Original Article

Simplified blood pressure measurement approaches and implications for hypertension screening: the Atherosclerosis Risk in Communities study

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Objectives: Averaging multiple blood pressure (BP) measurements is recommended for hypertension (HTN) screening but can be impractical, especially in resource-constrained settings. We aimed to explore the implications of fewer BP measurements on BP classification and subsequent cardiovascular disease (CVD) risk.

Methods: We studied 8905 middle-aged participants without diagnosed HTN and quantified misclassified HTN ($\geq$140/90 mmHg) by simplified BP approaches (e.g. single 1st BP, single 2nd BP, mainly 1st but 2nd BP if 1st was in a certain range) vs. the reference standard of the average of 2nd and 3rd BP. We also assessed CVD risk related to HTN status.

Results: There were 823 participants classified as HTN by the standard approach. With single 1st BP, 2.8% of non-HTN were overidentified as HTN, and 18.3% of HTN were identified as not having HTN. The corresponding estimates with single 2nd BP were 2.1 and 6.4%. Similar estimates were seen when 2nd BP was used if 1st BP at least 130/80 (1.9 and 8.1%), with only 27.8% requiring 2nd BP. Two thousand, one hundred and seventy-eight CVD cases were documented in this population over 30 years. HTN by either the standard approach or any of the simplified approaches conferred higher CVD risk vs. consistent no HTN by both approaches.

Conclusion: In those without diagnosed HTN, a simplified BP measurement approach using the 2nd BP only when the 1st BP is at least 130/80 could reduce the total number of BP measurements by more than 50%, identify HTN with limited misclassification (2–8%), and predict CVD risks reasonably well.

Keywords: blood pressure, blood pressure measurement/monitoring, cardiovascular disease, classification, high blood pressure, hypertension

Abbreviations: BP, blood pressure; CVD, cardiovascular disease; HTN, hypertension

INTRODUCTION

Accurate measurement of blood pressure (BP) is essential to properly screen, diagnose, and manage hypertension (HTN). Since BP can be highly variable due to physiological variation and measurement methods [1,2], clinical guidelines recommend measuring BP multiple times at each encounter and recording their average [3,4]. However, this recommendation can be a barrier for large HTN control programs, particularly in resource-constrained settings [5]. For example, May Measurement Month, a screening campaign initiated by the International Society of Hypertension, screened 1.5 million adults in 2018 with three measurements per person at a single visit [6]. If a few minutes can be saved by fewer measurements in each adult, the initiative might have screened many more individuals over the same time period.

Significantly, a recent study using data from the National Health and Nutrition Examination Survey demonstrated that a reclassification by the average of the last two measurements from initial BP was relatively small (<10%) [7]. This raises the possibility that fewer BP measurements may be acceptable in some individuals and certain scenarios.

To more comprehensively explore this issue, using data from a US community-based cohort, the Atherosclerosis Risk in Communities (ARIC) Study, we evaluated misclassification of HTN by several different simplified approaches (e.g., single 1st BP, single 2nd BP, or mainly 1st but 2nd BP if 1st BP in a certain range) vs. the reference standard of the average of 2nd and 3rd BP at a single visit. We also assessed the risk of cardiovascular disease (CVD) according to BP classification by simplified vs. standard BP approaches.

METHODS

Study population

The ARIC Study recruited 15 792 participants aged 45–64 years from four communities of the US (Forsyth County,

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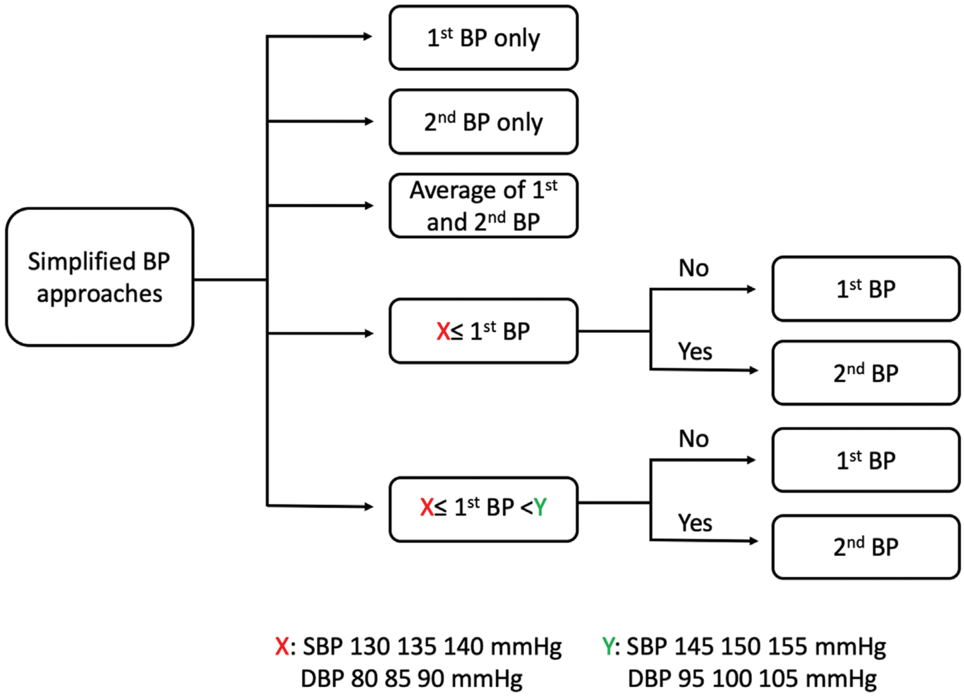

FIGURE 1 Definition of simplified blood pressure approaches. BP, blood pressure.

North Carolina; Jackson, Mississippi; suburban Minneapolis, Minnesota; and Washington County, Maryland) at baseline in 1987–1989 [8]. For cross-sectional analysis, out of 15 792 participants, we excluded 48 non-whites/blacks, 24 missing any BP measurements, eight lacking antihypertensive medication information, and 605 missing data on covariates of interest, leaving 15 107 participants. Of those, we primarily focused on 8905 participants without diagnosed HTN at baseline since our study was based on BP data on a single day and will be most relevant to screening. We secondarily explored those with diagnosed HTN. For the survival analysis, we further excluded 1520 prevalent CVD cases (including coronary heart disease, stroke, and heart failure) and 95 missing incident CVD information, leaving a sample size of 13 492 participants (including 8587 participants without diagnosed HTN).

The ARIC Study has been approved by the Institutional Boards of all study sites. Written informed consent was provided by each ARIC participant.

Blood pressure measurement in the Atherosclerosis Risk in Communities Study

BP in the seated position was measured by a certified, trained technician following a standardized protocol [9]. ARIC participants were requested not to smoke, eat, exercise, or expose themselves to cold temperature for at least 30 min before measurements. After 5 min of quiet rest, three readings were taken 1-min apart using a standardized Hawksley random-zero sphygmomanometer. Participants were classified as having a prior HTN diagnosis if they answered in the affirmative to either of following questions: 'having high BP or HTN ever diagnosed' or 'taking anti-HTN medication within the past 2 weeks.'

Reference standard blood pressure and simplified blood pressure approaches

The reference standard BP measurement for this study was the average of the 2nd and 3rd BP, which is the approach that is endorsed by research and clinical guidelines [3,9–11], and is in concordance with a survey protocol by the World Health Organization [11].

We explored several simplified BP assessment approaches requiring less than three BP measurements (Fig. 1). These included single 1st BP, single 2nd BP, and their average. We also explored approaches mainly relying on 1st BP but using 2nd BP only when 1st BP was higher than a certain threshold. As thresholds, we investigated all possible combinations of 1st SBP of 130, 135, 140 mmHg and DBP of 80, 85, 90 mmHg. As an extension of this approach, we added upper thresholds of SBP 145, 150, 155 mmHg and DBP 95, 100, 105 mmHg, and used 2nd BP only when the 1st BP level was between lower and higher thresholds.

Covariates

Demographic characteristics (age, sex, race, education), lifestyles (smoking, alcohol use), and clinical factors (BMI, heart rate, total and high-density lipoprotein cholesterols, cholesterol-lowering medication, estimated glomerular filtration rate, and diabetes) were collected at baseline following the standard protocol (Supplementary Material, http://links.lww.com/HJH/B482) [8].

Incident cardiovascular disease

Incident CVD included the first occurrence of coronary heart disease, stroke, or heart failure, whichever came first, and was ascertained via follow-up visits, annual follow-up contacts (semi-annual follow-up contacts after 2012), and

		Standard BP approach identified HTN	
		-	+
Simplified BP approach identified HTN	-	Consistent Non-HTN	Missed HTN (false negative)
	+	Overidentified HTN (false positive)	Consistent HTN

Proportion of Overidentified HTN= $\frac{Overidentified\ HTN}{Consistent\ NonHTN + Overidentified\ HTN}$

Proportion of Missed HTN= $\frac{Missed\ HTN}{Missed\ HTN + Consistent\ HTN}$

FIGURE 2 Blood pressure cross-categories in combinations of simplified vs. standard approaches. BP, blood pressure; HTN, hypertension.

community-wide hospital surveillance [12]. The end of follow-up for this study was 31 December 2016. Details are provided in the Supplementary Material, http://links.lww.com/HJH/B482.

Statistical analysis

Cross-sectional analysis

We quantified the proportion of overidentified HTN and missed HTN by simplified BP approaches when compared with the standard approaches (Fig. 2). HTN was defined as SBP/DBP at least 140/90 mmHg [3].

Survival analysis

We first evaluated the BP-CVD relationship based on different BP approaches. BP was modeled continuously with spline terms, with knots at SBP 120, 130, 140, and 150 and DBP 70, 80, and 90 mmHg. Subsequently, we evaluated the CVD risk across BP cross-categories in combinations of simplified vs. standard approaches mentioned in Fig. 2 (consistent no HTN in both approaches as the referent). We used Kaplan–Meier method to estimate the cumulative incidence of CVD, and then used Cox proportional hazards models to quantify the hazard ratios accounting for the covariates noted above.

Finally, we conducted a subgroup analysis according to age, sex, and race. All analyses were performed with Stata version 14.0, and a P value less than 0.05 was considered statistically significant.

RESULTS

Baseline characteristics and population-level blood pressure summary statistics

The mean age of 8905 participants without a previous diagnosis of HTN was 53.5 (SD 5.7) years, with 53.8% female and 18.9% black (Supplemental Table I, http://links.lww.com/HJH/B482). The mean SBP and DBP was similar (differences <0.5 mmHg) across 1st BP, 2nd BP, 3rd BP, and the average of 1st and 2nd, 2nd and 3rd, and all three measurements (Table 1). Accordingly, the prevalence of HTN (9–10%) were similar within each group regardless of BP approaches.

Individual-level blood pressure misclassification

The greatest proportion of HTN misclassification was seen when SBP and DBP were near the threshold of HTN, namely 140/90 mmHg (Supplemental Table II, http://links.lww.com/HJH/B482). When relying on 1st BP, 2.8% of non-HTN was overidentified as HTN while 18.3% of HTN was identified as not having HTN (e.g., missed HTN) (Fig. 3 and Supplemental Table III, http://links.lww.com/HJH/B482). Less misclassification was seen when we relied on the single 2nd BP (2.1% overidentified HTN and 6.4% missed HTN) or the average of 1st and 2nd BP (1.3 and 13.7%, respectively) but these approaches required 2nd BP in all participants.

Simplified approaches with restricted use of 2nd BP yielded similar proportions of overidenfied and missed HTN as when the single 2nd BP was employed for all. For example, when we used 2nd BP only if 1st BP was at least 130/80 mmHg, overidentified HTN and missed HTN occurred in 1.9 and 8.1%, respectively (Fig. 3 and Supplemental Table III, http://links.lww.com/HJH/B482); notably, only 27.8% required a 2nd BP with this approach. Adding upper thresholds in addition to lower threshold of 130/80 mmHg did not substantially change the estimates.

Incident cardiovascular disease according to blood pressure with simplified and standard approaches

During a median follow-up of 24.9 years (maximum of 30.1 years), we documented 2178 incident CVD. As shown in Supplemental Fig. I (A and B, http://links.lww.com/HJH/B482), at a population level, the BP-CVD relationship was

TABLE 1. Baseline blood pressure characteristics using single or averaged multiple blood pressure measurements among individuals without diagnosed hypertension

	1st	2nd	3rd	Avg (1st + 2nd)	Avg (2nd + 3rd)[a]	Avg (1st + 2nd + 3rd)
SBP	115.8 (16.3)	116.2 (16.3)	116.0 (16.0)	116.0 (15.9)	116.1 (15.8)	116.0 (15.7)
DBP	70.5 (10.5)	71.0 (10.2)	71.2 (10.2)	70.7 (10.0)	71.1 (9.9)	70.9 (9.9)
Hypertension (%)	900 (10.1)	936 (10.5)	905 (10.2)	814 (9.1)	823 (9.2)	776 (8.7)

[a]Standard approach (reference).

Simplified Approach	Misclassificaiton						
	Consistent Non-HTN	Overidentified HTN	Missed HTN	Consistent HTN	Proportion of Overidentified HTN (%)	Proportion of Missed HTN (%)	Proportion of paticipants requiring 2nd BP (%)
1st	7854	228	151	672	2.8	18.3	0
2nd	7916	166	53	770	2.1	6.4	100
Avg(1st+2nd)	7978	104	113	710	1.3	13.7	100
2nd if 1st BP ≥130/80	7932	150	67	756	1.9	8.1	27.8
2nd if 1st BP ≥135/85	7967	115	109	714	1.4	13.2	15.7
2nd if 1st BP ≥140/90	8020	62	177	646	0.8	21.5	10.1
2nd if 1st BP=130-145/80-95	7903	179	58	765	2.2	7.0	22.1
2nd if 1st BP=130-150/80-100	7921	161	63	760	2.0	7.7	23.8
2nd if 1st BP=130-155/80-105	7925	157	66	757	1.9	8.0	25.6

FIGURE 3 Hypertension misclassification by the simplified approaches vs. averaged last two blood pressure measurements among individuals without diagnosed hypertension at baseline (complete list showed in the Supplementary Materials, http://links.lww.com/HJH/B482). BP, blood pressure; HTN, hypertension.

largely the same regardless of simplified vs. standard approaches.

Incident cardiovascular disease according to blood pressure cross-categories by simplified and standard approaches

For single 1st BP vs. the average of 2nd and 3rd BP, cumulative incidence of CVD was the highest for consistent HTN and lowest for consistent no HTN (Fig. 4a). Cumulative incidence of CVD was similar between overidentified HTN and missed HTN until ~20 years, but then the latter showed higher cumulative incidence. When we used 2nd BP only if 1st BP was at least 130/80 mmHg (with lower misclassification than single 1st BP and 27.8% requiring 2nd BP), consistent HTN, overidentified HTN, and missed HTN showed similar cumulative incidence (Fig. 4b).

We generally confirmed this CVD risk pattern using multivariable Cox models (Table 2 and Supplemental Table IV, http://links.lww.com/HJH/B482). Compared with consistent no HTN, consistent HTN robustly showed significantly elevated CVD risk across all simplified approaches, with adjusted hazard ratios ~1.6. Missed HTN demonstrated hazard ratios 1.5–1.8. Hazard ratios for overidentified HTN were somewhat heterogeneous [e.g., hazard ratio 0.98 (0.76–1.26) for single 1st BP] but most scenarios had hazard ratio ~1.5–1.7.

Largely consistent misclassification and CVD risk patterns were obtained for demographic subgroups explored (Supplemental Table V–VII, http://links.lww.com/HJH/B482). However, among participants without prior HTN diagnosis, missed HTN demonstrated more evident associations with elevated CVD risks in females than in males (Supplemental Table VI, http://links.lww.com/HJH/B482). In general, more overidentified HTN, but less missed HTN, occurred in blacks than in whites (Supplemental Table VII, http://links.lww.com/HJH/B482). Moreover, blacks were two-times more likely to require a 2nd BP measurement than whites.

Results in participants with diagnosed hypertension

The prevalence of uncontrolled HTN among those with a prior HTN diagnosis (28–30%) and the BP-CVD relationship were similar regardless of BP approaches (Supplemental Fig. I, C and D, http://links.lww.com/HJH/B482). However, regarding individual-level misclassification,

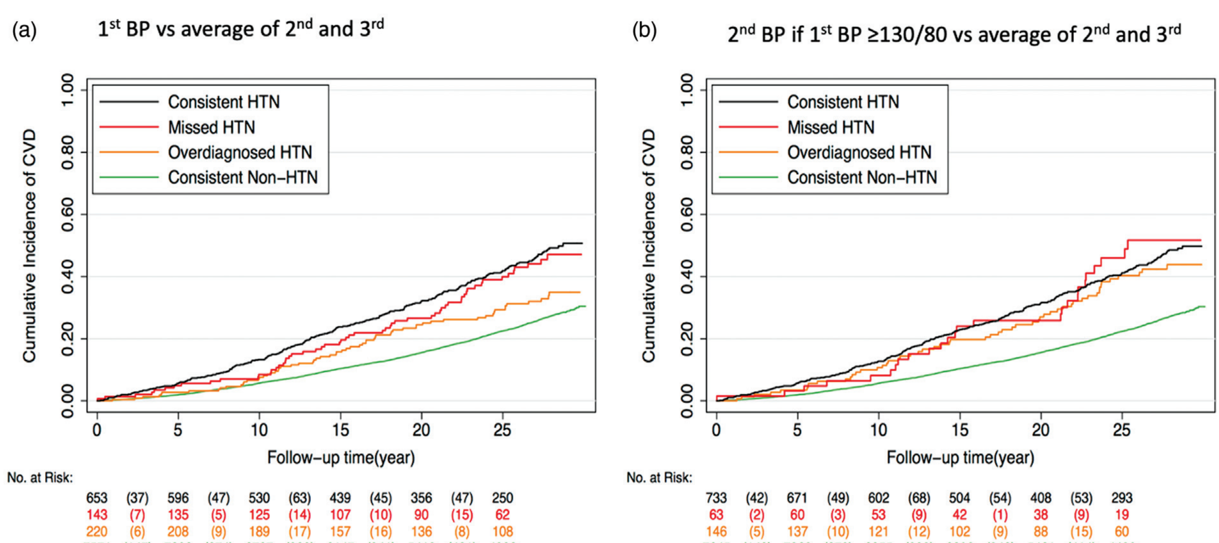

FIGURE 4 Kaplan–Meier curves showing cumulative incidence of cardiovascular disease by blood pressure cross-categories defined by 1st vs. averaged 2nd and 3rd blood pressure measurements (a), and by 2nd if 1st blood pressure at least 130/80 vs. averaged 2nd and 3rd blood pressure measurements (b) among individuals without diagnosed hypertensive at baseline. Kaplan–Meier for other simplified-standard approach combinations were not shown. BP, blood pressure; HTN, hypertension.

TABLE 2. Adjusted hazard ratios (95% confidence interval) of cardiovascular disease across blood pressure cross-categories by simplified approach vs. averaged last two readings among individuals without diagnosed hypertension (complete list showed in the supplementary materials, http://links.lww.com/HJH/B482)

Simplified approach	Consistent non-HTN	Overidentified HTN	Missed HTN	Consistent HTN
1st	1 (Ref.)	0.98 (0.76–1.26)	1.69 (1.30–2.21)*	1.60 (1.40–1.83)*
2nd	1 (Ref.)	1.57 (1.21–2.05)*	1.47 (0.93–2.31)	1.66 (1.46–1.88)*
Avg (1st + 2nd)	1 (Ref.)	1.18 (0.83–1.68)	1.74 (1.29–2.34)*	1.61 (1.41–1.83)*
2nd if 1st BP ≥ 130/80	1 (Ref.)	1.62 (1.23–2.13)*	1.79 (1.21–2.64)**	1.63 (1.43–1.85)*
2nd if 1st BP ≥ 135/85	1 (Ref.)	1.69 (1.24–2.32)**	1.77 (1.30–2.40)*	1.62 (1.42–1.85)*
2nd if 1st BP ≥ 140/90	1 (Ref.)	1.21 (0.75–1.95)	1.71 (1.34–2.18)*	1.60 (1.39–1.83)*
2nd if 1st BP = 130–145/80–95	1 (Ref.)	1.46 (1.14–1.88)**	1.65 (1.07–2.55)***	1.64 (1.45–1.86)*
2nd if 1st BP = 130–150/80–100	1 (Ref.)	1.49 (1.15–1.95)**	1.80 (1.20–2.70)**	1.63 (1.43–1.85)*
2nd if 1st BP = 130–155/80–105	1 (Ref.)	1.54 (1.18–2.01)**	1.75 (1.18–2.60)**	1.63 (1.44–1.86)*

Models adjusted for age, sex, and race, education level, smoking and drinking status, BMI, heart rate, total, and high-density lipoprotein cholesterol, cholesterol-lowering medication, estimated glomerular filtration rate, prevalent diabetes. BP, blood pressure; HTN, hypertension.
*$P < 0.001$.
**$P < 0.01$.
***$P < 0.05$.

compared with those without a prior HTN diagnosis, participants with a prior diagnosed HTN showed a higher proportion of overidentified uncontrolled HTN but lower proportion of missed uncontrolled HTN (e.g., 4.3 and 6.0% with 2nd BP if 1st BP ≥130/80) and were more likely to require 2nd BP (56.7%) (bottom half Supplemental Table III, http://links.lww.com/HJH/B482). In this population, an elevated CVD risk was largely restricted to consistent uncontrolled HTN by both a simplified approach and the standard approach (bottom half of Supplemental Table IV, http://links.lww.com/HJH/B482).

DISCUSSION

In this study using data from the large community-based cohort of ARIC, we observed several key findings. At the population level, the average BP levels and prevalence of HTN, and the BP-CVD risk relationship was very similar regardless of simplified and standard approaches. Therefore, if the goal is to estimate population-level prevalence of HTN or quantify the BP-CVD risk relationship, by following a standardized BP measurement process, simplified approaches, even single 1st BP, are likely to be reasonable options.

However, if the goal is to screen individuals for HTN, our study suggests that single 1st BP is not optimal among individuals without diagnosed HTN, with 2.8% overidentified HTN and 18.3% of missed HTN. These observations warn against employing a common practice for opportunistic screening with a single BP measurement [5,13,14]. Further enhancing the concern of relying on single 1st BP for HTN screening is that isolated high single 1st BP was not related to CVD risk.

A single 2nd BP, instead, performed relatively well in both classifying HTN status and classifying HTN-related CVD risks. However, taking two BP measurements for everyone can still be time and resources intensive. In fact, available evidence has shown that many clinical decisions are made based solely on a single BP reading [15]. Moreover, discarding the 1st BP measurement may bring some negative consequences. For example, if personnel measuring BP know that the 1st BP will be discarded, the first measurement may not be done appropriately, which may influence the quality of 2nd BP measurement as well.

Although it is ideal to measure BP multiple times per encounter, when this is not practical, our results suggest that obtaining a 2nd BP, only when 1st BP is in a certain range, seems to be a promising alternative option. For example, the use of 2nd BP if 1st BP at least 130/80 mmHg required a 2nd BP measurement in approximately a quarter of individuals without diagnosed HTN and resulted in 1.9% overidentified HTN and 8.1% missed HTN. Importantly, the threshold of 1st BP at least 130/80–90 mmHg for 2nd BP measurement demonstrated consistent optimal results using data from ARIC visits 2 and 3 (data not shown).

This simplified approach of using 2nd BP only if 1st BP at least 130/80 mmHg will reduce the total number of BP measurements by more than 50% (average of 1.28 measurements vs. three measurements in the standard approaches). Relevant clinical scenarios would be HTN screening and regular health check-ups. Protocolizing such a simplified approach could facilitate the process from screening to diagnosis as it would not heavily rely on decision-making by front-line staff nor would it require averaging of measurements by healthcare personnel, which would save time and medical resources and be less error-prone.

There are significant implications from misclassification of HTN status. Individuals with overidentified HTN in this study actually had significantly elevated risk for CVD. Thus, initiation of HTN treatment, particularly implementation of lifestyle modifications such as smoking cessation, reduced salt intake, improved diet, and increased physical activity, may be beneficial. By contrast, missed HTN may be more problematic since people in this category are at elevated CVD risk but would miss opportunities for risk reduction and counseling. Thus, regular screening programs (e.g. every few years) may be required to capture those missed HTN cases [16].

Our results were less definitive among individuals with a previous diagnosis of HTN. Specifically, a given simplified approach had a greater proportion of overidentified HTN in participants with diagnosed HTN vs. those without diagnosed HTN and required 2nd BP in a greater proportion. Moreover, elevated CVD risk was largely restricted to consistent uncontrolled HTN. These observations are likely to reflect high BP variability in hypertensive patients [17,18]; hence, relying on a single or a few inconsistent BP measures might lead to inadequate HTN management and CVD risk classification. Thus, whenever possible, standard approaches with more than two measurements seem especially preferable for these patients.

Our study has limitations. BP was measured by trained and certified staff following a standardized BP measurement protocol that included a 5-min premeasurement rest period, which may not reflect real world clinical settings. However, from another perspective, the high-quality BP measurements by staff without medical background in ARIC encourages task-shifting/sharing with appropriate training [19]. Second, BP was obtained using a mercury sphygmomanometer, and thus confirmatory studies with oscillometric devices would be warranted. Third, we did not have repeated BP on another day, which is recommended for diagnosing HTN. Finally, our study was conducted among blacks/whites aged 45–64 at baseline in the United States, and thus our results should be generalized cautiously to other racial groups, age ranges, and regions.

In conclusion, a simplified BP approach using a 2nd BP only when the 1st BP is at least 130/80 could potentially reduce the number of recommended BP measurements considerably, identify HTN with limited misclassification (2–8%), and predict CVD risks reasonably well in those without previously diagnosed HTN.

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Conflicts of interest

There are no conflicts of interest.

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