Relationship Between Elevated Automatic Blood Pressure Readings and Manual Blood Pressure Readings in Adult Patients With Normal and High Body Mass Index

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Context: Discrepancies in ambulatory blood mercury sphygmomanometers pressure readings exist between automated blood pressure machines and manual mercury sphygmomanometers. For patients with elevated blood pressure, consistent blood pressure readings between these methods are important across all body mass index (BMI) levels.

Objective: To determine the relationship between automated and manual blood pressure readings and the effect of BMI in patients with an elevated automated blood pressure reading.

Methods: Automated and manual blood pressure readings (using the same arm) were collected from July 2014 to December 2016 across community-oriented primary care clinics in New York City for a retrospective medical record review. Automated systolic blood pressure (SBP) readings greater than 140 mm Hg or diastolic blood pressure (DBP) readings greater than 90 mm Hg were qualifying criteria for a manual blood pressure assessment. The difference in automated blood pressure readings relative to a manual blood pressure reading was assessed overall and for any relationship with BMI using linear regression and analysis of variance.

Results: Data from 281 patients (166 [59%] women, 115 [41%] men; mean [SD] age of 57 [12.6] years) were assessed. For SBP, automated readings had an overall mean that was 8.0% greater than manual readings (P<.001). This relative difference decreased linearly by 2.7 points (95% CI, 1.0-4.4) for each 10-unit increase in BMI (P=.002). For DBP, automated readings had an overall mean that was 4.5% greater than manual readings (P<.001). This relative difference followed a quadratic relationship with BMI (P=.01), where the downward curve peaked at 6.6% (95% CI, 4.5-8.7) for a BMI of 35. When BMI was grouped into 4 categories, (normal weight, overweight, obese, and morbidly obese), morbidly obese patients had a smaller mean percentage SBP difference (4.3% [95% CI, 1.5-7.1]) compared with the other 3 categories (8.6% [95% CI, 7.2-9.9]; P=.007). No relative differences between automated and manual methods for DBP were found among the BMI categories (P=.11).

Conclusions: The current study found significant differences between automated and manual blood pressure readings. The relationship of these differences with BMI was also statistically significant, but their clinical significance remains inconclusive. Because manual blood pressure readings may have clinical value when evaluating or treating a patient with elevated blood pressure, better adherence to proper technique may improve accuracy.


Keywords: blood pressure, hypertension, obesity
Hypertension is a major risk factor for cardiovascular disease, stroke, and mortality. Proper measurement of blood pressure is vital in hypertension management. In clinical practice, the blood pressure reading is one of the most inaccurately performed measurements. Diagnosis and management of hypertension depend on accurate measurement of auscultatory blood pressure. In current practice, automated oscillometric blood pressure devices have largely replaced the manual mercury sphygmomanometer. Automated blood pressure devices are used extensively in outpatient clinic settings, especially by ancillary staff, to increase efficiency and productivity. According to the American Heart Association, however, the manual mercury sphygmomanometer is still the preferred method of taking accurate blood pressure readings.

Worldwide, hypertension is a prevalent comorbidity. An estimated 29.1% of adults aged 18 years or older in the United States have hypertension, which is defined as a systolic blood pressure (SBP) greater than or equal to 140 mm Hg or a diastolic blood pressure (DBP) greater than or equal to 90 mm Hg. In 2011, 3.7 million visits to hospital outpatient departments were billed for essential hypertension as a primary diagnosis. In 2013, 39.9 million patient visits to physician offices were primarily due to essential hypertension. In 2014, a total of 30,221 deaths were attributed to essential hypertension and hypertensive renal disease.

Research suggests that obesity can affect the accuracy of blood pressure measurements in the adult population. Furthermore, if not taken into account, inaccurate blood pressure readings due to suboptimal cuffing may lead to the mismanagement of hypertension. An accurate blood pressure measurement requires that the bladder length of the cuff should be at least 80% of the arm circumference and the width should be at least 40% of the arm circumference. Alternatively, an arm circumference of 2.5 times the bladder width is appropriate. Because of the high prevalence and morbidity of hypertension, the purpose of the current study was to determine the relationship between automated and manual blood pressure readings and the effect of body mass index (BMI) in patients with elevated automated blood pressure readings. We believe that inaccurate blood pressure readings could potentially lead physicians to overtreat patients with falsely elevated blood pressures. We hypothesized that percent changes between automated and manual blood pressure readings would increase with greater BMI because of suboptimal cuff fittings.

Methods

The current medical record review included outpatient encounters of adult patients aged 18 years or older from July 2014 through the beginning of December 2016 from 3 family health centers of NYU Langone Medical Center located in Brooklyn and Manhattan. The original sample size included 300 patient encounters, and each patient encounter represented a unique patient. Inclusion criteria were BMI of 20.0 to 50.0, an elevated automated blood pressure reading indicated by either SBP greater than 140 mm Hg or DBP greater than 90 mm Hg with documentation of the arm used for the reading, and a rechecked manual blood pressure reading from the same arm during the same visit. The readings from 19 patients were eliminated because a BMI greater than 50 was found or a reading with an undocumented matching arm was reported.

In all 3 clinic sites, initial blood pressure readings were automated and obtained by medical assistants while the patient was seated. For confirmation of the automated elevated blood pressure readings, a resident physician measured an aneroid sphygmomanometer manual reading during that encounter. Blood pressure values were rechecked while the patient was seated and within 20 minutes of triage time. Subsequently, values were recorded into the electronic medical record. Rechecked values were from the same extremity.

The outpatient electronic medical records were accessed through a protected computer system, and
data from patient encounters that met our inclusion criteria were transferred to an Excel (Microsoft Corporation) spreadsheet. The following information was recorded: sex, age, race/ethnicity, arm used for the blood pressure reading, patient BMI, automated SBP, automated DBP, manual SBP, and manual DBP. For confidentiality purposes, patient identifiers were not recorded in the spreadsheet.

An initial exploratory analysis of the data resulted in a scatterplot of the mean of the automated and manual readings vs the difference between the automated and manual readings for each patient. We used a \( \chi^2 \) test to assess for a uniform distribution of the ending digits for blood pressure readings across the digits 0 to 9 for each blood pressure type (systolic and diastolic) and method (automated and manual). The clinical relevance of the difference in the 2 blood pressure readings was determined by the percent change from the manual to automated readings relative to the blood pressure recorded from the manual reading. For inferential analyses, the SBP and DBP readings were used to test for overall mean percent change using an intercept-only model, linear or quadratic relationship with BMI using regression models, and difference among 4 BMI categories using analysis of variance (ANOVA) models.

The quadratic relationship was assessed by estimating the quadratic effect parameter in the regression model that also includes the linear effect parameter. The following BMI categories were used: normal (20 to <25), overweight (25 to <30), obese (30 to <35), and morbidly obese (35 to 50). We note that morbidly obese can be defined as having a BMI of 35 or more and experiencing obesity-related health conditions, such as high blood pressure or diabetes, or having a BMI greater than 40 with no obesity-related health conditions. The estimated percent change for the 25th and 75th percentile BMI, defined as 26 and 32, were also calculated. For regression analyses, we estimated an extra parameter to better model the error variance and reported differences in expected outcomes between participants separated by 10 BMI units. We used SAS 9.4 (SAS Institute Inc) to perform the analyses. Data were considered statistically significant at \( P \leq 0.05 \). Estimates of the percent changes were calculated with associated 95% CIs. Figures include 95% CL regions for the regression line and 95% prediction limits for a future observation.

Results

Of 281 patient encounters, 166 patients (59%) were women, 115 (41%) were men, and the mean (SD) age was 57 (12.6) years. The race/ethnicity of the majority of patients was black or Caribbean (165 [59%]), followed by white (82 [29%]), Hispanic/Latino (33 [12%]), and Arab (1 [<1%]).

Exploratory analysis indicated high frequencies of 0 as the ending digit for manual blood pressure readings: 143 SBPs (51%) and 155 DBPs (53%) (\( P < .001 \) for each) (Figure 1). No unique ending digit was as prevalent for the automated blood pressure method as “0” was for the manual method, but there was also evidence of nonuniform distribution of the ending digits of the automated blood pressure readings for each blood pressure type (\( P < .04 \) for each).

For systolic comparisons, the overall mean percent change was 8.0% greater in automated blood pressure readings than in manual readings (95% CI, 6.9-9.1; \( P < .001 \)). Mean percent change in blood pressure decreased with increasing BMI (\( P = .002 \)) (Figure 2A). The expected percent change decreased by 2.7 points (95% CI, 1.0-4.4) for each 10-unit increase in BMI. The expected percent change was 9.1% (95% CI, 7.7-10.5) for the 25th percentile BMI, and 7.5% (95% CI, 6.4-8.5) for the 75th percentile BMI. Body mass index categories were not equal (\( P = .048 \)). Patients who were morbidly obese had a significantly smaller mean percent change (4.3% [95% CI, 1.5-7.1]) than patients in the other 3 categories (8.6% [95% CI, 7.2-9.9]; \( P = .007 \)) (Figure 3A).

For diastolic comparisons, the overall mean percent change was 4.5% greater in automated blood pressure readings than in manual readings (95% CI, 3.1-5.9; \( P < .001 \)). Mean percent change in blood pressure
followed a quadratic relationship with BMI ($P=.01$) (Figure 2B). The curvature was downward with a peak of 6.6% (95% CI, 4.5-8.7) at a BMI of 35. The estimated mean percent change was 3.3% (95% CI, 1.4-5.2) for the 25th percentile BMI and 6.2% (95% CI, 4.4-8.0) for the 75th percentile. No differences in mean percent changes were found among the BMI categories ($P=.11$) (Figure 3B).

**Discussion**

Overall, results of the current retrospective medical record review demonstrate that automated blood pressure readings for SBP and DBP were greater than the readings obtained manually. The current study also found a statistically significant relationship between BMI and the relative differences in SBP and DBP. The SBP percent changes had a slight negative, linear trend, while the DBP percent changes were gently curved downward in a quadratic relationship, with a peak of 6.6% at a BMI of 35. Decreasing percent change with increasing BMI could potentially be attributed to the triage staff’s selection bias of cuff size. Participants who were morbidly obese showed a smaller mean percent change in SBP than those in the other 3 categories. However, no statistically significant differences were found for the mean percent changes in DBP for the 4 BMI categories. Comparatively, a report by Dobson$^6$ showed an increase of 2 to 5 mm Hg in SBP readings and of 1 to 3 mm Hg in DBP readings for every 5-cm increase in arm circumference (measured ≥35 cm).

A possible explanation for our observed results is that there may be a tendency for triage staff to use an improper blood pressure cuff size. In a study by Veiga et al$^7$ that identified arm circumference and blood pressure cuff fit, 82.7% of patients did not meet criteria for properly fitting a standard 12-cm blood pressure cuff, which resulted in overestimated or underestimated blood pressure readings. Although we did not collect cuff size information in the current study, some patients may not have been appropriately fitted for their initial blood pressure measurement, which may have affected our results. A larger-scale study should be conducted to investigate the clinical value of including manual blood pressure readings when evaluating or treating a
patient with a particular BMI. Because we found overall differences between automated and manual blood pressure readings, clinicians should be careful when using automated blood pressure machines and should ensure that a correctly sized cuff is used. Furthermore, they should verify that proper technique is consistently used when automated blood pressure readings are obtained by triage staff.

Our findings may be the result of “white coat hypertension,” where transient elevations of blood pressure may occur from anxiety associated with a physician encounter. It is plausible that some patients initially experienced anxiety, which ameliorated between the triage encounter (automated reading) and the physician encounter (manual reading). Anxiety and physical exertion may affect autonomic function, resulting in elevated SBP. Osteopathic manipulative treatment modalities, including myofascial release and rib raising that target the thoracolumbar (T9-L3) autonomic nervous system, viscerosomatic renal and adrenal Chapman reflex points, or musculoskeletal sources of pain may be incorporated judiciously, and future studies regarding its use in the clinical assessment of blood pressure should be pursued.

The present study had several limitations. For instance, we included data only from encounters with elevated automated blood pressure readings. Studying the differences between automated and manual blood pressure readings in patients with normal automated blood pressure readings might confirm or refute...
patterns noted in our study. The relationship between blood pressure reading and BMI may have been confounded by inaccuracy of automated or manual machinery, use of improperly sized cuffs, auditory acuity of the clinicians, or parallax incurred during measurement.

Other potential sources of error included additional psychosocial stress factors, the posture or arm position of the patient, and measuring biases such as rounded readings, particularly for manual blood pressure readings. Based on the high prevalence of 0 as the ending digit, our results suggest that there was a subconscious tendency of rounding a blood pressure reading to a multiple of 10. The decision of when to round may have been different among different clinicians, which may have further confounded comparisons between automated and manual blood pressure readings. Another potential limitation is that we used 2 electronic medical record systems for the medical record review. Although we reviewed only patient records in which the automated and manual blood pressure readings were obtained from the same arm (left or right), this criterion was dependent on correct notation by the triage staff. A final limitation may have arisen from equipment calibration error, and this error may have varied between various clinic sites.

Future investigations should include a larger population. Results from such a study may demonstrate equal mean percent change in SBP or DBP among patients with hypertension who have a higher BMI. These

![Graph of mean percent change in blood pressure by body mass index (BMI) category (N=281).](image-url)

Figure 3.
Mean percent change in blood pressure by body mass index (BMI) category (N=281). (A) Systolic blood pressure (SBP). (B) Diastolic blood pressure (DBP). BMI categories were defined as the following: normal, 20 to <25; overweight, 25 to <30; obese, 30 to <35; and morbidly obese, 35 to 50. Data are reported with associated 95% CIs. The letters represent the following BMI categories: A, 20 to <25; B, 25 to <27.5; C, 27.5 to <30; D, 30 to <32.5; E, 32.5 to <35; F, 35 to <40; and G, 40 to 50.
studies may benefit from measuring arm circumference as well as recording cuff size used by clinicians assisting with triage and physicians.

Conclusion
The current study found significant differences between automated and manual blood pressure readings. The relationship of these differences with BMI was also statistically significant, but their clinical significance remains inconclusive. Given our noted limitations, we hope a future prospective study will be conducted to address these limitations. Because manual blood pressure readings may have clinical value when evaluating or treating a patient with elevated blood pressure, better adherence to proper technique, regardless of modality, may improve accuracy.

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Author Contributions
All authors provided substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; all authors drafted the article or revised it critically for important intellectual content; all authors gave final approval of the version of the article to be published; and all authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References