra-arterial readings.[18] Furthermore, phase IV Korotkoff sounds are not reproducible among clinicians, whereas phase V sounds are.[19] Some physicians record both phase IV and phase V Korotkoff sounds. Thus, a blood pressure measurement may read as 140/80/50, with the last 2 numbers being 2 different diastolic blood pressure readings.

Faulty Equipment

Mercury sphygmomanometers should be considered inaccurate if the meniscus is not at 0 at rest. Aneroid (rotating needle–type) sphygmomanometers are more popular than mercury sphygmomanometers because of the potential environmental toxicity of mercury. However, aneroid sphygmomanometers require regular calibration and may become very inaccurate over time. Aneroid sphygmomanometers should be validated for accuracy against a standard mercury manometer at 6-month intervals.[20]

Atrial Fibrillation

Atrial fibrillation is the most common arrhythmia in elderly persons. Atrial fibrillation is commonly associated with hypertension, and the irregularly irregular pulse makes blood pressure measurement more difficult. It is estimated that approximately 2.3 million US adults currently have atrial fibrillation.[21] The use of automated devices in the presence of atrial fibrillation may lead to inaccurate readings.[5]

Moreover, interobserver variability among physicians can be significant with regard to patients with atrial fibrillation. A study by Sykes and colleagues prospectively evaluated interobserver variability in blood pressure measurement for patients with atrial fibrillation and patients with sinus rhythm and found a significantly greater degree of variability for patients with atrial fibrillation for both systolic and diastolic pressures.[22] The findings of the study suggested that physicians' interpretations of Korotkoff sounds are less uniform in the presence of atrial fibrillation.[22]

The Auscultatory Gap

Failure to detect an auscultatory gap is another potential source of error in blood pressure measurement and will likely result in falsely lower systolic readings.[23] The auscultatory gap is a period of abnormal silence that usually occurs during the phase 2 Korotkoff period, from 10 to 50 mm Hg. The pathogenesis of the auscultatory gap is not clearly understood but an association with atherosclerosis has been documented.[24] Palpation of the radial pulse during cuff inflation will ensure that an auscultatory gap is not missed.[23]

White-Coat Hypertension

White-coat hypertension is a condition in which a normotensive patient displays hypertensive blood pressure readings during a clinical encounter. White-coat hypertension is present in approximately 25% of people who appear to have hypertension through conventional measurement.[25] Anxiety can raise blood pressure by as much as 30 mm Hg. This response is most severe at the beginning of a clinical encounter; ambulatory blood pressure monitoring is useful in differentiating white-coat hypertension from persistent hypertension.[16]

CONCLUSION

A standardized method, such as the protocol recommended by the American Heart Association, should be used when determining blood pressure to ensure accurate measurements. Reliance on automated devices may lead to inaccurate readings in the presence of arrhythmias. Mercury sphygmomanometers are considered the gold-standard measuring devices for indirect blood pressure determination; aneroid sphygmomanometers are considered accurate if calibrated with a mercury manometer at regular intervals. The measurement of blood pressure through auscultation remains the most widely accepted method in everyday practice. **HP**

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