Accuracy of Blood Pressure Measurement in the Family Practice Center

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Background: **Equipment, physiologic, and technique factors can influence the accuracy of blood pressure measurement. The current study was designed to isolate certain technique factors and then assess the accuracy of nursing personnel measurements of blood pressure in three residency family practice centers.**

Methods: **An experienced registered nurse was trained in applying the American Heart Association recommendations for determining blood pressure by sphygmomanometry; three 1.5-hour practice sessions demonstrated her accuracy. Nine full days were then spent in the family practice centers rechecking as many staff blood pressure readings as possible while controlling for confounding variables.**

Results: **The following findings were significant: (1) the average absolute differences between control and study nurse systolic and diastolic blood pressure readings were 6.2 mmHg and 4.7 mmHg, respectively; (2) a unidirectional error of 3.8 mmHg in the measurement of diastolic blood pressure was found in one center, possibly because less care was taken with afternoon measurements; (3) variability in systolic blood pressure readings was higher in all three centers (± 8.5 mmHg) than attained during the training sessions for the control nurse (± 5.8 mmHg); (4) the average errors attributable to technique factors studied that were potentially correctable by training were only 1.8 mmHg for systolic and 0.7 mmHg for diastolic pressures.**

Conclusions: **The degree of inaccuracy in ambulatory nursing blood pressure readings attributable to errors in technique is quantified by this study. Training can reduce, but not abolish, this inaccuracy. Careful attention to proper blood pressure measurement technique and such variables as equipment calibration is essential for both nursing and physician observers. Taking multiple blood pressure measurements before making clinical decisions can limit the effect of these inaccuracies. (J Am Board Fam Pract 1998;11:252-8.)**

Appropriate diagnosis and optimal treatment of hypertension depends upon accurate blood pressure measurement by nursing and physician personnel. Although the accuracy of this common technique is generally assumed in clinical settings, such indirect measurements are fraught with inconsistency. First, the discrepancies between indirect and direct measurements for the same patients range from 3 to 24.6 mmHg,[1] emphasizing that indirect blood pressure measurement is, at best, an approximation of the true value. Second, even assuming that indirect blood pressure measurements truly correlate with direct readings, the medical literature on hypertension clearly documents a remarkable degree of variation in auscultatory blood pressure values resulting from multiple potentially controllable factors[2] (Table 1).

The American Heart Association (AHA) recommendations for determining blood pressure by sphygmomanometry were developed to standardize blood pressure measurement protocol, thereby controlling for many of these factors and allowing for greater comparability of readings between studies. Although the diligent teaching and implementation of these guidelines have undoubtedly led to more comparable measurements, medical practitioners continue to show lack of consistency in fully adhering to the established protocol.[5,6] When the known potential for equipment errors and physiologic patient variations are also considered, it would not be surprising to find differences in systolic and diastolic blood pressure measurements exceeding ±28 mmHg and ±20 mmHg, respectively,*

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*Numbers are derived from four studies and represent the average of their 95 percent confidence limits (1.96 × standard deviation of the differences between readings).

Table 1. Factors Confounding the Accuracy of Auscultatory Blood Pressure Measurements

Confounding Factor	Effect(s) and Degree of Effect(s)	Remedy
Body posture		
Sitting without back support	Increased DBP > SBP (5 - 10 mmHg)[3]	Use standard seated position with back support
Standing	Increased DBP > SBP[3]	
Lying (greater difference in pregnancy)[4]	Decreased DBP > SBP[3]	
Arm support - active support (vs passive)[4]	Increased DBP & SBP (4+ mmHg)[4]	Use passive support of arm
Arm position[4]		
At level of sternomanubrial junction	Decrease in DBP & SBP (5 mmHg)	Use standard arm position at fourth intercostal space
At level of xiphoid process	Increase in DBP & SBP (5 mmHg)	
Rate of deflation - too fast[1,4]	Underestimation of SBP[3] Overestimation of DBP[3]	Deflate at 2 mmHg/sec
Auscultatory gap - missed	Underestimation of SBP[1,3,4]	1. Determine point of maximal inflation by palpation, then inflate to 30 mmHg above this value,[4] or 2. Inflate to 230 mmHg
Pressure on head of stethoscope		
10 mmHg	Decreases DBP (K-V) (10 mmHg)[3]	Apply only enough pressure to head of stethoscope to seal against skin
Firm pressure	Sounds may persist down to 0 mmHg[3]	
Use of bell vs diaphragm	< 2 mmHg difference[3]	Considered insignificant (use either bell or diaphragm)
Size of cuff		
Too small[1]	Overestimation of SBP (5 - 9.5 mmHg)[3] Overestimation of DBP (4 - 7 mmHg)[3]	Consider always using large cuffs, as the degree of effect if cuff is too large seems negligible
Too large	Underestimation of SBP (0 - 4 mmHg)[3]	
No resting period between readings[1,4]	Inaccurate auscultation of K-I and K-V	Allow at least 30 sec between readings
Lack of bilateral measurements	Up to 10 mmHg difference between arms in 1% - 6% of patients[1,3,4]	Take measurements in both arms, and then follow the arm with the higher pressure Always document on which arm the reading is taken
Improper selection of Korotkoff sounds (DBP)[5]	Overestimation of DBP (5 - 10 mmHg)[3,4]	Make sure that K-V is selected as the DBP (the very last sound heard)
Digit preference (rounding to nearest 5 or 10 mmHg)[4,5]	0 - 5 mmHg inaccuracy	Round to the nearest 2 mmHg[4]
Equipment errors[1,5]		
Aneroid sphygmomanometers	22% - 60% inaccurate[1]	Regular inspection, repair, and calibration
Mercury column manometers	2% - 8% inaccurate[1]	
Environmental		
Cold room (12°C vs 24°C)	Increase in DBP (up to 15 mmHg)[1]	Take measurements in warm rooms
Talking during measurement	Increase in DBP (8 - 15 mmHg)[1]	No talking when taking reading
Pseudohypertension (from atherosclerosis)[3,4]	Overestimation of SBP/DBP (≥ 15 mmHg)	Clinical suspicion Osler maneuver (suggestive test)
Cuff-inflation hypertension[4]	Overestimation of SBP/DBP	Clinical suspicion (debated)

DBP - diastolic blood pressure, SBP - systolic blood pressure, K - Korotkoff.

for the same patient between office visits 5 percent of the time.[7,8] Just how much of this variation is due solely to practitioner technique is unclear, but one report has estimated that measurements can vary 15 mmHg or more from basal blood pressure.[4]

Anecdotal concerns regarding the accuracy of nursing blood pressure readings led to a small uncontrolled local study showing highly significant differences between nurse and physician readings for the same patient during the same visit. This current study was performed to better quantify the accuracy of blood pressure readings obtained by nurses in three family practice centers.

Methods

Setting

The three PinnacleHealth System family practice residency centers were selected for this study. Centers 1 and 2 are urban practices of 6000 to 7000 patients each. Center 3 is a suburban-rural practice of approximately 15,000 patients. Each center has a physician medical director and a nurse manager. The three centers share one administrator.

Table 2. Characteristics of Study Variables.

Characteristic	Number
Total sets of blood pressure readings	166
Center 1	52
Center 2	59
Center 3	55
Personnel assessed at center 1	7 (2 MAs, 2 LPNs, 3 RNs)
Personnel assessed at center 2	9 (3 MAs, 6 LPNs, 0 RNs)
Personnel assessed at center 3	10 (3 MAs, 6 LPNs, 1 RN)
Obesity* absent	74
Obesity present	92
Cardiovascular disease† absent	108
Cardiovascular disease present	58
Reading taken in morning	101
Reading taken after noon	65

MA - medical assistant, LPN - licensed practical nurse, RN - registered nurse.

*Height and weight were recorded, with ideal body weight (IBW) = 100 lb + 5 lb (height in inches - 60 in) for women, and IBW = 105 lb + 5 lb (height in inches - 60 in) for men. Obesity = IBW + 0.1 IBW + 0.2(IBW + 0.1 IBW)

†Cardiovascular disease included history of high blood pressure, diabetes mellitus, coronary artery disease, arteriosclerotic heart disease, atrial fibrillation, congestive heart failure, or arteriosclerotic peripheral vascular disease.

The true subjects of this study were the staff nurses and medical assistants at each center. Patients aged 18 years or older who came to the centers during the days of the study were randomly involved. Evidence of cardiovascular disease, height, and weight (to calculate for obesity) were recorded for each patient, as these factors could make measuring blood pressure technically more difficult. The staff responsible for blood pressure measurements for all patients at each center consisted of a mixture of medical assistants, licensed practical nurses (majority), and registered nurses. Table 2 summarizes pertinent demographics of the staff and patients involved in the study.

Procedures

This prospective, blinded study evaluated the ability of staff nurses and medical assistants (study nurses) to obtain accurate blood pressure measurements. Blood pressure measurement by an experienced registered nurse (control nurse) with no reported hearing difficulties from a reliable temporary agency was used as the reference standard with which the study nurses' measurements were compared.

The control nurse's technique was developed, after reading the study protocol and supporting literature,[1-5,7] in three 1.5-hour morning sessions of blood pressure measurement using modified AHA recommendations for determining blood pressure by sphygmomanometry (Table 3). Blood pressure readings of volunteers were obtained by the control nurse as well as two trainers, and the technique was refined until blood pressure readings regularly agreed to within ± 4 mmHg. The volunteers were kept in the same room, chair, and position for each set of three readings. One to 2 minutes were allowed between readings, the same blood pressure device was used for each set of readings, and the order of taking measurements was intentionally varied among the three participants. Table 4 includes the precise variability limits attainable with this instruction and practice. The control nurse's technique was thereby certified as correct and her readings considered to represent as close to the basal readings as could be obtained (ie, the reference standard).

During 3-day periods at each center the control nurse rechecked the study nurses' blood pressure readings on a convenience sample of patients. Physiologic factors were limited by (1) keeping the patient in the same room and in the same position for both study nurse and control nurse readings; (2) arranging the flow of information gathering in such a way as to keep 1 to 2 minutes between comparison readings; (3) using the same arm to take both readings; and (4) randomizing (by the throw of a die) the order in which the study nurses and control nurse took their measurements (to neutralize the statistical effects of any phasic or time differences). Equipment factors were eliminated by using the same blood pressure device for comparison readings. In centers 1 and 3 mercury manometers were used; in center 2 aneroid sphygmomanometers were used.

Study nurses were not informed about the purpose of the study other than notification several days before that a "quality improvement blood pressure study" would take place. Neither the control nurse nor the study nurses were aware of each other's readings. In addition to each pair of blood pressure measurements, the control nurse recorded the center, the study nurse's name, the time of day, whether the patient had any cardiovascular diseases (Table 2), and the height and weight of each patient.

Before beginning the main study, all center 1 mercury sphygmomanometers were inspected and calibrated, revealing a widespread need for tubing replacement on most of the devices. Because the study protocol dictated the use of the same measurement device for each pair of readings (to nullify equipment errors), further calibration of devices at the other two centers was not considered necessary for the purposes of this study.

Analyses

The data for training and regular sessions were analyzed using one-way and two-way paired t-tests, in addition to one-way analysis of variance (ANOVA). The means of the absolute values of the differences between readings were also calculated, as the practicing clinician would want to know the average variance to expect for each blood pressure reading regardless of whether that variance is greater or lesser than the true reading.

After completion of the study, an analysis of the order in which the blood pressures were taken (ie, whether the control nurse or study nurse took the reading first) showed no significance for diastolic readings and borderline significance for systolic readings ($P = 0.049$). When days 1 through 9 were compared, there were no significant or progressive trends in the data that would suggest failure to implement the study. Poststudy qualitative review with the control nurse confirmed careful attention to following the protocol through the very last day of data collection.

Results

A total of 166 sets of blood pressure measurements and related data were collected during the main study, and 54 sets of blood pressure measurements were taken during the training sessions (Table 2).

The average systolic and diastolic readings for the sample as a whole obtained by control and study nurses were 126.10/78.90 mmHg and 125.58/77.42 mmHg, respectively. This difference was similar to the mean and the diastolic and systolic readings of 115.11/73.11 mmHg and 114.15/71.70 mmHg, respectively, for control nurse and trainers during the training sessions.

When comparing the individual pairs of readings obtained by the control and study nurses, the absolute difference in diastolic blood pressure readings averaged 4.71 mmHg, only 0.71 mmHg greater than the average absolute difference achieved during the training sessions. Interestingly, one-way ANOVA among centers was significant ($P = 0.002$) with analysis of the actual diastolic differences, identifying a highly significant 3.78-mmHg negative difference at center 3 (lower readings by the center study nurses). Analysis of the performance of individual study nurses in all centers approached significance for diastolic measurement (ANOVA = 1.56, $P = 0.057$), again with nurses from center 3 largely responsible. In addition, only in center 3 did afternoon readings show significantly less accuracy (difference = 3.77 mmHg, $P = 0.025$). These findings together suggested a systemic error at center 3 in obtaining accurate diastolic pressure readings that resulted in a skewing of the data mostly in one direction. Similar skews in blood pressure measurements, however, were not found at any other center for either diastolic or systolic readings.

When comparing the individual pairs of read-

Table 3. American Heart Association Recommendations (Modified) for Determining Blood Pressure by Sphygmomanometry.

1. The patient's arm should be supported at heart level
2. The patient should be sitting with back support
3. The manometer should be at eye level, easy to read, and deflated to zero before measurement begins
4. The proper size bladder should be selected (when in doubt, select the larger size)
5. The bladder center, located by folding the cuff in half, is aligned with the brachial artery, and the cuff should be affixed so that its inferior edge lies 2.5 - 3.0 cm above the antecubital fossa
6. The point of maximal inflation should be identified by palpating the radial artery and inflating the cuff to 30 mmHg above the pressure where the pulse is last palpated. If radial artery cannot be palpated, inflate cuff up to 230 mmHg
7. The bell or diaphragm of the stethoscope can be used, but must be pressed lightly over the brachial artery
8. The cuff is rapidly inflated to the predetermined point of maximal inflation and then deflated slowly at 2 - 3 mmHg/sec
9. The systolic blood pressure, the point at which at least two consecutive faint tapping beats are heard, is noted, and recorded in even numbers (K-I)
10. For adults the diastolic pressure is taken as the point at which the last muffled sound is heard (K-V). After 10 - 20 mmHg of silence, the cuff can be rapidly deflated to zero
11. Record the systolic and diastolic pressures as well as the cuff size, the patient's position, and the arm used in the measurement
12. No talking should occur between technician and patient during the measurement of the blood pressure[1]
13. Repeat measurements should be delayed by 1 - 2 minutes to allow time for blood to drain from the arm

Modified from Bailey and Bauer,[1] Campbell et a[1,2] Baker and Ende,[3] Campbell et al,[4] and Frohilch.[9]

Table 4. Differences in Blood Pressure Readings: Main Study and Training Sessions.

	Main Study			Training Sessions				
Variable*	Mean of Absolute Differences† (mmHg)	Variability‡ (SD) (mmHg)	No.	Mean of Absolute Differences (mmHg)	Variability‡ (SD) (mmHg)	No.	Mean Error Potentially Correctable by Training§ (mmHg)	Excess Potentially Correctable by Training‖ (mmHg)
Systolic BP								
Total	6.21 (0.51)	8.53	166	4.37	5.81	54	1.84	± 2.72
Center 1	6.27 (0.88)	9.94	52					
Center 2	5.97 (0.27)	7.75	59					
Center 3	6.42 (0.42)	8.04	55					
Diastolic BP								
Total	4.71 (1.49)	6.21	166	4.00	5.74	54	0.71	± 0.47
Center 1	4.54 (1.04)	6.10	52					
Center 2	4.10 (-0.24)	5.74	59					
Center 3	5.53 (3.78)	6.20	55					

BP - blood pressure.

*All differences were calculated by subtracting the study nurse or trainer readings from the control nurse reading.

†Numbers in parentheses represent the means of the actual differences (not absolute), and demonstrates that most of the diastolic error at center #3 was in one direction (those in italics reached statistical significance).

‡Statistically derived from analyses of the actual (not absolute) systolic and diastolic differences. Note: standard deviations cannot be derived from non-normally distributed data, such as absolute values.

§Calculation = mean of absolute differences from main study minus mean of absolute differences for training sessions.

‖Calculation = variability from main study minus variability from training sessions.

ings obtained by control and study nurses, the absolute difference in systolic blood pressure readings averaged 6.21 mmHg: this time 1.84 mmHg greater than the average absolute difference achieved during the training sessions for systolic measurement. Though unidirectional skewing of significance was absent for systolic readings between centers, quite a bit of variability existed: 2.72 mmHg greater than that observed during the training sessions. Interestingly, systolic blood pressure readings in obese patients were more accurate (mean of actual differences for obese patients -0.70 mmHg, and mean for nonobese patients 2.01 mmHg, $P = 0.042$), traceable only to center 1.

Table 4 includes the main study results regarding systolic and diastolic blood pressure readings.

Discussion

In this study average absolute differences in systolic and diastolic blood pressure readings were 6.21 mmHg and 4.71 mmHg between control and study nurses, respectively. If the training session data are assumed to represent the most accurate technique that can be achieved, then average absolute blood pressure differences potentially correctable by training were only 1.84 mmHg systolic and 0.71 mmHg diastolic (Table 4). Such small variations from the reference standard reflect favorably on the ability of the staff nurses to follow accepted blood pressure measurement techniques in the office setting.

Analysis of the average actual differences (positive or negative) revealed an error of almost 4 mmHg in one direction for diastolic readings at center 3, suggesting poor implementation of some aspect(s) of accepted technique among staff at that center. Consistent with this theory was the finding that center 3 alone had less agreement between pairs of diastolic readings in the afternoons (as compared with the mornings), presumably from less careful technique toward the end of a full day's work. When data for individual center 3 nurses were analyzed, 4 of 10 study nurses had readings consistently lower than those of the control nurse; 3 of these 4 nurses took the blood pressure measurements almost exclusively in the afternoons. Patient factors, such as obesity or cardiovascular diseases, did not help explain the diastolic differences found at center 3.

Finally, variation in systolic readings (as represented by the standard deviation of the actual differences in systolic blood pressure readings) was higher in all three centers (± 8.53 mmHg) than during the training sessions for the control nurse (± 5.81 mmHg). Once again, if the training sessions data are assumed to represent the most accurate technique that can be achieved, then systolic variability potentially correctable by training becomes just ± 2.72 mmHg, a very tolerable number, indeed.

Previous studies have reported differences in systolic pressure measurement of 4 mmHg or more to be to the following variables: rate of deflation,[3] missing an auscultatory gap,[1,3,4] terminal digit preferences,[4,5] and arm support and position.[4] Differences of 4 to 15 mmHg and greater in diastolic pressure measurement have been previously documented for rate of deflation,[3] pressure on the head of the stethoscope,[3] improper selection of Korotkoff sounds,[3-5] terminal digit preference,[4,5] and talking during measurement.[1] Taken as a group, as in this study, these variables could produce large discrepancies in comparative readings. The relatively small magnitude of the differences found in the current study suggests, however, that technique errors by the study nurses either were largely absent or, if present, were aligned in opposite directions.

Of course, in the practicing physician's office, currently controlled factors such as body posture, blood pressure cuff size, using different arms for measurement, using different noncalibrated devices, room temperature, and physiologic variations that occur with time would necessarily contribute to further inaccuracies in obtaining useful and comparable readings. Having only 1 or 2 nurses taking measurements, rather than the many nurses in the study centers, would amplify any existing errors in following established protocol, just as office physicians, when rechecking blood pressures, would be likely to regularly reproduce errors in their own techniques. Indeed, the pilot study for this project documented an average actual difference of 10 mmHg in both systolic and diastolic readings during the same visits on the same patients. Only 1 physician and a few nursing assistants were involved in the study, which strongly suggests that the same error or errors were affecting the readings at each measurement. Admittedly, the current study did not attempt to assess all factors that could affect the accuracy of auscultatory blood pressure measurement.

In addition, direct comparison of main study with training session data must be made cautiously because of the following differences in the two parts of the study: (1) there were fewer volunteers (7) for the training sessions than there were patients whose blood pressures were measured, and each volunteer stayed for more than one pair of measurements, whereas there was a different patient for each pair of measurements in the main study; (2) the averages of blood pressure readings for the training data were lower than those for the main study; (3) the training session data were collected only in the morning, whereas the main study data were collected during both mornings and afternoons; (4) the control nurse was a registered nurse, whereas the study nurses were mostly licensed practical nurses and medical assistants; and (5) this study did not involve an additional phase during which all nurses were trained and then reassessed.

Finally, the current study, which looked at how much inaccuracy in blood pressure readings at the family practice centers was due to technique factors, highlights several important issues for the practicing physician. First, questioning and then studying basic practice procedures are the only ways to find out what is really happening in the office setting. Second, relying on a single blood pressure reading to make any important clinical decision is inadvisable, because so many variables can affect the accuracy of that measurement. Third, even if all possible variables are addressed, the minimum potential error in systolic or diastolic auscultatory blood pressure measurement between different observers is 4 mmHg (based upon the results of the training sessions). Fourth, such factors as equipment calibration, cuff size, bilateral readings, etc, must be addressed if measurements in the office are to possess any validity for comparison with time (Table 1).

Fifth, regular (re)training office nursing personnel in the proper measurement of office blood pressures should help limit inconsistencies. Sixth, physicians themselves must remember to use proper technique when rechecking their patients' blood pressures. Seventh, multiple readings with time should help limit the clinical consequences of individual erroneous measurements, a concept that is already incorporated into the initial diagnostic criteria for hypertension.

Because of many of the above issues, some researchers have assessed 24-hour ambulatory blood pressure monitoring, and initial studies have shown better correlation with left ventricular wall thickness by echocardiography than with single or multiple visit office measurements.[10,11] Nevertheless, this 24-hour method is not supported by long-term and large-scale epidemiologic studies similar to those proving the benefit of diagnosing and treating hypertension based upon casual office readings.[12] More importantly, recent research supports the validity of continued use of office blood pressure measurements rather than 24-hour ambulatory monitoring in the diagnosis and treatment of hypertension.[13] It appears that the accurate measurement of blood pressure in the office setting will remain central to the optimal treatment of patients.

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