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Comparing Automated Office Blood Pressure Readings With Other Methods of Blood Pressure Measurement for Identifying Patients With Possible Hypertension
A Systematic Review and Meta-analysis

Michael Roerecke, PhD; Janusz Kaczorowski, PhD; Martin G. Myers, MD, FRCPC

IMPORTANCE Automated office blood pressure (AOBP) measurement involves recording several blood pressure (BP) readings using a fully automated oscillometric sphygmomanometer with the patient resting alone in a quiet place. Although several studies have shown AOBP measurement to be more accurate than routine office BP measurement and not subject to a "white coat effect," the cumulative evidence has not yet been systematically reviewed.

OBJECTIVE To perform a systematic review and meta-analysis to examine the association between AOBP and office BP readings measured in routine clinical practice and in research studies, and ambulatory BP recorded during awake hours, as the latter is a standard for predicting future cardiovascular events.

DATA SOURCES The MEDLINE, Embase, and Cochrane Library were searched from 2003 to April 25, 2018.

STUDY SELECTION Studies on systolic and diastolic BP measurement by AOBP in comparison with awake ambulatory BP, routine office BP, and research BP measurements were included if they contained 30 patients or more.

DATA EXTRACTION AND SYNTHESIS Study characteristics were abstracted independently and random effects meta-analyses and meta-regressions were conducted.

MAIN OUTCOMES AND MEASURES Pooled mean differences (95% CI) of systolic and diastolic BP between types of BP measurement.

RESULTS Data were compiled from 31 articles comprising 9279 participants (4736 men and 4543 women). In samples with systolic AOBP of 130 mm Hg or more, routine office and research systolic BP readings were substantially higher than AOBP readings, with a pooled mean difference of 14.5 mm Hg (95% CI, 11.8-17.2 mm Hg; n = 9; I^2 = 94.3%; P < .001) for routine office systolic BP readings and 7.0 mm Hg (95% CI, 4.9-9.1 mm Hg; n = 9; I^2 = 85.7%; P < .001) for research systolic BP readings. Systolic awake ambulatory BP and AOBP readings were similar, with a pooled mean difference of 0.3 mm Hg (95% CI, −1.1 to 1.7 mm Hg; n = 19; I^2 = 90%; P < .001).

CONCLUSIONS AND RELEVANCE Automated office blood pressure readings, only when recorded properly with the patient sitting alone in a quiet place, are more accurate than office BP readings in routine clinical practice and are similar to awake ambulatory BP readings, with mean AOBP being devoid of any white coat effect. There has been some reluctance among physicians to adopt this technique because of uncertainty about its advantages compared with more traditional methods of recording BP during an office visit. Based on the evidence, AOBP should now be the preferred method for recording BP in routine clinical practice.

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Supplemental content

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Ambulatory blood pressure (ABP) monitoring is now recognized as the best method for predicting the risk of cardiovascular events in relation to an individual's blood pressure (BP) level. The association between ABP and the risk of cardiovascular events is continuous, consistent, and independent of other risk factors. Although the accurate measurement of BP is the cornerstone for appropriate diagnosis and treatment of hypertension, recent guidelines have questioned the accuracy, and consequently the role, of manual BP measurement in routine clinical practice.[1-3] Routine office BP measurement is not only more susceptible to a "white coat effect" (when BP measured in the office is higher than ABP), but is also less accurate, correlating relatively poorly with the awake ABP, and is more likely to be associated with digit preference (rounding off readings to the nearest zero value).[4] The advent of oscillometric sphygmomanometers as a replacement for manual BP measurement may improve the quality of office BP readings by recording multiple measurements automatically and by eliminating some aspects of human error.[5]

During the past decade, oscillometric sphygmomanometers have been used in mostly 2 ways. One approach has been to adapt oscillometric sphygmomanometers designed for self-measurement of BP by patients in the home for use in the office. These oscillometric sphygmomanometers provide 1 or more BP readings, with most other aspects of the BP measurement process remaining the same, including office staff in close proximity to the patient. The net result is that oscillometric BP recordings in clinical practice are not much different from manual BP readings, with both methods being associated with a marked white coat effect.[6,7]

A second approach followed the introduction of oscillometric recorders such as the Omron 907 (Omron Healthcare) and BpTRU (BpTRU Medical Devices Inc), which were capable of recording multiple BP readings automatically without the need to have a physician or nurse present with the patient. These devices have a built-in delay that allows time for office staff to initiate the readings and then leave the patient alone before the first reading starts. The most important innovation with this technique, subsequently called automated office BP (AOBP) measurement,[8] was that conversation between the patient and office staff was no longer possible because the patient was alone, as talking was known to be a major cause of the white coat effect. Also, removing clinic staff likely reduces any anxiety caused by the presence of nurses or physicians. Automated office BP measurement may also be obtained if the readings are recorded with the patient sitting alone in the waiting area of the physician's office or in a community pharmacy, provided that office or pharmacy staff are not interacting with the patient.[9,10] Subsequent research into the use of AOBP measurement has confirmed the initial belief that reducing human involvement in the measurement of BP in the office would improve the quality of the readings.[6] Despite encouraging results in clinical studies in different settings, physicians in the United States and Europe have been slow to adopt AOBP measurement into routine office practices, often claiming it was not feasible to do so.[11] The Canadian experience suggests otherwise, with 1 recent survey reporting that more than 50% of physicians in primary care may be now using AOBP measurement in their practices.[12]

Until now, to our knowledge, there has not yet been a comprehensive evaluation of the literature on the comparability of AOBP measurement and conventional office BP measurement. In the present study we have performed a systematic review and meta-analysis of various aspects of the use of AOBP measurement, including a comparison with office BP measurement in routine clinical practice, office BP recorded in research studies, and awake ABP. Systolic BP is the primary focus of this review, because diastolic BP has been less than 80 mm Hg in most studies involving AOBP. Systolic BP is also more affected by the white coat response and is a more important determinant of an individual's risk of experiencing a cardiovascular event.

Key Points

Question Should automated office blood pressure (recording several blood pressure readings using a fully automated oscillometric sphygmomanometer with the patient resting alone in a quiet place) measurement replace readings recorded by nurses and physicians in routine clinical practice?

Findings This systematic review and meta-analysis of 31 articles comprising 9279 participants compared automated office blood pressure with awake ambulatory blood pressure, a standard for predicting cardiovascular risk. Mean automated office blood pressure readings were similar to the awake ambulatory blood pressure readings and did not exhibit the "white coat effect" associated with routine office blood pressure measurement.

Meanings Automated office blood pressure measurement should replace the recording of blood pressure by nurses and physicians in routine clinical practice.

Methods

Search Strategy and Selection Criteria

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses,[13] we conducted a systematic literature search (eFigure 1 in the Supplement) using MEDLINE, Embase, and the Cochrane Library from 2003 through April 25, 2018, as well as our personal libraries, using key words relating to automated BP measurement (eTable 1 in the Supplement). In addition, we searched reference lists of identified articles and related meta-analyses and reviews. Inclusion criteria were as follows: (1) full-text article with unattended and fully automated AOBP assessment, (2) reported mean difference (MD) and SE (or enough data to calculate these) between AOBP and at least 1 of 3 other BP measurements (awake ABP, research BP, or routine office BP), (3) sample size of 30 or more individuals, (4) maximum time elapsed between 2 types of BP measurement 1 month or less, (5) maximum interval between AOBP measurements 2 minutes or less, (6) at least 3 readings for AOBP (except 2 readings for the Mobil-o-graph device [IEM Gmbh]), and (7) study conducted in or after 2003 (when AOBP was first introduced).

No other restrictions were applied and authors were contacted for missing or additional information, when required. Two of us independently excluded articles based on title and abstract on the first pass. Articles with unsure eligibility were obtained in full text and discussed until consensus was reached. Eligibility of articles retrieved in full text was determined by consensus of all 3 of us.

Data Extraction

From all relevant articles, we extracted the first author's name, year of publication, country, calendar year(s) the study was conducted, setting of the study, age of participants, body mass index (BMI) of participants, sex of participants (percentage of men and women), number treated for hypertension, number of participants, details of BP assessment (added rest period, number of measurements, interval between measurements, attendance by personnel, device, sequence, and randomization), inclusion and exclusion criteria, and subgroup results defined by hypertension status (systolic AOBP, ≥130 mm Hg).

Assessment of BP

We considered unattended BP measurement recorded with fully automated devices as valid measurements of AOBP if they did not require any involvement of the patient, such as activating the device. All but 1 study[14] used either the BpTRU (5 readings at 1- to 2-minute intervals after an initial test reading without antecedent rest), Omron 907 (3 readings, usually at 1-minute intervals with 5 minutes of antecedent rest), or the WatchBP Office (Microlife AG; 1-minute delay then 3 readings at 1-minute intervals).

No additional rest was mandated before the initiation of the AOBP measurements, although several studies,[15-18] which otherwise followed AOBP principles, did include an additional rest period. We used daytime or awake ABP as the standard for BP measurement. Automated office BP measurement was available from all 31 eligible studies and awake ABP from 22 studies.

The techniques used to record a separate manual or oscillometric BP in research studies varied somewhat. We defined a research quality office BP as a measurement performed according to standard guidelines, such as those of the American Heart Association.[3] A routine office BP measurement was defined as a manual or electronic BP reading taken in usual clinical practice and not as part of a research study. These readings were obtained retrospectively after office staff, who were unaware that the measurements would be used in a research study, had recorded them. In order for the BPs to be considered routine and to avoid observer bias, they could not be measured prospectively as part of a study.

Quality Assessment

Quality score use in meta-analyses remains controversial.[19,20] We restricted our inclusion to studies in which AOBP measurement was performed in the absence of research staff (unattended) and recorded with a fully automated device in at least 30 participants. In the case of duplicate publications involving the same individuals, we used the most comprehensive data available for each analysis.

For studies with a mean systolic AOBP of 130 mm Hg or more, the influence of age, BMI, sex, source of the sample, interval between BP measurements, additional rest periods, proportion of patients being treated for hypertension, and the type of automated device being used for BP measurement were evaluated in meta-regression and subgroup analyses. Furthermore, we rated studies as high quality for a comparison between AOBP and awake ABP based on the following criteria (in addition to our inclusion criteria): (1) no additional rest period, (2) not based on a retrospective review of the medical record, (3) patients were alone during AOBP measurement, and (4) at least 3 AOBP readings were used to calculate a mean. Studies that fulfilled all criteria were classified as high methodological quality.

Statistical Analysis

We used the reported MD with 95% CI to calculate the difference between each BP measurement type. When such data were not available, we calculated the MD and 95% CI based on reported means, 95% CIs were calculated based on reported SEs or SDs, and the correlation coefficient or *P* value for the MD of paired data.[21] All *P* values were from 2-tailed tests and results were deemed statistically significant at $P < .05$. Interquartile ranges were used to estimate the SDs by the method of Wan et al.[22] In cases in which only the mean and SD for 2 types of BP measurement were available (n = 3 studies for a comparison of AOBP and awake ABP), we used the weighted mean correlation coefficient from studies that provided such data.[21]

Mean differences were pooled with inverse-variance weighting using DerSimonian-Laird random-effect models to allow for between-study heterogeneity[23] Small-study effects were examined using the regression-based test of Egger et al.[24] Variation in the effect size because of between-study heterogeneity was quantified using the I^2 statistic.[25] Applying a random-effects meta-regression[26] significance level of $P < .10$, we conducted analyses for the effect of: (1) mean age (continuous, years), (2) mean BMI (continuous, calculated as weight in kilograms divided by height in meters squared), (3) hypertension status (systolic BP ≥130 mm Hg based on AOBP), (4) rest period (standard procedure vs added rest), (5) interval between AOBP measurements, (6) setting (referral or specialist clinic vs general practice setting or population-based), (7) device (BpTRU, Omron 907, WatchBP Office, or Mobil-o-graph), and (8) percentage of treated patients. In a sensitivity analysis, we used awake systolic ABP (≥130 mm Hg) as the definition for hypertension status. All meta-analyses were conducted with Stata statistical software, version 14.2 (Stata Corp).

Results

Literature Search and Study Characteristics

Of 2359 initial unique articles, 59 were reviewed in full text (eFigure 1 in the Supplement). Twenty-eight reports were excluded (reasons for exclusion are shown in eTable 2 in the Supplement). In total, we used data from 31 articles (**Table 1**;[10,14-18,27-51] eTable 3 in the Supplement) including 9279

Table 1. Characteristics of 31 Studies on the Differences in BP for AOBP, Awake ABP, Research BP, and Routine BP Measurements

Source	Location	Study Type	Age, y, Mean (SD)	BMI, Mean (SD)	Sample Size, No.	Males, No. (%)	HTN, No. (%)	Treated HTN, No. (%)	AOBP, Mean (SD), mm Hg		Awake APB, Mean (SD), mm Hg		Routine BP, Mean (SD), mm Hg		Research BP, Mean (SD), mm Hg	
									SBP	DBP	SBP	DBP	SBP	DBP	SBP	DBP
Agarwal,[44] 2017	Indiana; general medicine clinic, Richard L. Roudebush Veterans Affairs Medical Center	Cross-sectional	69.2 (10.1)	30.9 (4.7)	275	269 (97.8)	0 (0.0)	269 (97.8)	121.7 (17.9)	59.7 (11.7)	129.6 (14.3)	71.5 (9.3)	134.5 (19.5)	71.8 (12.8)	NA	NA
Andreadis et al,[47] 2012	Greece; 3rd Department of Internal Medicine, Evangelismos General Hospital	Cross-sectional	53.0 (13.0)	NR	139	70 (50.4)	139 (100.0)	0 (0.0)	139.9 (16.5)	87.7 (11.8)	134.9 (15.0)	86.1 (10.2)	NA	NA	NA	NA
Andreadis et al,[48] 2018	Greece; Hypertension Center, Evangelismos General Hospital	Cross-sectional	56.0 (12.0)	NR	146	78 (53.4)	90 (100.0)	69 (47.0)	129.0 (14.0)	79.0 (13.0)	128.0 (13.0)	79.0 (11.0)	NA	NA	NA	NA
Armstrong et al,[10] 2015	Canada; community-based cardiac and hypertension specialty clinic, Kingston Heart Clinic	Cross-sectional	58.6 (14.1)	NR	422	202 (47.9)	NR	248 (58.8)	140.5 (19.8)	83.1 (11.2)	139.4 (13.4)	80.7 (10.6)	NA	NA	NA	NA
Bauer et al,[49] 2018	Germany; 4 general practitioners' offices	Cross-sectional	Mean, 69.5 (range, 21-97)	29.6 (5.6)	107	58 (54.2)	107 (100.0)	97 (90.7)	144.1 (19.2)	80.0 (11.5)	NA	NA	NA	NA	144.6 (21.0)	81.0 (10.7)
Beckett et al,[27] 2005	Canada; Centre for Studies in Primary Care, Queen's University	Cross-sectional	64.9 (11.6)	30.6 (5.22)	481	210 (43.7)	481 (100.0)	479 (99.6)	140.0 (17.7)	79.8 (10.5)	141.5 (13.3)	79.7 (7.79)	150.8 (10.3)	82.9 (8.44)	NA	NA
Bhatt et al,[42] 2016	Alabama; Birmingham hypertension clinic, University of Alabama	Retrospective medical record review	PR, mean, 63.0 (IQR, 52-72); TR, mean, 58.0 (IQR, 48-67)	PR, mean, 32.8 (IQR, 27-39); TR, mean, 33.3 (IQR, 28.7-38.0)	PR, 43; TR, 87	PR, 26 (60.5); TR, 9 (10.3)	PR, NR; TR, NR	PR, 43 (100.0); TR, 87 (100.0)	PR, 129.0 (10.0); TR, 159.0 (16.6)	PR, 75.0 (10.7); TR, 89.0 (13.6)	NA	NA	PR, 155.0 (13.8); TR, 171.0 (8.4)	PR, 85.0 (12.3); TR, 92.0 (16.6)	NA	NA
Campbell et al,[28] 2005	Canada	Cross-sectional	47.0 (7.8)	NR	All, 672; Clinic, 50	All, 670 (99.7); Clinic, 50 (100.0)	All, NR; Clinic, NR	All, NR; Clinic, NR	All, 119.7 (10.8); Clinic, 131.0 (24.0)	All, 76.3 (8.2); Clinic, 76 (13.0)	NA; NA	NA; NA	NA; NA	NA; NA	All, 122.4 (10.8); Clinic, 139.0 (28.3)	All, 77.9 (7.8); Clinic, 82.8 (15.0)

(continued)

Table 1. Characteristics of 31 Studies on the Differences in BP for AOBP, Awake ABP, Research BP, and Routine BP Measurements (continued)

Source	Location	Study Type	Age, y, Mean (SD)	BMI, Mean (SD)	Sample Size, No.	Males, No. (%)	HTN, No. (%)	Treated HTN, No. (%)	AOBP, Mean (SD), mm Hg		Awake APB, Mean (SD), mm Hg		Routine BP, Mean (SD), mm Hg		Research BP, Mean (SD), mm Hg	
									SBP	DBP	SBP	DBP	SBP	DBP	SBP	DBP
Edwards et al,[15] 2013	Canada; tertiary care clinic, The Renal Hypertension Clinic, Ottawa Hospital-Riverside Campus	Retrospective medical record review	61.8 (15.4)	NR	329	161 (48.9)	329 (100.0)	NR	136.3 (21.9)	74.1 (13.0)	139.3 (14.3)	76.5 (12.2)	NA	NA	143.9 (19.9)	76.8 (13.6)
Filipovský et al,[45] 2016	Czech Republic; hypertension center	Cross-sectional	61.4 (13.1)	NR	353	178 (50.4)	353 (100.0)	344 (97.5)	131.2 (21.8)	77.8 (12.1)	NA	NA	146.9 (20.8)	85.8 (12.4)	NA	NA
Filipovský et al,[17] 2018	Czech Republic; arterial hypertension or cardiology outpatient clinics, 4 university hospitals	Cross-sectional	Mean, 63.7 (range, 21-83)	29.0 (NR)	172	88 (51.2)	172 (100.0)	172 (100.0)	119.1 (12.6)	74.6 (9.9)	123.4 (11.2)	74.1 (8.2)	127.6 (12.1)	77.6 (10.0)	NA	NA
García-Donaire et al,[51] 2012	Spain; specialist clinics, arterial hypertension unit 12 de Octubre	Cross-sectional	All, 57.9 (14.6); TRUE-HTA, 61.6 (11.4)	All, 28.8 (4.9); TRUE-HTA, 29.3 (5.9)	All, 300; TRUE-HTA, 101	All, 147 (49.0); TRUE-HTA, 48 (47.5)	All, 228 (76.0); TRUE-HTA, 101 (100.0)	All, 222 (74.0); TRUE-HTA, NR	All, 130.8 (21.5); TRUE-HTA, 144.4 (22.1)	All, 79.6 (11.1); TRUE-HTA, 82.3 (12.8)	NA; TRUE-HTA, 137.4 (14.9)	NA; TRUE-HTA, 75.3 (10.0)	NA	NA	All, 140.6 (23.7); TRUE-HTA, 150.0 (21.4)	All, 83.0 (12.3); TRUE-HTA, 81.7 (12.5)
Godwin et al,[36] 2011	Canada; Centre for Studies in Primary Care, Queen's University	Baseline data from 2 randomized clinical trials	63.0 (18.0)	30.7 (5.2)	654	283 (43.3)	649 (99.2)	652 (99.7)	139.2 (17.9))	79.8 (10.9	140.9 (13.3)	79.6 (7.8)	148.5 (10.9)	82.5 (8.4)	NA	NA
Goldberg et al,[43] 2017	New England; level I tertiary referral academic ED	Cross-sectional	Mean, 39.0 (IQR, 28-51)	NR	354	181 (51.1)	NR	0 (0.0)	126.8 (NR)	81.8 (NR)	NA	NA	146.8 (18.4)	87.8 (12.3)	NA	NA
Ishikawa et al,[18] 2012	New York and Greece; outpatient hypertension clinics, Columbia University Medical Center and hypertension center, 3rd University Department Sotiria Hospital	Cross-sectional	56.1 (13.8)	27.1 (4.9)	75	41 (54.7)	75 (100.0)	38 (50.7)	134.7 (16.9)	82.3 (12.8)	137.1 (14.7)	81.0 (12.0)	NA	NA	137.0 (19.4)	81.6 (14.3)
Lamarre-Cliché et al,[37] 2011	Canada; specialty hypertension clinic, Institut de Recherches cliniques de Montréal	Randomized crossover trial	58.2 (11.5)	28.4 (5.5)	99	55 (54.0)	99 (100.0)	NR	128.4 (13.9)	80.0 (9.4)	135.5 (11.4)	82.0 (11.9)	NA	NA	129.9 (13.7)	80.9 (9.3)

(continued)

Table 1. Characteristics of 31 Studies on the Differences in BP for AOBP, Awake ABP, Research BP, and Routine BP Measurements (continued)

Source	Location	Study Type	Age, y, Mean (SD)	BMI, Mean (SD)	Sample Size, No.	Males, No. (%)	HTN, No. (%)	Treated HTN, No. (%)	AOBP, Mean (SD), mm Hg		Awake APB, Mean (SD), mm Hg		Routine BP, Mean (SD), mm Hg		Research BP, Mean (SD), mm Hg	
									SBP	DBP	SBP	DBP	SBP	DBP	SBP	DBP
Moore et al,[14] 2018	Australia and Poland; specialist clinics, Menzies Institute for Medical Research, University of Tasmania and Wroclaw Medical University	Cross-sectional	62.8 (12.1)	29.4 (5.1)	189	94 (49.7)	NR	NR	134.0 (22.0)	82.0 (13.0)	137.0 (17.0)	83.0 (11.0)	NA	NA	NA	NA
Myers,[29] 2006	Canada; hypertension specialist clinic	Cross-sectional	62 (16.0)	NR	50	22 (44.0)	NR	38 (76.0)	142.0 (21.0)	80.0 (12.0)	NA	NA	155.0 (31.0)	87.0 (17.0)	NA	NA
Myers et al,[30] 2008	Canada; ABPM center	Cross-sectional	63.0 (14.0)	NR	1-min, 104; 2-min, 100	1-min, 48 (46.2); 2-min, 46 (46.0)	1-min, 104 (100.0); 2-min, 100 (100.0)	1-min, NR; 2-min, NR	1-min, 139.0 (22.0); 2-min, 140.0 (19.0)	1-min, 76.0 (12.0); 2-min, 81.0 (12.0)	1-min, 144.0 (11.0); 2-min, 140.0 (12.0)	1-min, 82.0 (10.0); 2-min, 83.0 (10.0)	NA	NA	NA	NA
Myers et al,[31] 2008	Canada; BP clinic	Cross-sectional	Male, 50.0 (15.0); female, 47.0 (15.0)	Male, NR; Female, NR	238	96 (40.3)	59 (24.8)	42 (17.6)	115.0 (16.0)	71.0 (10.0)	NA	NA	NA	NA	118.0 (16.0)	74.0 (10.0)
Myers et al,[32] 2009	Canada; hypertension specialist office and ABPM unit	Cross-sectional	65.0 (11.0)	NR	62	31 (50.0)	NR	58 (93.5)	140.0 (21.0)	77.0 (11.0)	141.0 (15.0)	77.0 (11.0)	NA	NA	147.0 (18.0)	81.0 (12.0)
Myers et al,[33] 2009	Canada; ABPM unit, academic hospital	Cross-sectional	62.7 (14.6)	NR	309	139 (45.0)	NR	183 (59.2)	132.0 (19.0)	75.0 (12.0)	134.0 (13.0)	77.0 (10.0)	152.0 (18.0)	87.0 (11.0)	140.0 (17.0)	80.0 (11.0)
Myers,[34] 2010	Canada	Cross-sectional	56.8 (15.1)	NR	254	121 (47.6)	NR	0 (0.0)	132.6 (17.4)	80.0 (11.1)	135.3 (12.4)	81.0 (10.2)	149.7 (15.2)	89.3 (9.5)	NA	NA
Myers et al,[35] 2010	Canada; ABPM unit, Sunnybrook Health Sciences Centre	Cross-sectional	60 (14.0)	NR	All, 300; HTN, 139; Normal BP, 161	All, 136 (45.3); HTN, NR; Normal BP, NR	All, 139 (46.3); HTN, NR; Normal BP, NR	All, 173 (57.7); HTN, NR; Normal BP, NR	All, 131.0 (16.0); HTN, 141.0 (15.0); Normal BP, 123.0 (11.0)	All, 78.0 (11.0); HTN, 82.0 (12.0); Normal BP, 76.0 (9.0)	All, 136.0 (12.0); HTN, 142.0 (11.0); Normal BP, 132.0 (9.0)	All, 79.0 (10.0); HTN, 81.0 (12.0); Normal BP, 78.0 (9.0)	NA	NA	All, 139.0 (15.0); HTN, 152.0 (9.0); Normal BP, 128.0 (9.0)	All, 79.0 (12.0); HTN, 84.0 (12.0); Normal BP, 75.0 (10.0)
Myers et al,[38] 2011	Canada; primary care practices	Multisite cluster randomized controlled trial	Mean, 65.0 (range, 45-90)	NR	299	107 (35.8)	299 (100.0)	290 (95.6)	135.6 (17.3)	77.7 (10.9)	133.2 (12.4)	74.4 (9.8)	149.5 (10.8)	81.4 (8.3)	NA	NA
Myers et al,[39] 2012	Canada; primary care practices	Multisite cluster randomized controlled trial	Mean, 64.4 (range, 45-85)	29.6 (NR)	252	89 (35.3)	252 (100.0)	245 (97.2)	133.1 (16.8)	76.5 (10.3)	130.3 (12.4)	71.9 (9.8)	NA	NA	NA	NA
Myers et al,[40] 2012	Canada; ABPM unit	Cross-sectional	61.8 (12.2)	NR	100	44 (44.0)	NR	51 (51.0)	138.6 (13.7)	79.7 (9.0)	136.8 (12.4)	79.0 (10.8)	NA	NA	NA	NA

(continued)

Table 1. Characteristics of 31 Studies on the Differences in BP for AOBP, Awake ABP, Research BP, and Routine BP Measurements (continued)

Source	Location	Study Type	Age, y, Mean (SD)	BMI, Mean (SD)	Sample Size, No.	Males, No. (%)	HTN, No. (%)	Treated HTN, No. (%)	AOBP, Mean (SD), mm Hg		Awake APB, Mean (SD), mm Hg		Routine BP, Mean (SD), mm Hg		Research BP, Mean (SD), mm Hg	
									SBP	DBP	SBP	DBP	SBP	DBP	SBP	DBP
O'Shaughnessy et al,[50] 2011	Ireland; single university-based tertiary referral center	Cross-sectional	55.1 (16.7)	NR	80	45 (56.3)	80 (100.0)	78 (97.5)	122.6 (18.7)	75.1 (9.3)	NA	NA	132.6 (18.9)	77.4 (10.1)	NA	NA
Padwal et al,[16] 2015	Canada; Alberta Diabetes Institute Clinical Trials Unit	Baseline data from a cohort study	59.7 (12.8)	30.5 (7.5)	100	47 (47.0)	100 (100.0)	78 (78.0)	135.7 (14.2)	79.4 (10.0)	135.5 (11.7)	79.7 (10.0)	NA	NA	NA	NA
Ringrose et al,[41] 2018	Canada; hypertension clinic, University of Alberta	Retrospective medical record review	52.6 (16.7)	29.5 (5.9)	All, 96; BHTN, 76; No BHTN, 20	All, 38 (39.6); BHTN, NR; No BHTN, NR	All, 76 (79.2); BHTN, NR; No BHTN, NR	All, NR; BHTN, NR; No BHTN, NR	All, 130.8 (15.5); BHTN, 133.3 (15.8); No BHTN, 121.5 (9.8)	All, 82.3 (10.7); BHTN, 83.7 (10.8); No BHTN, 77.0 (8.3)	All, 142.8 (14.9); BHTN, 146.4 (14.3); No BHTN, 129.0 (7.3)	All, 83.9 (11.2); BHTN, 85.7 (11.5); No BHTN, 76.9 (6.5)	NA	NA	NA	NA
Wohlfahrt et al,[46] 2016	Czech Republic; study center	Cross-sectional	47.3 (11.3)	NR	2145	972 (45.3)	NR	440 (20.5)	120.8 (15.6)	80.0 (9.4)	NA	NA	NA	NA	127.4 (82.6)	82.6 (9.5)

Abbreviations: ABP, ambulatory blood pressure; ABPM, ambulatory blood pressure monitoring; AOBP, automated office blood pressure; BHTN, baseline hypertension; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); BP, blood pressure; DBP, diastolic blood pressure; ED, emergency department; HTN, hypertension; IQR, interquartile range; NA, not applicable; NR, not reported; PR, pseudoresistant; SBP, systolic blood pressure; TR, true resistant.

participants, with data from 4736 men and 4543 women. The sample size ranged from 43 to 2145 participants. The weighted mean age of participants was 55.9 years (range, 39-69.5 years). In approximately half of the studies, participants had a mean systolic AOBP of 130 mm Hg or more (n = 4892). Studies were conducted in a range of high-income countries (Table 1). Most studies (n = 18) were conducted in Canada[10,15,16,27-41]; 3 in the United States[42-44]; 3 in the Czech Republic[17,45,46]; 2 in Greece[47,48]; 1 each in Germany,[49] Ireland,[50] and Spain[51]; and 2 studies included multiple countries,[14,18] including Australia and Poland. Two reports of the CAMBO (Conventional vs Automated Measurement of Blood Pressure in the Office) trial[38,39] were used because the BP assessments were performed 2 years apart. Five studies randomized the order of BP measurement.[18,28,29,31,37] All but 3 of the studies that reported awake ABP measurements[17,37,47] performed ambulatory blood pressure monitoring (ABPM) on the same day after AOBP measurements.

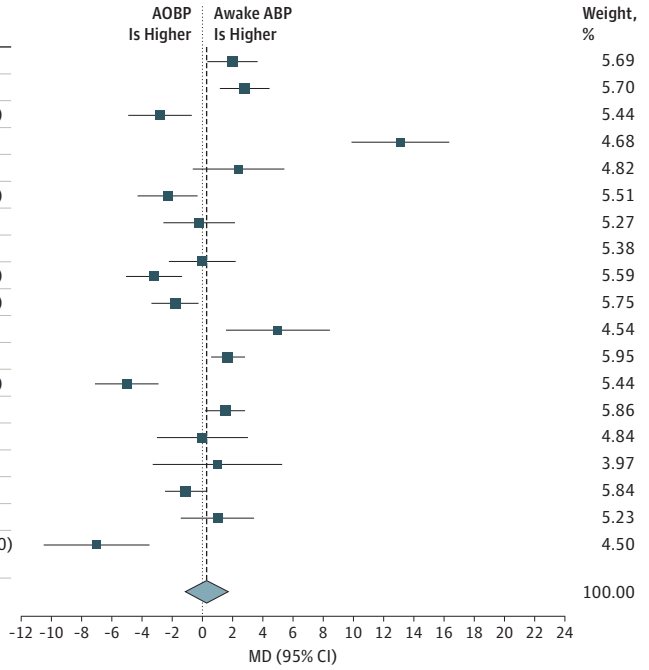
Meta-analyses

The pooled MD in systolic BP between routine BP and awake ABP measurements[14,27,33,34,36,38] was 13.4 mm Hg (95% CI, 9.5-17.5; I^2 = 96%; P < .001) (eFigure 2 in the Supplement). For diastolic BP, the pooled MD was 5.9 mm Hg (eFigure 3 in the Supplement). Based on 5 studies[17,35,37,44,47] the pooled MD between awake ABP and AOBP measurements in studies with systolic AOBP less than 130 mm Hg was 5.4 mm Hg (95% CI, 1.7-9.1; I^2 = 96%; P < .001) (eFigure 4 in the Supplement), showing that awake ABP was higher than AOBP in this normotensive BP range. The difference in MD between patients with normal BP and hypertension based on AOBP was statistically significant. Nineteen samples from 18 articles[10,14-16,18,27,30,32-36,38-41,47,51] reported comparisons between awake ABP, research BP, and routine BP measurements and mean systolic AOBP of 130 mm Hg or more. There was no difference in systolic BP between awake ABP and AOBP (pooled MD, 0.3; 95% CI, −1.1 to 1.7; n = 19; I^2 = 90%, P < .001) (**Figure 1**). Blood pressure measurements obtained under research conditions[15,18,28,32,33,35,49,51] were substantially higher compared with systolic AOBP (pooled MD, 7.0; 95% CI, 4.9-9.1; n = 9 samples; I^2 = 85.7%; P < .001) (**Figure 2**). The largest difference between routine BP measurements and systolic AOBP measurements was observed in 9 studies[14,27,29,33,34,36,38,42,45] (pooled MD, 14.5; 95% CI, 11.8-17.2; I^2 = 94.3%; P < .001) (**Figure 3**). This difference was comparable with the difference between awake ABP and routine office BP measurements (eFigure 2 in the Supplement). Repeating the analysis with diastolic BP readings showed similar results (eFigure 5 in the Supplement).

We conducted several meta-regression analyses to investigate the statistical heterogeneity observed in the comparison between AOBP and awake ABP measurements in studies with AOBP of 130 mm Hg or more. Age (−0.3 mm Hg per increase in years; n = 19; P = .22), BMI (−0.2 mm Hg per 1-unit increase in BMI; n = 7; P = .93), number of treated patients (0.001-mm Hg increase per 1% increase in proportion of treated patients; n = 16; P = .76), and sex (−0.2 mm Hg per 1% increase in the proportion of males; n = 19; P = .45) did not explain the statistical heterogeneity. Four studies[15,16,18,47] used

Figure 1. Mean Difference (MD) in Systolic Blood Pressure Between Automated Office Blood Pressure (AOBP) (Reference) and Awake Ambulatory Blood Pressure (ABP) Measurement in Samples With Systolic AOBP of 130 mm Hg or Higher

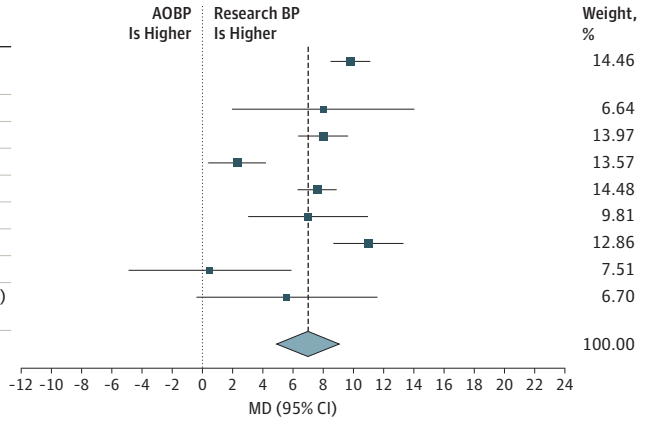
Source	AOBP, mm Hg	No. of Patients	MD (95% CI)	Weight, %
Myers et al,[33] 2009	132.0	309	2.00 (0.33 to 3.67)	5.69
Myers,[34] 2010	132.6	254	2.80 (1.15 to 4.45)	5.70
Myers et al,[39] 2012	133.1	252	-2.80 (-4.90 to -0.70)	5.44
Ringrose et al,[41] 2018	133.3	76	13.10 (9.86 to 16.34)	4.68
Ishikawa et al,[18] 2012	134.7	87	2.40 (-0.63 to 5.43)	4.82
Myers et al,[38] 2011	135.6	299	-2.30 (-4.29 to -0.31)	5.51
Padwal et al,[16] 2015	135.7	100	-0.20 (-2.57 to 2.17)	5.27
Moore et al,[14] 2018	136.0	189	0.00 (-2.21 to 2.21)	5.38
Edwards et al,[15] 2013	136.3	329	-3.20 (-5.06 to -1.34)	5.59
Myers et al,[40] 2012	138.6	100	-1.80 (-3.36 to -0.24)	5.75
Myers et al,[30] 2008 (1 min)	139.0	104	5.00 (1.56 to 8.44)	4.54
Godwin et al,[36] 2011	139.2	654	1.70 (0.57 to 2.83)	5.95
Andreadis et al,[47] 2012	139.9	139	-5.00 (-7.11 to -2.89)	5.44
Beckett et al,[27] 2005	140.0	481	1.50 (0.17 to 2.83)	5.86
Myers et al,[30] 2008 (2 min)	140.0	100	0.00 (-3.01 to 3.01)	4.84
Myers et al,[32] 2009	140.0	62	1.00 (-3.27 to 5.27)	3.97
Armstrong et al,[10] 2015	140.5	422	-1.10 (-2.47 to 0.27)	5.84
Myers et al,[35] 2010	141.0	139	1.00 (-1.43 to 3.43)	5.23
García-Donaire et al,[51] 2012 (TRUE-HTA)	144.4	101	-7.00 (-10.50 to -3.50)	4.50
Overall effect: I^2 = 89.5%; P < .001			0.29 (-1.13 to 1.71)	100.00



Weights are from random-effects analysis. TRUE-HTA is a study name.

Figure 2. Mean Difference (MD) in Systolic Blood Pressure (BP) Between Automated Office Blood Pressure (AOBP) (Reference) and Research BP Measurement in Samples With Systolic AOBP of 130 mm Hg or Higher

Source	AOBP, mm Hg	No. of Patients	MD (95% CI)	Weight, %
García-Donaire et al,[51] 2012 (TRUE-ESP)	130.8	300	9.80 (8.49 to 11.11)	14.46
Campbell et al,[28] 2005	131.0	50	8.00 (1.96 to 14.04)	6.64
Myers et al,[33] 2009	132.0	309	8.00 (6.34 to 9.66)	13.97
Ishikawa et al,[18] 2012	134.7	87	2.30 (0.39 to 4.21)	13.57
Edwards et al,[15] 2013	136.3	329	7.60 (6.31 to 8.89)	14.48
Myers et al,[32] 2009	140.0	62	7.00 (3.03 to 10.97)	9.81
Myers et al,[35] 2010	141.0	139	11.00 (8.68 to 13.32)	12.86
Bauer et al,[49] 2018	144.1	107	0.50 (-4.89 to 5.89)	7.51
García-Donaire et al,[51] 2012 (TRUE-HTA)	144.4	101	5.60 (-0.40 to 11.60)	6.70
Overall effect: I^2 = 85.7%; P < .001			6.99 (4.92 to 9.06)	100.00



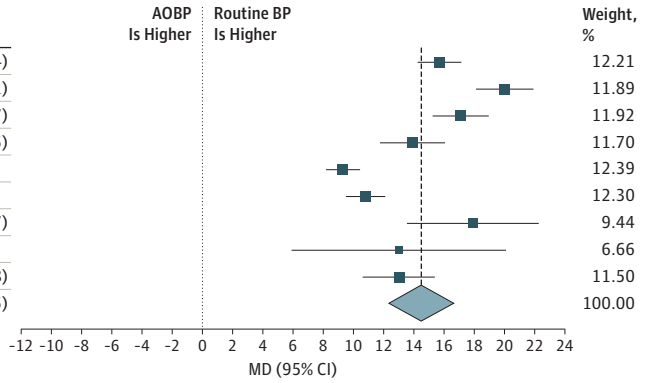
Weights are from random-effects analysis. TRUE-ESP and TRUE-HTA are study names.

added rest before AOBP measurement, which did not result in a significant difference compared with standard AOBP measurement in comparison with awake ABP measurement for each device (−2.4 mm Hg; n = 19; P = .31) (eFigure 6 in the Supplement). Similarly, the interval between AOBP measurements (1 or 2 minutes) was not significantly associated with the difference between AOBP and awake ABP (−1.9 mm Hg; n = 14; P = .25) (eFigure 7 in the Supplement).

There was consistency among the recording devices, which showed no significant differences between AOBP and awake ABP (BpTRU, 0.8 mm Hg; 95% CI, −1.0 to 2.5 mm Hg; n = 14; WatchBP, −1.3 mm Hg; 95% CI, −4.0 to 1.4 mm Hg; n = 4; Mobil-o-graph, 0.00 mm Hg; 95% CI, −2.2 to 2.2 mm Hg; n = 1) (eFigure 8 in the Supplement). In addition, there was no difference in AOBP and awake ABP for studies that included patients from specialist clinics or those referred for 24-hour ABPM (pooled MD, 0.6 mm Hg; 95% CI, −1.4 to 2.6 mm Hg; n = 14; I^2 = 91%; P < .001) and for unselected samples of patients (pooled MD, −0.3 mm Hg; 95% CI, −2.1 to 1.6 mm Hg; n = 5; I^2 = 83%; P < .001) (eFigure 9 in the Supplement). Studies that

Figure 3. Mean Difference (MD) in Systolic Blood Pressure (BP) Between Automated Office Blood Pressure (AOBP) (Reference) and Routine Office BP Measurement in Samples With Systolic AOBP of 130 mm Hg or Higher

Source	AOBP, mm Hg	No. of Patients	MD (95% CI)
Filipovský et al,[45] 2016	131.2	353	15.70 (14.26 to 17.14)
Myers et al,[33] 2009	132.0	309	20.00 (18.09 to 21.91)
Myers,[34] 2010	132.6	254	17.10 (15.23 to 18.97)
Myers et al,[38] 2011	135.6	299	13.90 (11.75 to 16.05)
Godwin et al,[36] 2011	139.2	654	9.30 (8.18 to 10.42)
Beckett et al,[27] 2005	140.0	481	10.80 (9.50 to 12.10)
Moore et al,[14] 2018	141.0	83	17.90 (13.53 to 22.27)
Myers,[29] 2006	142.0	50	13.00 (5.90 to 20.10)
Bhatt et al,[42] 2016	159.0	87	13.00 (10.62 to 15.38)
Overall effect: I^2 = 94.3%; P < .001			14.49 (11.83 to 17.15)



Weights are from random-effects analysis.

Table 2. Mean Differences in Systolic Blood Pressure Between AOBP and Awake ABP, Research BP, and Routine Office BP Measurements in Patients With Hypertension[a]

Comparison of BP Measurements	No. of Samples	Mean Difference (95% CI), mm Hg	Conclusion
Main Analyses			
AOBP vs awake ABP measurement	19	−0.3 (−1.1 to 1.7)	AOBP = ABP
AOBP vs research BP measurement	9	7.0 (4.9 to 9.1)	AOBP < research BP
AOBP vs routine office BP measurement	9	14.5 (11.8 to 17.2)	AOBP < routine office BP
Subgroup Analyses			
AOBP vs awake ABP measurement			
No added rest	15	0.8 (−0.8 to 2.3)	AOBP = ABP
Added rest	4	−1.7 (−1.1 to 1.7)	AOBP = ABP
1-min interval	8	−0.2 (−2.2 to 1.9)	AOBP = ABP
2-min interval	6	−2.0 (−3.5 to −0.4)	AOBP > ABP
BpTRU	14	0.8 (−1.0 to 2.5)	AOBP = ABP
WatchBP Office	4	−1.3 (−4.0 to 1.4)	AOBP = ABP
Mobilo-graph	1	0.0 (−1.1 to 1.7)	AOBP = ABP
Unselected population	5	−0.3 (−2.2 to 1.6)	AOBP = ABP
Referral or specialist	14	0.6 (−1.4 to 2.6)	AOBP = ABP
High-quality studies	12	0.2 (−1.3 to 1.6)	AOBP = ABP
Awake ABP ≥130 mm Hg	21	1.1 (−0.7 to 2.8)	AOBP = ABP

Abbreviations: ABP, ambulatory blood pressure; AOBP, automated office blood pressure; BP, blood pressure.

[a] Hypertension defined as AOBP of 130 mm Hg or higher.

were classified as high quality, which were more clinically homogeneous, showed similar results as our main analysis (pooled MD, 0.2 mm Hg; 95% CI, −1.3 to 1.6 mm Hg; I^2 = 85%; P < .001) (eFigure 10 in the Supplement). **Table 2** summarizes the results of the main and subgroup analyses.

We found no evidence for small-study effects or publication bias for the main analysis of a comparison between AOBP and awake ABP for individuals with hypertension based on funnel plots (eFigures 11 and 12 in the Supplement) or formal tests (Egger test, P = .93 for systolic BP and P = .67 for diastolic BP). There was little evidence of possible bias in the form of financial support by manufacturers of devices for the studies. Only 2 of 31 studies included in the meta-analysis declared partial support from a manufacturer.[18,28] The results from 5 studies that randomized the order of BP measurement were generally in the same range as analyses using all available studies.

Leaving each trial out of the analysis one at a time revealed no meaningful differences in MD (eFigures 13 and 14 in the Supplement). A sensitivity analysis using awake systolic ABP of 130 mm Hg or more as the definition of hypertension showed similar results (pooled MD, 1.1 mm Hg; 95% CI; −0.7 to 2.8 mm Hg; n = 21; I^2 = 94%; P < .001) for a comparison between AOBP and awake ABP.

Discussion

This study is the first comprehensive systematic review and meta-analysis, to our knowledge, to compare AOBP with other

techniques of BP measurement in identifying patients with possible hypertension to be confirmed subsequently by ABPM or home BP. The meta-analysis comparing AOBP with awake ABP in patients with hypertension showed that the mean systolic BP reading derived from 19 samples from 18 articles[10,14-16,18,27,30,32-36,38-41,47,51] was virtually identical for both techniques (Figure 1). Systolic AOBP differed from awake ABP by more than 5 mm Hg in only 2 studies,[41,51] 1 of which[41] was a retrospective medical record review from an ABPM center.

Otherwise, despite the large statistical heterogeneity, which is expected considering the relatively large sample size in each study, the results exhibited a minimal amount of clinical heterogeneity, with results being confirmed in our analysis of high-methodological quality studies. Although most of the studies did not randomize the sequence of BP measurements, leaving the possibility of an order effect, the studies that did randomize the sequence of BP measurements reported similar results to those that did not. With regard to timing of the measurements, almost all studies measured AOBP and awake ABP on the same day, thus minimizing differences due to timing. Furthermore, no study had an overly large influence, pooled results were consistent across subgroup and meta-regression analyses, and there was no evidence of publication bias. In addition, we examined the association between AOBP and awake ABP in patients with normal BP.[17,35,37,44,48] With 1 exception,[48] the mean AOBP was lower than the mean awake ABP by approximately 5 mm Hg. These findings are consistent with other comparisons between awake ABP and both manual and oscillometric office BP readings in patient populations with normal BP.[52]

Among the studies on AOBP included in our analyses, we also identified 6 studies[14,27,33,34,36,38] comparing office BP readings recorded in routine clinical practice with awake ABP (eFigure 2 in the Supplement). The MD for routine office BP was significantly higher (13.5 mm Hg; 95% CI, 9.5-17.5 mm Hg) and similar in magnitude to the difference observed in other studies. Previous reviews of office BP recorded in research studies according to guidelines have equated an office BP of 140/90 mm Hg with an awake ABP of 135/85 mm Hg. The results of our meta-analyses clearly show that the routine office BP is substantially higher, suggesting that proper BP measurement techniques in clinical practice were rarely followed. This white coat effect was also present when office BP in primary care was recorded in duplicate using an oscillometric sphygmomanometer. In 27 211 patients with hypertension in the Spanish ABPM Registry, the mean oscillometric office BP was 160/89 mm Hg, compared with a mean awake ABP of 135/78 mm Hg.[7] Thus, simply replacing manual BP with an oscillometric device did not eliminate the white coat effect.

Given that the AOBP in patients with hypertension is comparable with the awake ABP, a routine office BP should be substantially higher than the corresponding AOBP reading. Our meta-analysis of 9 studies[14,27,29,33,34,36,38,42,45] involving patients with hypertension showed the mean routine office systolic BP to be almost 15 mm Hg higher than the mean AOBP (Figure 3). This difference was similar in magnitude to what was seen in the comparison between the routine office BP and the awake ABP and was consistent. If a white coat effect is defined on the basis of the difference between mean office BP and mean awake ABP, then AOBP appeared to eliminate the overall white coat effect usually associated with office BP.

Because AOBP is comparable to the awake ABP in hypertensive patients, one would also expect the AOBP to be lower than office BP readings recorded in research studies according to guidelines. Results from the meta-analysis of 9 samples from 8 articles[15,18,28,32,33,35,49,51] involving patients with hypertension (Figure 2) confirmed this hypothesis, with the mean systolic AOBP being 7 mm Hg lower than the corresponding mean research office BP. Thus, even if a research quality BP were to be performed in routine clinical practice, AOBP would still have the advantage of having the same threshold as awake ABP (135/85 mm Hg) for diagnosing hypertension, whereas the research office BP threshold would still be 140/90 mm Hg. The 3 key aspects of AOBP must always be followed if higher readings are to be avoided: multiple BP readings, recorded with a fully automated device, with the patient resting quietly and alone. Only 1 study, by Bauer et al,[49] has reported a mean research quality systolic BP similar to the AOBP. In contrast, the findings in the other 8 samples from 7 articles comparing research BP with AOBP showed the research BP to be consistently higher (Figure 2). It is questionable if the very strict BP measurement conditions in the study of Bauer et al,[49] especially no conversation or other interaction with the patient, can be realistically reproduced in routine clinical practice.

If AOBP is to be used in clinical practice, readings must closely adhere to the procedures used in the AOBP studies in this meta-analysis, including multiple BP readings recorded with a fully automated oscillometric sphygmomanometer while the patient rests alone in a quiet place. Using this approach, AOBP has been the preferred technique for office BP measurement in the evidence-based Hypertension Canada guidelines[2] since 2016 and is now routinely used by many Canadian primary care physicians.[12] The existing evidence supports the use of AOBP to screen patients for possible hypertension in clinical practice, especially if one takes into account the white coat effect associated with current manual or oscillometric techniques for office BP measurement. The use of AOBP in clinical practice has also been recognized elsewhere, such as in a forthcoming statement on blood pressure measurement from the American Heart Association and in the recent guidelines from the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines.[3] Automated office BP should now be the preferred method for recording BP in routine clinical practice to identify patients with possible hypertension, with the diagnosis to be confirmed by 24-hour ABPM or home BP.

ARTICLE INFORMATION

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Concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: All authors.
Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Roerecke.
Administrative, technical, or material support: All authors.
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