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Arm Position and Blood Pressure Readings
The ARMS Crossover Randomized Clinical Trial

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IMPORTANCE Guidelines for blood pressure (BP) measurement recommend arm support on a desk with the midcuff positioned at heart level. Still, nonstandard positions are used in clinical practice (eg, with arm resting on the lap or unsupported on the side).

OBJECTIVE To determine the effect of different arm positions on BP readings.

DESIGN, SETTING, AND PARTICIPANTS This crossover randomized clinical trial recruited adults between the ages of 18 and 80 years in Baltimore, Maryland, from August 9, 2022, to June 1, 2023.

INTERVENTION Participants were randomly assigned to sets of triplicate BP measurements with the arm positioned in 3 ways: (1) supported on a desk (desk 1; reference), (2) hand supported on lap (lap), and (3) arm unsupported at the side (side). To account for intrinsic BP variability, all participants underwent a fourth set of BP measurements with the arm supported on a desk (desk 2).

MAIN OUTCOMES AND MEASURES The primary outcomes were the difference in differences in mean systolic BP (SBP) and diastolic BP (DBP) between the reference BP (desk 1) and the 2 arm support positions (lap and side): (lap or side − desk 1) − (desk 2 − desk 1). Results were also stratified by hypertensive status, age, obesity status, and access to health care within the past year.

RESULTS The trial enrolled 133 participants (mean [SD] age, 57 [17] years; 70 [53%] female); 48 participants (36%) had SBP of 130 mm Hg or higher, and 55 participants (41%) had a body mass index (calculated as weight in kilograms divided by height in meters squared) of 30 or higher. Lap and side positions resulted in statistically significant higher BP readings than desk positions, with the difference in differences as follows: lap, SBP Δ 3.9 (95% CI, 2.5-5.2) mm Hg and DBP Δ 4.0 (95% CI, 3.1-5.0) mm Hg; and side, SBP Δ 6.5 (95% CI, 5.1-7.9) mm Hg and DBP Δ 4.4 (95% CI, 3.4-5.4) mm Hg. The patterns were generally consistent across subgroups.

CONCLUSION AND RELEVANCE This crossover randomized clinical trial showed that commonly used arm positions (lap or side) resulted in substantial overestimation of BP readings and may lead to misdiagnosis and overestimation of hypertension.

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Supplemental content

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Key Points

Question What is the effect of commonly used arm positions on blood pressure (BP) measurements compared to the standard, recommended position?

Findings This crossover randomized clinical trial of 133 adults showed that supporting the arm on the lap overestimated systolic BP by 3.9 mm Hg and diastolic BP by 4.0 mm Hg. An unsupported arm at the side overestimated systolic BP by 6.5 mm Hg and diastolic BP by 4.4 mm Hg, with consistent results across subgroups.

Meaning Commonly used, nonstandard arm positions during BP measurements substantially overestimate BP, highlighting the need for standardized positioning.

Hypertension is the leading cause of cardiovascular disease and preventable mortality worldwide.[1] Accurate blood pressure (BP) measurement is a cornerstone of hypertension diagnosis and management. The latest clinical practice guidelines emphasize several key steps for accurate measurement, including appropriate cuff size selection, back support, feet flat on the floor with legs uncrossed, and appropriate arm position (ie, midcuff positioned at heart level with arm supported on a desk or table). Despite these recommendations, proper arm position is commonly overlooked in daily practice.[2,3] For example, in the US, BP is often measured with patients seated on an examination table without any arm support or with inadequate support (eg, resting on their lap or supported by health care professionals holding the patient's arm). In resource-limited settings, a desk or table for arm support is often unavailable.

Few studies have rigorously evaluated the effects of arm position on BP. Previous studies documenting statistically significant BP overestimation when the arm is unsupported or is positioned with the BP cuff lower than heart level were limited by suboptimal design (eg, nonrandomized comparisons with the reference condition, small sample size, or evaluations in which patients were supine or standing).[4-7] In this context, we performed a crossover randomized clinical trial comparing 3 seated arm positions: (1) the standard reference position (arm supported on a desk with midcuff at heart level), (2) arm resting on the participant's lap, and (3) arm unsupported on the participant's side while adhering to all other recommended BP measurement steps in each condition. We also investigated whether hypertensive level of systolic BP (SBP), older age, obesity status, and no access to health care within the past year affected the effect of arm position on BP readings.

Methods

Study Design

This was a randomized crossover trial conducted among adults in Baltimore, Maryland. The 3 measurement conditions that were conducted in random order were (1) arm supported on a desk with midcuff at approximately midheart level (hereafter, desk 1; reference), (2) hand supported on the lap (hereafter, lap), and (3) arm unsupported on the side (hereafter, side). To account for intrinsic BP variability, all participants underwent a fourth set of triplicate BP measurements with the arm supported on a desk with midcuff at midheart level (hereafter, desk 2), which is the same condition as desk 1. Thus, each participant underwent a total of 12 BP measurements (3 sets of triplicate measurements in randomized order plus 1 set of triplicate measurements with the arm on the desk [desk 2]) (**Figure 1**).

An institutional review board at the Johns Hopkins University School of Medicine reviewed and approved the protocol (Supplement 1).[8] All participants provided written informed consent, and the study adhered to the Consolidated Standards of Reporting Trials (CONSORT) reporting guidelines.

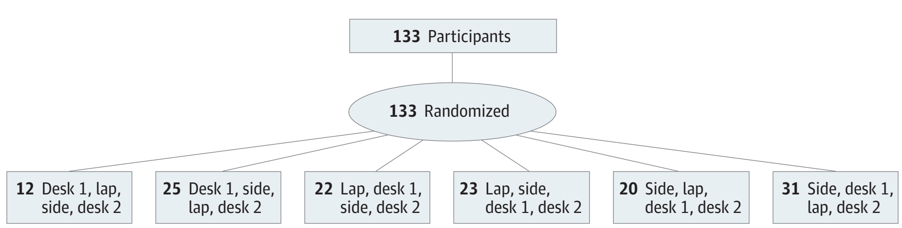
Study Population

Eligible participants were adults between the ages of 18 and 80 years. We excluded individuals presenting with 1 or more of the following conditions: rashes, gauze dressings, casts, edema, paralysis, tubes, open sores or wounds, or arteriovenous shunts on both arms; mental impairment; pregnancy; or a mid-upper arm circumference of more than 55 cm.

Recruitment

From August 9, 2022, to June 1, 2023, we recruited participants using multiple approaches: (1) BP screenings at a public

Figure 1. Randomization Diagram



Participants were randomly assigned to 1 of 6 groups to ensure that each participant experienced all blood pressure measurement conditions in a sequence designed to minimize any potential order effects and biases. Measurement conditions included (1) arm supported on a desk with midcuff at approximately midheart level (desk 1; reference), (2) hand supported on the lap (lap), and (3) arm unsupported at the side (side). To account for intrinsic blood pressure variability, all participants underwent a fourth set of triplicate measurements with the arm supported on a desk with midcuff at midheart level (desk 2).

food market located near the Johns Hopkins University School of Medicine; (2) direct, personalized mailings to previous study participants; (3) informational brochures about the trial placed at Johns Hopkins University hypertension clinics; and (4) recommendations from physicians who specialize in treating individuals with hypertension.

The research team collected self-reported data from participants, including age, sex, racial and ethnic background, weight (body mass index [BMI; calculated as weight in kilograms divided by height in meters squared]), and medical history of hypertension, diabetes, chronic kidney disease, and myocardial infarction, along with the use of antihypertensive medication. Participants were asked to report the approximate date of their last health care professional visit (for either acute or chronic care); health care utilization in the past year was dichotomized as any health care visit in the past 365 days (yes/no).

Sample Size

Assuming 80% power and a type I error probability of a 2-sided α of .05, the target sample size was at least 100 participants to allow us to detect a clinically meaningful difference of 2.5 mm Hg, based on observed standard deviation of BP differences in our previous studies of 8 to 10 mm Hg.[9,10] To allow for prespecified subgroup analyses, we tried to enrich the number of individuals with SBP of 130 mm Hg or higher; thus, the final sample size exceeded 100 participants.

Randomization

Using the RANDBETWEEN function in Excel (Microsoft), we created randomization allocations; the allocation table was uploaded to REDCap (Vanderbilt University).[11] After consent, research staff accessed REDCap to determine the participant's randomization assignment; there was no way for the research staff to know the order of measurement conditions before this step. Participants were randomly assigned to 1 of 6 groups based on the orders mentioned previously, ensuring that each participant experienced all measurement conditions in a sequence designed to minimize any potential order effects and biases.

BP Measurement Procedure

All BP measurements were conducted by 2 research staff members who received standardized training and completed a certification test in BP measurement, administered by an author (J.C.). Measurements took place from 9 AM to 6 PM using a validated oscillometric BP device (ProBP 2000 Digital Blood Pressure Device [Welch Allyn]).[12] Unless a specific condition was present, such as the presence of an open sore, the right arm was used for all measurements. Other than the arm position, all other patient preparatory and positioning recommendations were consistently applied per guidelines for the 3 measurement conditions in this study.

After obtaining consent and asking participants to empty their bladders, participants walked for 2 minutes to replicate a typical clinical scenario before arriving at a BP measurement station. They then underwent a 5-minute seated rest period with their back and feet supported, after which 1 set of 3 BP readings was taken, with measurements spaced 30 seconds apart, using an upper-arm cuff selected based on the participant's measured mid-upper arm circumference. On completing the initial set of triplicate BP measurements, the cuff was removed, and the participant walked for another 2 minutes. After resting again for 5 minutes, another set of 3 BP readings was obtained in the same manner. This cycle was repeated until 4 sets of triplicate BP measurements (totaling 12 readings) were completed. All of the measurements were conducted in a quiet and private space, and participants were asked not to talk to researchers or use their smartphones during BP measurements. BP used in the analysis was the average of the triplicate BP measurements in each set.

Outcomes

The primary outcomes were the difference in differences in mean SBP and diastolic BP (DBP), between the reference BP (desk 1) and the 2 arm positions (lap and side). Specifically, the difference between (1) lap and desk 1 (lap − desk 1) and (2) side and desk 1 (side − desk 1) was compared to the difference between desk 2 and desk 1 (desk 2 − desk 1). The secondary outcomes were the difference in differences in mean SBP and DBP among subgroups. In the subgroup analysis, we examined differences in the primary outcomes by hypertensive BP status (SBP of ≥130 mm Hg vs <130 mm Hg), age (≥60 years vs <60 years), obesity status (BMI of ≥30 vs <30), and health care utilization (no health care visit vs ≥1 health care visit in the past 365 days).

Statistical Analysis

Using paired *t* tests, we assessed the difference in differences of the mean BPs obtained when the arm was in a nonstandard position (lap or side) and when the arm was positioned properly (desk). Specifically, for SBP and DBP, we determined (lap − desk 1) − (desk 2 − desk 1) and (side − desk 1) − (desk 2 − desk 1). This method of calculating the difference in differences, incorporating (desk 2 − desk 1), allowed us to take into account intrinsic, within-person variability of BP. Bland-Altman plots were used to show BP variability among different arm positions. We conducted these analyses for the study population overall and then by the a priori defined subgroups noted previously.

During the analysis of the study, we found that there were unequal numbers of participants allocated to each condition. Exploration of the Excel function RANDBETWEEN[11] revealed that this program did not have the capability of assigning equal numbers of participants to each assignment; thus, the allocation tables that were developed and used during randomization were unequal. This finding prompted us to conduct sensitivity analyses to explore the effect of this unequal distribution on the primary outcomes using linear mixed effect models. For these sensitivity analyses, we defined the main exposure through a dummy variable representing the treatment groups: 0 for the reference group (desk 2 − desk 1), 1 for the (lap − desk 1) group, and 2 for the (side − desk 1) group. The outcome was defined as the difference in mean BP readings between each condition (lap, side, and desk 2) and desk 1. Participant identification number was included as a random intercept to account for individual variability. In these models, we adjusted for the following covariates: age (years), body weight (kg), antihypertensive medication use (yes/no), upper-arm length (cm), arm circumference (cm), SBP (mm Hg), DBP (mm Hg), and the order of BP measurement sets.

A 2-sided $P < .05$ was considered statistically significant. All analyses were performed using R, version 4.2.3 (R Project for Statistical Computing).

Results

Participant Characteristics

A total of 133 participants were randomized into 1 of 6 possible groups that differed by order of the 3 arm positions used for sets of triplicate measurements, with the number of participants in each group ranging from 12 to 31 (Figure 1). The mean (SD) age of the study participants was 57 (17) years, and 70 participants (53%) were female (**Table**). There were 55 participants (41%) with a BMI of 30 or higher, and 109 participants (82%) participants reported recent (<365 days) health care utilization. Detailed participant characteristics by randomized sequence can be found in eTable 1 in Supplement 2.

BP Difference Across Arm Positions in the Entire Population

Average SBP/DBP was 126/74 mm Hg for each of the desk 1 and desk 2 positions, 130/78 mm Hg for the lap position, and 133/78 mm Hg for the side position (**Figure 2**). The distribution of SBP and DBP by arm position is shown in eFigures 1 and 2 and eTable 2 in Supplement 2. The mean (SD) difference between desk 2 and desk 1 was −0.21 (7.26) mm Hg for SBP and 0.09 (3.78) mm Hg for DBP (eTable 3 in Supplement 2). Using the planned difference-in-differences analysis, the lap arm position resulted in statistically significant higher BP readings for both SBP and DBP: ([lap − desk 1] − [desk 2 − desk 1]: mean Δ SBP of 3.9 [95% CI, 2.5-5.2] mm Hg and mean Δ DBP of 4.0 [95% CI, 3.1-4.9] mm Hg). The side arm position resulted in even greater BP differences: ([side − desk 1] − [desk 2 − desk 1]: mean Δ SBP of 6.5 [95% CI, 5.1-7.9] mm Hg and mean Δ DBP of 4.4 [95% CI, 3.4-5.4] mm Hg) (Figure 2). Bland-Altman plots for each contrast are shown in eFigures 3 and 4 in Supplement 2. The variation of BP between 2 arm positions was largely consistent across the ranges of BP.

Subgroup Analysis

Results were largely consistent across subgroups (**Figure 3**). Notably, there was a statistically significant larger difference in lap BPs among those who had not received medical care in the past year (vs those who had) and in side SBPs among those with an SBP of 130 mm Hg or higher (vs <130 mm Hg) (Figure 3).

Sensitivity Analysis

The sensitivity analysis to explore the limitations of the randomization procedure revealed similar results as the primary analysis (eTable 4 in Supplement 2). Therefore, the planned analysis by randomized group is presented as the main analysis.

Table. Characteristics of Participants (N = 133)

Characteristics	No. (%)
Demographic information	
Age	
Mean (SD), y	57 (17)
≥60 y	74 (56)
Sex	
Female	70 (53)
Male	63 (47)
Race[a]	
Asian	3 (2)
Black	103 (77)
White	21 (16)
≥1 Race	6 (5)
Ethnicity[a]	
Hispanic	2 (2)
Non-Hispanic	129 (97)
Other	2 (2)
Medical history	
Prescribed antihypertensive medications	79 (59)
Took antihypertensive medications that day	64 (48)
History of hypertension or myocardial infarction	44 (33)
Acute care visit in past 365 d	71 (53)
Chronic care visit in past 365 d	109 (82)
Anthropometric measurements	
Weight, mean (SD), lb	189 (52)
BMI ≥30	55 (41)
Blood pressure measurements	
SBP, mean (SD), mm Hg	126 (21)
SBP ≥130 mm Hg	48 (36)
DBP, mean (SD), mm Hg	74 (10)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DBP, diastolic blood pressure; SBP, systolic blood pressure.

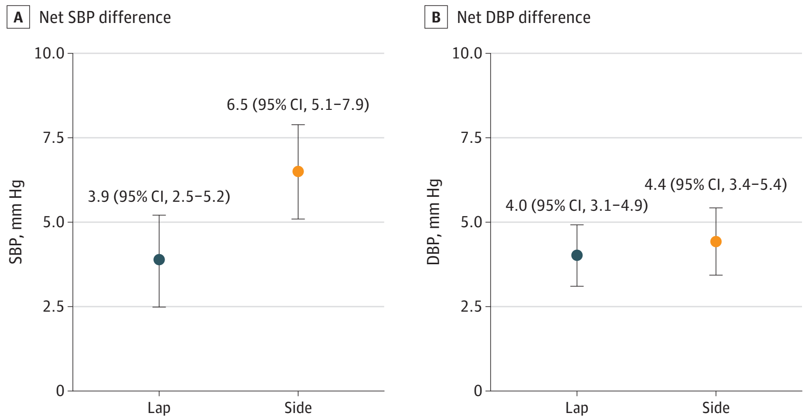
[a] Race and ethnicity were self-selected by the patient.

Discussion

This crossover randomized clinical trial demonstrates the considerable effect of arm position on BP readings. Specifically, when BP measurements are obtained with arm positions frequently used in clinical practice (ie, on the lap or at the side), the readings obtained are markedly higher than those obtained with the arm positioned according to published guidelines. Although the error in SBP with the arm supported in the lap was less striking in magnitude than when the arm was unsupported at the side (approximately 4 mm Hg vs approximately 7 mm Hg), BP readings in either position were sufficiently high to raise concerns for overdiagnosis and overtreatment. These findings were consistent, and also more extreme, among higher-risk groups: SBP was overestimated by approximately 9 mm Hg among individuals with hypertensive BP when their arm was positioned at the side.

This statistically significant BP measurement error when guideline-recommended arm positions are not implemented aligns with prior research.[5-7] Earlier studies have shown that

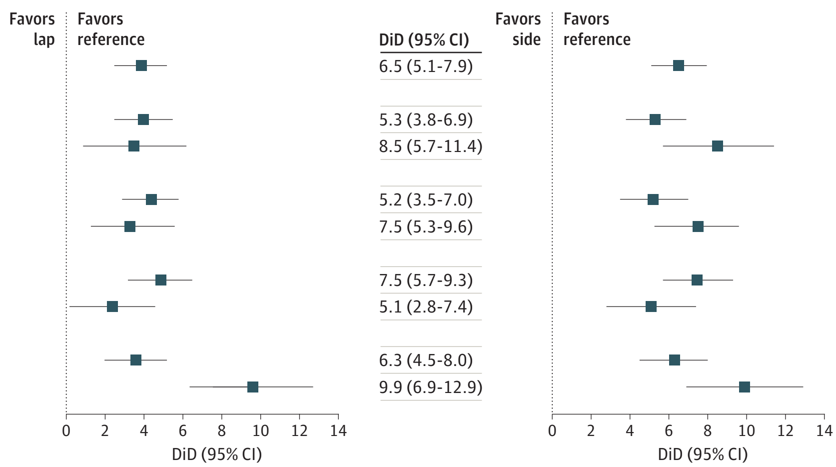
Figure 2. Difference-in-Differences Analysis for Blood Pressure Obtained With the Arm in Different Positions Compared to the Reference Standard



Results compare the difference in differences in blood pressure when the arm is positioned on the lap or hanging at the side compared to when blood pressure is measured with the arm resting on a desk with the cuff at midheart level (reference). DBP indicates diastolic blood pressure; SBP, systolic blood pressure. Error bars represent 95% CIs.

Figure 3. Difference-in-Differences (DiD) Analysis for Systolic Blood Pressure (SBP) Obtained With the Arm in Different Positions Compared to the Reference Standard Among Subgroups

Subgroup	No. of participants	DiD (95% CI) (lap)	DiD (95% CI) (side)
All	133	3.9 (2.5-5.2)	6.5 (5.1-7.9)
SBP			
<130 mm Hg	85	4.0 (2.5-5.3)	5.3 (3.8-6.9)
≥130 mm Hg	48	3.5 (0.9-6.2)	8.5 (5.7-11.4)
Age			
<60 y	59	4.4 (2.9-5.8)	5.2 (3.5-7.0)
≥60 y	74	3.3 (1.3-5.6)	7.5 (5.3-9.6)
BMI[b]			
<30	78	4.9 (3.2-6.5)	7.5 (5.7-9.3)
≥30	55	2.4 (0.2-4.7)	5.1 (2.8-7.4)
Last health care utilization			
<365 d	101	3.6 (2.0-5.2)	6.3 (4.5-8.0)
≥365 d	8	9.6 (6.4-12.7)	9.9 (6.9-12.9)



Results compare the difference in differences in BP when the arm is positioned on the lap or hanging at the side compared to when BP is measured with the arm resting on a desk with the cuff at midheart level (reference). BMI indicates body mass index (calculated as weight in kilograms divided by height in meters squared).

unsupported or arm positioning below heart level can overestimate SBP by 4 to 23 mm Hg and DBP by 3 to 12 mm Hg.[4] However, the present study has notable strengths over these earlier studies. The randomized crossover design we implemented is ideal for the study of differences in BP, which is in contrast to the majority of published studies where the order of arm positions before seated BP measurement was not randomized or not clearly described.[5,7] The sample size in the present study was also substantially greater than that of prior trials (<50 participants).[6,7] Another differentiating characteristic of this trial is that we focused the investigation on arm positions commonly used in BP screening environments and clinical settings. Most published studies compare BP measurements obtained with the arm positioned while standing or supine, which are not the recommended postures for diagnosing and managing hypertension.[4,13-15] Finally, we provide rigorous data regarding the effect of arm position on BP measurement when using an automated device instead of a manual sphygmomanometer,[6,14,16] reflecting contemporary clinical practice.[17,18]

In addition to overcoming the limitations of other studies, this study also offers several unique observations not previously reported. We demonstrate that when the arm is completely unsupported and hanging at the side, as is often the case when arm support on a desk or chair is not possible or when a patient is seated on the examination table in a clinic room, BP is greatly overestimated. Furthermore, positioning the arm in the lap, a typical compromise for the above scenarios, also results in considerable BP overestimation. Thus, these arm positions should not be used, even in the setting of limited time or resources.[19-23] Proper arm position may be even more important for individuals at higher risk for cardiovascular disease, particularly those with hypertensive SBP.

Several physiological mechanisms likely explain why BP measurements are higher when the arm is not optimally positioned or supported. First, the vertical distance between the heart and the cuff increases when the arm is positioned in the lap or at the side (vs when it is supported on a desk with midcuff at heart level). This increase in distance when the arm is positioned at levels below the heart leads to an increase in hydrostatic pressure (the force exerted due to gravitational pull) in the brachial artery.[24] Additionally, with these lower arm positions, there is decreased venous return and compensatory vasoconstriction leading to an increase in vascular resistance and an increase in BP.[13,25] Moreover, an unsupported arm can lead to muscle contraction, which may cause transient increases in BP.[26,27] It should be noted that the present trial was not designed to distinguish between the effects of arm position and support (eg, the side arm position included both lower arm position and lack of support).

Although clinical guidelines emphasize positioning the arm at midheart level with support during BP measurements, this practice is often overlooked in clinical settings.[17,18] Several factors contribute to this discrepancy: lack of health care professional awareness about the effect of arm position on measurement accuracy, as well as limitations in training, resources, and equipment, particularly in resource-limited environments.[28] The error in BP measurement resulting from nonadherence to this recommendation has the potential to lead to substantial hypertension overdiagnosis, unnecessary patient follow-ups, and overtreatment. Inaccurate arm positioning can overestimate BP by up to 5 mm Hg generally and close to 10 mm Hg in individuals with high levels of SBP. Based on our calculations using data from the National Health and Nutrition Examination Survey, improper arm position would result in 16% of US adults, equating to 40 million individuals, being misclassified as hypertensive when using a SBP cutoff of 140 mm Hg and higher, and 22% (54 million individuals) would be misclassified when using a SBP cutoff of 130 mm Hg and higher.[29] Considering the varied health care practices, equipment standards, and training levels across different countries, the likelihood of misdiagnosis could be even greater.

Discrepancies in BP data between electronic health records and research settings have been reported[30]; suboptimal measurement technique, including nonadherence to supported arm positioning, likely contributes to these differences. Since the number of studies using electronic health record data is increasing, researchers should cautiously interpret BP data in this context and understand their limitations. Simultaneously, health care systems should continue efforts to improve and maintain the quality of BP measurements obtained for patient management and research, and even consider a regulatory approach to promote standardized measurements of BP.[31] Out-of-office BP measurement, often conducted in the home environment, is important in the diagnosis and management of hypertension.[32,33] Appropriate patient preparation and positioning prior to BP measurements, including using the appropriate arm position, is as important for home measurements as it is for measurements obtained in the clinic. Therefore, education and training of both clinical staff and patients regarding BP measurement is essential for hypertension control and cardiovascular disease prevention.

Limitations

This study has limitations. First, as noted previously, the use of the RANDBETWEEN function resulted in the unequal random distribution of participants to each group. However, an extensive set of sensitivity analyses adjusting for participant characteristics and order demonstrated consistent results with the a priori analysis. Second, some subgroups included relatively small sample sizes; thus, the results of subgroup analyses need to be interpreted carefully. Finally, it is uncertain to what extent the present results can be generalizable to other settings (eg, different BP devices).

Conclusions

This crossover randomized clinical trial shows that not adhering to the guideline-recommended arm position and support during BP measurement can result in overestimation of BP by 4 to 10 mm Hg. This degree of BP error could lead to a substantial number of people being overdiagnosed with hypertension.

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Concept and design: Sabit, Ishigami, Charleston, Miller, Matsushita, Appel, Brady.
Acquisition, analysis, or interpretation of data: Liu, Zhao, Sabit, Pathiravasan, Miller, Matsushita, Appel, Brady.
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