Measuring Blood Pressure for Decision Making and Quality Reporting: Where and How Many Measures?

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Background: The optimal setting and number of blood pressure (BP) measurements that should be used for clinical decision making and quality reporting are uncertain.

Objective: To compare strategies for home or clinic BP measurement and their effect on classifying patients as having BP that was in or out of control.

Design: Secondary analysis of a randomized, controlled trial of strategies to improve hypertension management. (ClinicalTrials.gov registration number: NCT00237692)

Setting: Primary care clinics affiliated with the Durham Veterans Affairs Medical Center.

Patients: 444 veterans with hypertension followed for 18 months.

Measurements: Blood pressure was measured repeatedly by using 3 methods: standardized research BP measurements at 6-month intervals; clinic BP measurements obtained during outpatient visits; and home BP measurements using a monitor that transmitted measurements electronically.

Results: Patients provided 111 181 systolic BP (SBP) measurements (3218 research, 7121 clinic, and 100 842 home measurements) over 18 months. Systolic BP control rates at baseline (mean SBP <140 mm Hg for clinic or research measurement; <135 mm Hg for home measurement) varied substantially, with 28% classified as in control by clinic measurement, 47% by home measurement, and 68% by research measurement. Short-term variability was large and similar across all 3 methods of measurement, with a mean within-patient coefficient of variation of 10% (range, 1% to 24%). Patients could not be classified as having BP that was in or out of control with 80% certainty on the basis of a single clinic SBP measurement from 120 mm Hg to 157 mm Hg. The effect of within-patient variability could be greatly reduced by averaging several measurements, with most benefit accrued at 5 to 6 measurements.

Limitation: The sample was mostly men with a long-standing history of hypertension and was selected on the basis of previous poor BP control.

Conclusion: Physicians who want to have 80% or more certainty that they are correctly classifying patients' BP control should use the average of several measurements. Hypertension quality metrics based on a single clinic measurement potentially misclassify a large proportion of patients.

Primary Funding Source: U.S. Department of Veterans Affairs Health Services Research and Development Service.

Ann Intern Med. 2011;154:781-788. www.annals.org

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The measurement and treatment of blood pressure (BP) is one of the most common and important reasons for visiting a physician (1, 2). Advances in antihypertensive therapy have dramatically reduced cardiovascular, cerebrovascular, and renal events (3–5), and the ability to effectively treat high BP is one of the greatest medical advances of the past century.

It is widely believed that the harmful effects of elevated BP are primarily attributable to a person's average daily (or true) BP (6–8), with particular emphasis given to systolic BP (SBP) (9, 10). However, a person's underlying true BP is not readily available at the point of care, and the clinician must infer the true value on the basis of a small number of measurements from either the clinic or the home. Early evidence linking BP with clinical outcomes was based on standardized research measurements by using a well-defined protocol and mercury sphygmomanometers (11–13). Clinic measurements with nonmercury devices attempt to replicate this standard but frequently fall short because of measurement technique or observer effects (that is, white-coat effect) (14–16). Furthermore, although any home or clinic BP measurement approximates the patient's true BP, it is also subject to short-term biological fluctuations and measurement error, which together result in substantial short-term variability of observed BP (17). This short-term variability has been recognized as an important threat to both clinical decision making and hypertension research (14, 18–20).

There is no consensus among clinical guidelines and quality-reporting standards on the setting, timing, and total number of BP measurements that should be used for classifying patients and making treatment decisions. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High

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Context

Blood pressure readings obtained during clinical encounters are generally used to determine the adequacy of treatment of hypertension and are increasingly used as measures of quality of care.

Contribution

In a secondary analysis of a large, randomized, clinical trial, blood pressure varied widely in the short term, whether measured in the home, clinic, or research setting. A single measurement was generally inadequate to correctly determine whether blood pressure was being adequately controlled.

Caution

Most patients were men with previous poor control of blood pressure.

Implication

Several measurements are needed to assess blood pressure control. A single blood pressure recording is not a meaningful quality metric.

—The Editors

Blood Pressure (10) recommends initially identifying hypertension on the basis of the mean of 2 or more seated clinic measurements on separate days but does not provide guidance on how BP should be measured to guide ongoing monitoring and treatment. For patients with hypertension, the measurement and reporting of quality of care also relies on the clinic measurement: The Healthcare Effectiveness Data and Information Set of the National Committee for Quality Assurance evaluates quality of care on the basis of the lowest BP measurement at a single clinic visit (21).

Blood pressure is increasingly monitored by patients at home, and recent surveys report that approximately 43% of primary care patients with hypertension use home monitors (22, 23). When properly calibrated, home BP monitors can provide inexpensive, accurate, and reproducible readings (24). Home measurements are strongly predictive of target organ damage, and treatment based on home BP readings may reduce unnecessary treatment of white-coat hypertension (25–27). The reproducibility of home measurements can be improved by averaging several measurements; however, the number of measurements recommended by different authors has varied from a minimum of 5 to 30 or more (28–30). Recent position statements from the American Society of Hypertension and the European Society of Hypertension have called for greater use and reimbursement for home BP monitoring in the management of known or suspected hypertension, with a recommendation for 12 or more home readings for making clinical decisions (31, 32).

Despite the availability and accuracy of home BP monitors, most BP treatment decisions are based on clinic measurements. In the clinic, providers identify uncertainty about the patient's true BP as one of the most common reasons for not treating patients with elevated clinic readings (33). In this study, we compare home, clinic, and research SBP measurements in primary care patients with hypertension and estimate the certainty with which a patient's true BP can be determined by using different measurement strategies.

METHODS

Patient Recruitment

We analyzed data from HINTS (Hypertension Intervention Nurse Telemedicine Study), an 18-month, randomized, controlled trial designed to evaluate the effect of a self-management intervention administered by a nurse over the telephone, a medication management intervention of hypertension directed by a physician, or both compared with usual care. In addition to their ongoing primary care, patients in the 3 intervention groups electronically transmitted home BP readings, and the intervention was triggered by an elevated average home BP over the previous 2 weeks. Patients receiving self-management support received telephone modules delivered by the study nurse; patients receiving medication management support had medication and BP review by study physicians who relayed medication recommendations through the study nurse. Inclusion and exclusion criteria are presented in the **Appendix** (available at www. annals.org), and a detailed study protocol is presented elsewhere (34). We recruited participants from primary care clinics affiliated with the Durham Veterans Affairs (VA) Medical Center, Durham, North Carolina, on the basis of a previous diagnosis of hypertension and a history of inadequate BP control defined by a mean clinic SBP of 140 mm Hg or more or a mean diastolic BP of 90 mm Hg in the year before enrollment. For this analysis, we excluded patients in the usual care group because they did not provide home BP monitoring data. The institutional review board at the Durham VA Medical Center approved the study.

Clinic BP Measurement

Blood pressure was measured concurrently by 3 methods throughout the 18-month study. Clinic BP was measured at varying intervals in the ambulatory care clinics as a part of the patient's routine clinic visit. Nurses who obtained all clinic BP measurements in any local VA clinic recorded the value in the VA's electronic medical record system. Trained nurses obtained the clinic BPs at a scheduled outpatient visit according to standards maintained by the VA. We excluded BP measured during unscheduled visits (for example, the emergency department) or inpatient stays. The clinic nurses were blinded to the patients' participation and were unaware of the study hypotheses. All clinic BPs were obtained by using Alaris, models 4200s and 4410s/4415s, automated devices (IVAC, San Diego, California).

Research BP Measurement

As part of the research protocol, BP measurements were recorded at baseline and at 6, 12, and 18 months by using a BpTRU digital BP monitor, model BPM-100 (BpTRU Medical Devices, Coquitlam, British Columbia, Canada). At each measurement, 2 resting BP measurements were obtained 5 minutes apart while the patient was seated (35). The digital sphygmomanometers were inspected quarterly to ensure accurate calibration.

Home BP Measurement

All patients receiving an intervention were provided a digital home BP monitor (A&D Medical, model UA-767PC, San Jose, California) and telemedicine device (Carematix, model 102, Chicago, Illinois). Patients were instructed on the proper measurement of home BP and asked to provide at least 3 measurements per week. Each BP measurement was time-stamped, and the monitor could store several measurements. The telemedicine device connected to a telephone line, and the patient's home BP measurements were sent automatically through a toll-free telephone number to a secure server.

Statistical Analysis

We restricted all analyses to SBP because of its greater importance in cardiovascular events and treatment decision making and examined each method of measurement (research, home, and clinic) separately. We calculated descriptive statistics, including means and SDs, for all SBP measurements during the first 30 days after study enrollment and before the intervention began, as well as during the entire 18-month study. For each method of measurement, we calculated the mean within-patient coefficient of variation (individual SD divided by individual mean SBP) as a standardized measure of individual variability.

Expanding on the methods of Keenan and coworkers (18), we assumed that each observed SBP measurement comprised the true underlying SBP plus the within-patient variance. Within-patient variance can be caused by short-term biological fluctuations or measurement error and causes the observed SBP measurements to deviate from the underlying true values. To better understand how each method of SBP assessment would be affected by increasing the number of measurements, we first derived estimates of the within-patient variance from random-effects models. Separate random-effects models were fit for research, home, and clinic values. The models included an overall mean (that is, no change in SBP over time); a patient-level random effect, which yielded an estimated between-patient variance; and a measurement error, which yielded an estimated within-patient variance (**Appendix**). An important assumption in creating these models was the period over which a patient's mean SBP and within-patient variance could reasonably be assumed to be stable. Longer time frames allow a sufficient number of measurements to capture within-patient variance; however, the stability of a patient's mean is less certain. We compared results for data modeled under 3 time frame assumptions: The entire 18 months treated as a single time frame with all measurements included, only the first 30 days of measurements before the intervention began, or the average of model estimates based on sequential 30-day measurement intervals (that is, the average of 18 distinct 30-day intervals over the entire study period) for home BP and 90-day intervals for clinic BP. The results were essentially unchanged for 2 or more measurements and only modestly differed for a single measurement regardless of which time frame was modeled, suggesting that our results are robust to different time frame assumptions. Here, we present the averages obtained from sequential 30-day and 90-day intervals for home and clinic measurements, respectively. These models also assumed a constant correlation between measurements, regardless of their timing. A sensitivity analysis using only 1 measurement per day did not appreciably change the results.

Finally, we assessed how much information a set of given SBP readings provides for determining a patient's true SBP. We used estimates from the random-effects models to estimate the mean, variance, and covariance terms of each distribution (**Appendix**). By using the derived bivariate normal distributions, we calculated the probability that a patient's true SBP was out of control according to guideline recommendations (SBP $\geq$140 mm Hg for clinic or research measurements and SBP $\geq$135 for home measurements) given an observed mean SBP. We estimated these probabilities separately on the basis of 1 SBP measurement or the average of 2, 5, or 10 measurements. We did all analyses by using SAS software, version 9.2 (SAS Institute, Cary, North Carolina).

Role of the Funding Source

The U.S. Department of Veterans Affairs Health Services Research and Development Service funded the study. The funding source had no role in the study design, data collection and interpretation, writing of the report, or decision to submit the manuscript for publication.

RESULTS

Patient Characteristics

Table 1 summarizes patient characteristics. The mean age was 64 years. Most of the patients were men (92%), nearly half were black, and 75% had hypertension for at least 10 years.

Research, Clinic, and Home SBP and Variability

Table 2 shows the number of measurements, observed means, and variability in SBP according to the setting of measurement. The proportion of patients who had control of his or her SBP in the first 30 days ($<$140 mm Hg for clinic or research measurement; $<$135 mm Hg for home measurement) differed between method of measurement: 28% were in control according to clinic measurement,

Table 1. **Baseline Sample Characteristics for the Hypertension Intervention Nurse Telemedicine Study**

Characteristic	Patients (n = 444)*
Mean age (SD), *y*	64 (10)
Race, %	
White	49
Black	48
Men, %	92
Mean body mass index (SD), kg/m^2	30.5 (5.2)
Current smoker, %	21
Medical history	
≥10-y history of hypertension, %	75
Diabetes, %	41
Mean hypertension medications (SD), *n*	2.4 (1.2)
Mean clinic blood pressure (SD), *mm Hg*	
Systolic	144.9 (16.9)
Diastolic	80.1 (13.3)

* Represents patients in the 3 intervention groups who provided home measurements through telemonitoring.

47% were in control according to home measurement, and 68% were in control according to research measurement. Only 33% of patients were consistently categorized as having BP in or out of control across all 3 methods of measurement.

The **Appendix Figure** shows trajectories of SBP measured at home, in the clinic, or by research staff during the 18-month study for 4 representative patients. The relationship between mean clinic and home SBP also varied substantially: 51.6% of patients had a mean clinic SBP at least 10 mm Hg greater than their mean home SBP, and 5.0% of patients had a mean clinic SBP at least 10 mm Hg less than their mean home SBP.

Relationship Between the Mean of Increasing the Number of Measurements and Within-Patient Variance

Figure 1 shows the relationship between within-patient variance and increasing the number of measurements for home, clinic, and research SBP. The within-patient variance decreased markedly as the number of measurements increased, and the relationship was similar across all 3 methods of measurement. The rate of decrease was greatest in moving from 1 to 2 measurements and rapidly diminished with subsequent measurements, with little added value of additional readings beyond 4 to 6 observed SBP measurements for all 3 methods.

Classification of BP According to Frequency and Setting of Measurements

Figure 2 shows the probability of having a true SBP greater than or equal to the recommended SBP treatment threshold of 140 mm Hg for clinic measurements and 135 mm Hg for home measurements over a range of measured values. We compared the probability of correct classification over this range on the basis of a single measurement, or the mean of 2, 5, or 10 measurements. No single clinic SBP measurement from 120 mm Hg to 157 mm Hg allowed correct classification of a patient as having BP that was in or out of control with 80% or greater certainty. A patient from this group with 1 clinic measurement of 132 mm Hg has a 40% probability of having a true SBP of 140 mm Hg or more, but with the mean of 5 clinic measurements at 132 mm Hg, would have a less than 18% probability of having a true SBP of 140 mm Hg or more. Similarly, a patient with a single clinic SBP of 150 mm Hg would have less than 70% probability of having a true SBP of 140 mm Hg or more, whereas an average of 5 readings at 150 mm Hg would have greater than 92% probability of having a true SBP of 140 mm Hg or more. For mean clinic SBP measurements from 136 mm Hg to 144 mm Hg, the mean of at least 10 measurements are required before a patient can be correctly classified with at least 80% probability.

Results for home BP measurements using a treatment threshold of 135 mm Hg are similar to results reported for clinic measurement. For a single observed measurement, only readings of 123 mm Hg or less or 153 mm Hg or more could be correctly classified as in or out of control with at least 80% probability. Increasing the number of

Table 2. **Number of Measurements and Blood Pressure Variability According to Study Group and Method of Measurement**

Source of Measurement	Measurements, *n*	Mean Measurements per Patient (Range), *n*	Sample Mean SBP Measurement (SD), *mm Hg*	Median Individual SD (Range), *mm Hg*	Median Individual Coefficient of Variation (Range)
Research SBP					
First 30 d	886	2 (1–2)	129.4 (21.5)	4.2 (0–63.6)*	0.03 (0–0.51)*
18 mo	3218	7 (1–8)	127.3 (19.4)	11.9 (0–40.1)	0.09 (0–0.29)
Clinic SBP					
First 30 d	3446	8 (1–39)	144.9 (16.9)	12.7 (0.71–35.8)	0.09 (0.01–0.24)
18 mo	7121	16 (2–79)	141.2 (17.7)	14.0 (1.0–32.9)	0.10 (0.01–0.24)
Home SBP					
First 30 d	7642	18 (1–83)	135.3 (19.6)	10.8 (1.8–41.0)	0.08 (0.01–0.31)
18 mo	100 842	232 (1–1454)	131.6 (18.3)	13.0 (2.1–31.2)	0.10 (0.02–0.24)

SBP = systolic blood pressure.
* The 2 research measurements in the first 30 d were taken only minutes apart and do not reflect the biological variation over hours or days.

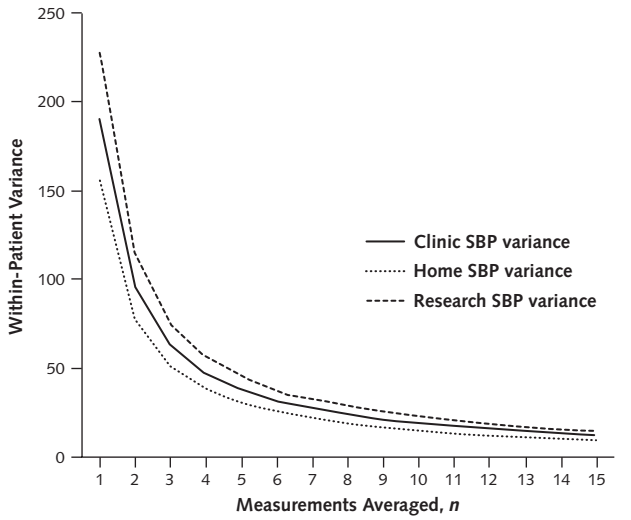
measurements greatly improved the accuracy of categorization according to the treatment threshold, and most observed mean SBPs could be accurately categorized with 80% probability based on the mean of 5 home measurements.

DISCUSSION

Current treatment of patients with hypertension relies heavily on clinic measurement of BP, and the quality of this care is evaluated solely in this setting. Providers cite uncertainty about the patient's true BP on the basis of clinic measurements as a common reason for not changing therapy (33); our data suggest that this concern is well-founded. It comes from 2 sources: The substantial difference between mean home and clinic BP and the inherent within-patient variability of BP over short periods. The difference between mean clinic and home BP is accounted for, in part, by lowering treatment goals for home BP by 5 mm Hg (31). However, estimates of the upper limit of normal home SBP have ranged from 125 mm Hg to 140 mm Hg (29). A recent systematic review reported a mean 8.6–mm Hg difference between home and clinic SBP (36), similar to our observed 9.6–mm Hg difference. It is not surprising, therefore, that treatment based on a target home SBP of less than 135 mm Hg results in less aggressive medication intensification than treatment to a target clinic BP of less than 140 mm Hg (26, 27). Recent clinical trials have sought to define optimal treatment goals for clinic BP (37, 38) and ambulatory BP (39); however, further research is needed on optimal treatment goals for self-measured home BP.

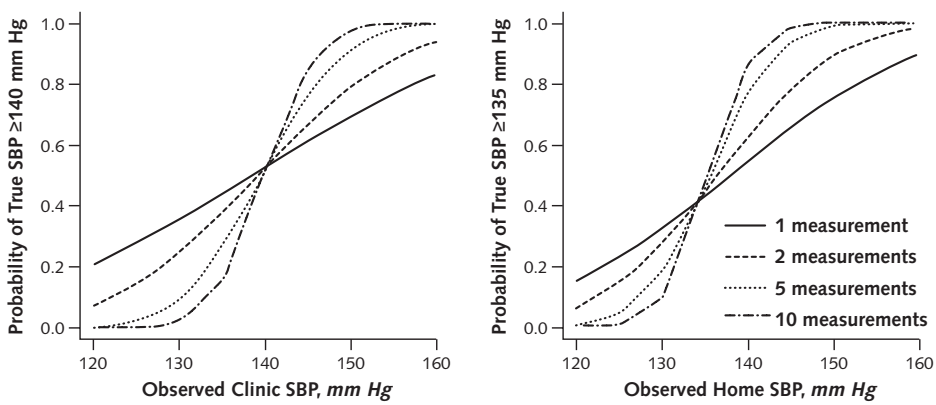
Uncertainty in treatment decisions also stems from the inherent within-patient variability of BP over time. Our observed within-patient SD and coefficient of variation were similar to those reported in other trials (40, 41), and the coefficient of variation in the current study was similar for home, clinic, or research measurement. This variation changed little over time, suggesting that short-term biological fluctuations are an inescapable part of BP measurement that influence the categorization of patients as having BP that is in or out of control. The effect of within-patient variability could be greatly reduced by averaging 5 to 6

Figure 1. **Within-patient SBP variance and number of measurements.**



Results are from a group of mostly male patients who received treatment for hypertension and had a history of elevated blood pressure measurements. Results may differ in other samples. The total individual variance combines both the between- and the within-patient variance and is calculated as the variance is reduced by taking the mean of increasing number of measurements. Random-effects models were used to derive estimates of the within-patient variance for each mode of assessment. Research variance is calculated from a model using all 18 months of data, whereas clinic and home variances are based on the average of multiple, shorter time frames. Details of the derivations are provided in the **Appendix**, available at www.annals.org. SBP = systolic blood pressure.

Figure 2. **Probability of correct SBP classification.**



Results are from a group of mostly male patients who received treatment for hypertension and had a history of elevated blood pressure measurements. Results may differ in other samples. SBP = systolic blood pressure. **Left.** Clinic measurement. **Right.** Home measurement.

measurements but with even more measurements required for confident decision making in the patients closest to treatment thresholds. Home BP guidelines have provided recommendations on the number of measurements to be used for decision making; however, the signal–noise ratio is no better for clinic measurements and may be even worse. Current decisions about medication therapy are often made on the basis of 1 or 2 clinic measurements; these data suggest that this could be substantially improved for patients with a history of elevated BP measurements when decisions are based on the average of several measurements, regardless of the setting.

Although the effect of within-patient variability could be reduced with more frequent clinic measurement, this would not eliminate white-coat effects and is not practical for most patients and providers. These measurements could not be obtained all at the same visit because measurements taken minutes apart do not fully capture the within-patient variance that occurs over hours to days. Furthermore, averaging data from either clinic or home can be cumbersome for busy providers. If providers are supposed to rely more on averaged measurements, new ways of capturing and presenting these data at the point of care are needed. Calculated averages from home monitors, BP control charts (42) that visually display the signal–noise relationship, or personalized algorithms that account for each patient's own variability may improve the interpretation of BP and facilitate more informed and individual decisions. These methods may also better identify medication treatment response over time, a process that is also confounded by high short-term variability (18, 43).

Our study has several limitations to consider when interpreting the results. Our sample was mostly men who had hypertension for 10 or more years and were selected on the basis of a previous elevated BP measurement. Our conditional probability plots (**Figure 2**) apply to a sample of patients with hypertension and a history of elevated BPs; it is likely that decisions can be made with more certainty based on fewer measurements when the readings are consistent with an established history of normal BP. Although the results may differ for other samples, the difference in BP at home and at the clinic and the high individual variability are similar to other reports (40, 41). This study considered only the underlying mean SBP, but other components of BP independently predict risk, including diastolic BP, maximum SBP, BP variability (40, 44), morning BP surge (45), and nocturnal BP (46); yet, their role in decision making is less well-defined and requires further exploration. Finally, we obtained home BP measurements electronically, but reliance on patients' self-report may result in biased estimates of home BP (47). Despite these limitations, the results have important implications for the long-term management of patients with hypertension.

Our data support the recent position statements calling for use and reimbursement for home BP monitoring (31, 32) and question the ability to provide high-quality personalized care without the use of averaged home readings. Current quality-of-care measures may provide a snapshot of BP control within a large sample, but these metrics frequently misclassify a patient's level of control (48), and performance pay for physicians who use these measures is based on substantial uncertainty. For patients who visit their physician to receive personalized health recommendations, high-quality care should reflect good clinical decision making based on adequate information. In hypertension, simple changes in the setting and number of BP measurements used for decision making could greatly enhance the personalization of care.

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An abstract of this paper was presented at the 34th annual meeting of the Society of General Internal Medicine, Phoenix, Arizona, 4–7 May 2011.

Disclaimer: The views expressed in this manuscript are those of the authors and do not necessarily represent the views of the U.S. Department of Veterans Affairs or the U.S. government.

Acknowledgment: The authors thank Dr. David Simel for his helpful review.

Grant Support: By a grant from the U.S. Department of Veterans Affairs Health Services Research and Development Service (IIR 04-426). Dr. Powers is supported by a U.S. Department of Veterans Affairs Career Development Award (CDA 09-212). Dr. Bosworth is supported by an Established Investigator Award from the American Heart Association and a U.S. Department of Veterans Affairs Health Services Research and Development Service Career Scientist Award (08-027).

Potential Conflicts of Interest: Drs. Powers, Oddone, and Bosworth: *Grant (money to institution):* U.S. Department of Veterans Affairs Health Services Research and Development Service. Dr. Woolson: *Employment:* Medical University of South Carolina, University of Iowa. Disclosures can also be viewed at www.acponline.org/authors/icmje/ConflictOfInterestForms.do?msNum=M10-2595.

Reproducible Research Statement: *Study protocol, statistical code, and data set:* Available from Dr. Olsen (e-mail, olsen008@mc.duke.edu).

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Appendix

Inclusion and Exclusion Criteria for HINTS

We included patients if they had hypertension, were receiving a BP-lowering medication, and had inadequate clinic BP control (>140/90 mm Hg for all patients) based on the average of the previous 12 months of clinic BP recordings obtained from electronic medical records. We excluded patients who received dialysis; had a serum creatinine level greater than 221 μmol/L (>2.5 mg/dL) or no documentation of renal function; had an organ transplant; were hospitalized for stroke, myocardial infarction, or coronary artery revascularization within 3 months of contact; had a diagnosis of metastatic cancer or dementia; did not have a home telephone; resided in a nursing home; received home health care; or had severely impaired hearing or speech.

Details of Analysis

Part 1: Models Used to Create Figure 1

Let Y_{ij} be the SBP for individual i at time j. We fit the following random-effects model for each method of assessment (research, clinic, and home).

$$Y_{ij} = \beta + b_i + \varepsilon_{ij} \quad (1)$$

where b_i and ε_i are independent and normally distributed,

$$b_i \sim N(0,\sigma_b^2) \text{ and } \varepsilon_i \sim N(0,\sigma_\varepsilon^2 I).$$

Estimates of σ_b^2 and σ_ε^2 represent the between-patient variance and within-patient variance, respectively. Note that this model assumes a constant mean (β) for the entire study period and a constant correlation between time points. For the research BPs, all available measurements for the entire 18-month study were included in a single model. For the clinic BPs, we divided the 18-month study into 6 sequential 90-day intervals. All available measurements within each 90-day period were included in the analysis models. The 6 estimates of σ_b^2 and σ_ε^2 from each 90-day model were averaged. Finally, for the home BPs, we divided the 18-month study into 18 sequential 30-day intervals. All available measurements within each 30-day period were included in the analysis models. The 18 estimates of σ_b^2 and σ_ε^2 from each 30-day model were averaged. **Figure 1** shows the estimated quantity of the within-patient variance $\bar{\sigma}_\varepsilon^2/n$ for an increasing number of measurements and each mode of assessment.

Part 2: Methods and Models for Figure 2

Figure 2 describes the probability of correct SBP classification based on observed clinic BPs. That is, given that a patient's set of mean observed SBPs is X, what is the probability (p) that his or her true SBP is 140 mm Hg or greater? If Z is 140 mm Hg or greater, p represents the probability of a true-positive result and $1 - p$ represents the probability of a false-positive result. If Z is less than 140 mm Hg, then p represents the probability of a false-negative result and $1 - p$ is the probability of a true-negative result. We use estimated values averaged from the six 90-day models of equation (1) for clinic BP to derive these probabilities. The estimated values are $\beta = 141.00$ mm Hg, $\bar{\sigma}_b^2 = 114.7$, and $\bar{\sigma}_\varepsilon^2 = 191.1$.

We assume that the true SBP (Z) and the mean of the observed SBPs (X) vary together with a bivariate normal distribution. Following methodology in Keenan and coworkers (18), we use estimates specified earlier for the mean, variance, and covariance terms of this bivariate distribution, as follows:

$$\begin{pmatrix} Z \\ X \end{pmatrix} \sim BVN\left(\begin{pmatrix} 141.00 \\ 141.00 \end{pmatrix}, \begin{pmatrix} 114.7 & 114.7 \\ 114.7 & \dfrac{191.1}{n} + 114.7 \end{pmatrix}\right).$$

So, $\mu_Z = 141.00$, $\mu_X = 141.00$, $\sigma^2{}_Z = 114.7$,

$$\sigma^2{}_X = \frac{191.1}{n} + 114.7, \text{ and } \rho = \frac{114.7}{\sqrt{114.7}\sqrt{\dfrac{191.1}{n} + 114.7}}.$$

The curves in **Figure 2** (*left*) show the conditional probability $P(Z > 140 \mid X > x)$ for $n = 1$, 2, 5, or 10 measurements and a range of observed SBPs, x, from 120 to 160 mm Hg. By using properties of bivariate normal distributions, the conditional distribution has the following form:

$$Z|X \sim N(\mu_Z + (\rho\sigma_Z/\sigma_X)(X - \mu_X), \sigma^2{}_Z(1 - \rho)),$$

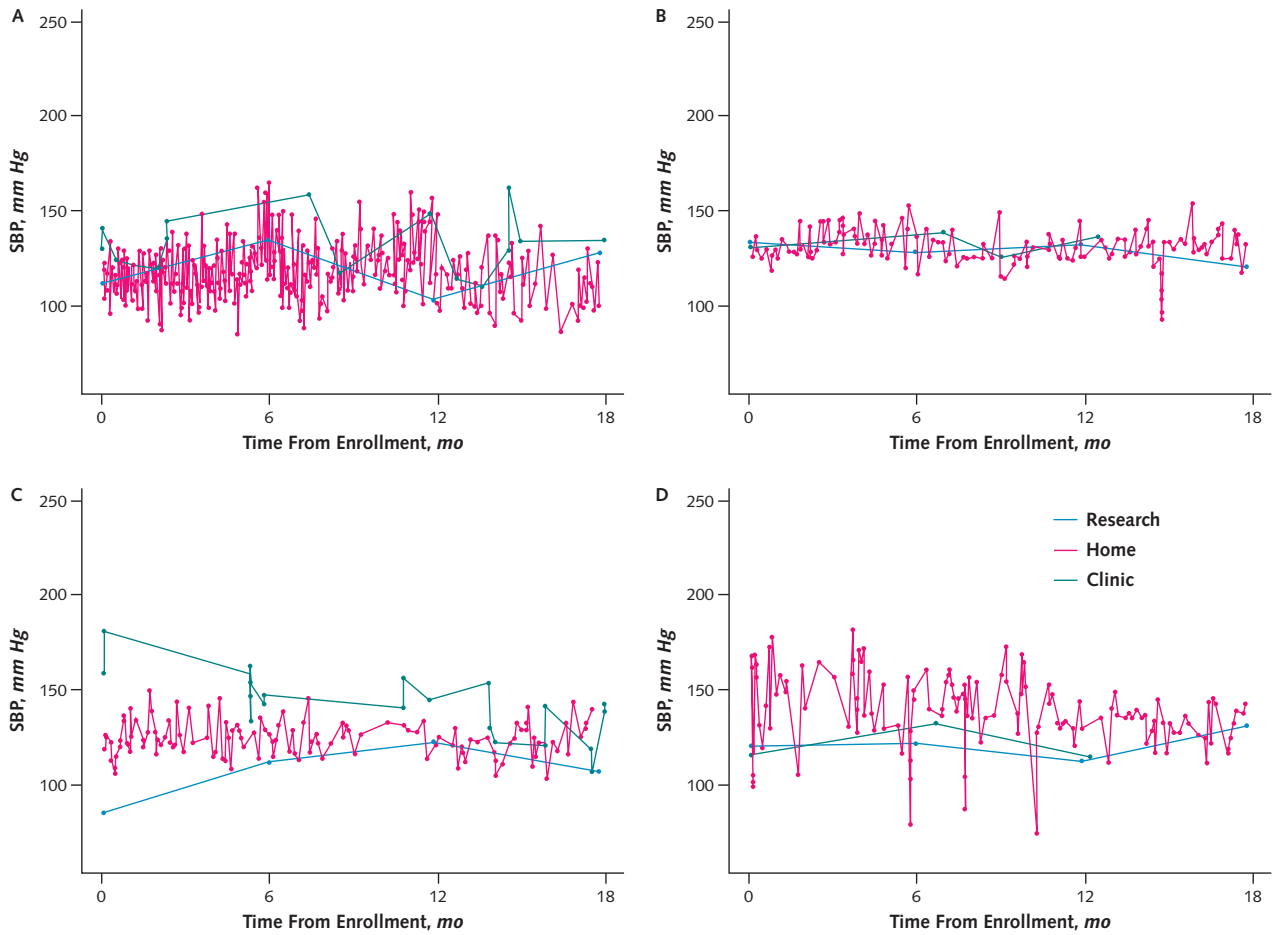
which we use to determine these conditional probabilities.

Figure 2 (*right*) was derived by using similar methodology but with different estimated quantities. The estimated values averaged from the eighteen 30-day models of equation (1) for home BP measurements are $\beta = 131.62$ mm Hg, $\bar{\sigma}_b^2 = 172.7$, and $\bar{\sigma}_\varepsilon^2 = 157.0$. As a result, the bivariate normal distribution used to estimate the probability of correct SBP classification is:

$$\begin{pmatrix} Z \\ X \end{pmatrix} \sim BVN\left(\begin{pmatrix} 131.62 \\ 131.62 \end{pmatrix}, \begin{pmatrix} 172.7 & 172.7 \\ 172.7 & \dfrac{157.0}{n} + 172.7 \end{pmatrix}\right)$$

for $n = 1$, 2, 5, or 10 measurements and a range of observed SBPs, x, from 120 to 160 mm Hg.

Appendix Figure. **Sample SBP data from individual patients.**



SBP = systolic blood pressure. **A.** Patient with high within-patient variability. Mean clinic measurement was 135 mm Hg (SD, 17); coefficient of variation = 0.128. Mean home measurement was 118 mm Hg (SD, 15); coefficient of variation = 0.125. **B.** Patient with low within-patient variability and high correlation among home, clinic, and research measurements. Mean clinic measurement was 139 mm Hg (SD, 8); coefficient of variation = 0.054. Mean home measurement was 131 mm Hg (SD, 10); coefficient of variation = 0.073. **C.** Patient with consistently higher clinic SBP compared with home measurement (i.e., white-coat hypertension). Mean clinic measurement was 135 mm Hg (SD, 18); coefficient of variation = 0.133. Mean home measurement was 124 mm Hg (SD, 9); coefficient of variation = 0.074. **D.** Patient with consistently higher home SBP than clinic or research SBP (i.e., masked hypertension). Mean clinic measurement was 130 mm Hg (SD, 21); coefficient of variation = 0.160. Mean home measurement was 139 mm Hg (SD, 19); coefficient of variation = 0.139.