Diagnostic performance of clinic and home blood pressure measurements compared with ambulatory blood pressure: a systematic review and meta-analysis

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Abstract

Background: Currently, clinic blood pressure measurement (CBPM) is most commonly used for screening hypertension, but it is facing with white coat hypertension (WCHT) and masked hypertension (MHT). Home blood pressure measurement (HBPM) may be an alternative, but its diagnostic performance is inconclusive relative to CBPM. Therefore, this systematic review aimed to estimate the performance of CBPM and HBPM compared with ambulatory blood pressure measurement (ABPM) and to pool prevalence of WCHT and MHT.

Methods: Medline and Scopus databases were searched up to 23rd January 2020. Studies having diagnostic test as CBPM or HBPM, reference standard as ABPM, and reported sensitivity and specificity of either or both tests and/or proportion of white coat or masked hypertension were eligible. Diagnostic performance of CBPM and HBPM were pooled using bivariate mixed-effect regression model. Random effect model was applied to pool prevalence of WCHT and MHT.

Results: Fifty-eight studies were eligible. Pooled sensitivity, specificity, and diagnostic odds ratio of CBPM were 70% (95%CI: 63%-76%), 81% (95%CI: 73%-81%), and 9.84 (95%CI: 6.82-14.20), respectively. Pooled prevalence of WCHT and MHT were 28% (95%CI: 25%-32%) and 27% (95%CI: 22%-31%). Pooled sensitivity, specificity, and diagnostic odds ratio of HBPM were 74% (95%CI: 66%-80%), 83% (95%CI: 76%-89%), and 13.73 (95%CI: 8.55-22.03), respectively. Pooled WCHT and MHT were 17% (95%CI: 11%-22%) and 30% (95%CI: 19%-42%), respectively.

Conclusions: Diagnostic performances of HBPM were slightly higher than performance of CBPM. However, prevalence of MHT was high in both negative CBPM and HBPM. Therefore, ABPM is still necessary for hypertension diagnosis, especially in people suspected with masked hypertension.

Background

Screening for hypertension (HT) is an important strategy for prevention of cardiovascular diseases (CVD). Currently, several approaches have been used for measuring blood pressure (BP) including ambulatory (ABPM), home (HBPM), and clinic blood pressure measurements (CBPM), in which CBPM is the most commonly used in a routine clinical practice. However, patients may falsely have high BP only in the clinical setting, i.e., a phenomenon known as white coat hypertension (WCHT), or they may have normal BP in the clinic, but have an elevated BP measured by ABPM, known as masked hypertension (MHT) (1). The effect of WCHT on risk of CVD is slightly higher than normotension, i.e., it increased risk of CVD about 19% when compared to normotension (2, 3), whereas MHT significantly increased risk of CVD about 3 times when compared to normotension (4). Patients with WCHT receive unnecessary treatments whereas patients with MHT receive delayed proper treatments. Therefore, accurate diagnosis of HT is very important in order to prevent complications of HT and avoid unnecessary treatment. Guidelines by European Society of Cardiology and the European Society of Hypertension (ESH) 2018 (5), and American Heart Association (AHA) 2017 (1) suggest using ABPM as the reference standard for HT diagnosis. However, ABPM is not practical for routine use in clinical practice because of its high cost and poor patient compliance. HBPM is less expensive and more convenient than ABPM, therefore it has been suggested as an alternative for diagnosis of WCHT and or MHT (6). However, the performance of HBPM as the gold standard for HT diagnosis is still uncertain (7).

A meta-analysis (8) was conducted in 2011 to assess the diagnostic performance of CBPM (N = 7) and HBPM (N = 3) using day-time ABPM as the reference standard. Overall sensitivity of CBPM was lower than HBPM (74.6% vs. 85.7%), but the specificity was higher (74.6% vs. 62.4%). Another systematic review in 2015 has reported that patients with high BP by CBPM actually had high BP confirmed by ABPM or HBPM about 35% to 95% (9). However, this study did not apply meta-analysis to pool the diagnostic accuracy of CBPM.

To date, several individual studies for CBPM and few for HBPM have been published since 2011. Furthermore, some factors such as age, sex, measurement technique, and types of ABPM were highly associated with HT diagnosis (10-12). Then, a subgroup analysis by these factors may be useful to guide BP screening strategy. Therefore, this systematic review was conducted with following aims: 1) update the diagnostic performances of CBPM and HBPM using ABPM as the standard test and, 2) pool prevalence of WCHT among positive CBPM and HBPM, and pool prevalence of MHT among negative CBPM and HBPM, 3) perform subgroup analysis by those potential factors associated with HT diagnosis. Results from this study will be useful for guiding primary care, internal medicine doctors, and cardiologists about the proper measurements used for diagnosis of HT.

Methods

The protocol of this systematic review has been registered in PROSPERO (CRD42018099647). The review protocol is available at https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42018099647

Selection of studies

Relevant studies were identified from Medline and Scopus databases up to 23rd January 2020 using search terms and strategies described in the Additional Appendix. Reference lists of the included studies were searched to identify additional studies.

Study selection was manually performed by 2 independent reviewers (AK and TA). Studies were selected based on titles and abstracts, and full articles were retrieved if more information was needed. The studies were eligible, if they include participants as adults aged ≥ 18 years, had diagnostic test as CBPM or HBPM, reference standard as ABPM and reported sensitivity and specificity and/or WCHT proportion among CBPM/HBPM positive or MHT proportion among CBPM/HBPM negative. Endnote X9 was used to manage references during the process of study selection.

Study and standard tests

The study tests were CBPM and HBPM. CBPM was performed in a health care setting, whereas HBPM was self-performed in a household using manual or automatic sphygmomanometers. Thresholds used for defining HT were BP $\geq 140/90$ mmHg for CBPM and BP $\geq 130/80$ or $135/85$ mmHg for HBPM(13-15). The reference standard test was ABPM, a continuously measured BP in day-time (10-16 hours), night-time (6 hours), or 24 hours.

Outcome of interest

The interested outcome was HT diagnosed by ABPM using the thresholds of individual studies, which were 135/85, 120/70, and 130/80 mmHg for day-time/awake, night-time, and 24-hr, respectively. Diagnostic performance of studied tests (i.e., CBPM and HBPM) compared to the standard test (i.e. ABPM) was assessed by estimating sensitivity (i.e., probability of having positive CBPM among HT patients diagnosed by ABPM), specificity (i.e., probability of having negative CBPM among non-HT patients diagnosed by ABPM), likelihood ratio positive (LR+, i.e., sensitivity/(1-specificity)), likelihood ratio negative (LR-, i.e., (1-sensitivity)/specificity) and diagnostic odds ratio (DOR, i.e., LR+/LR-). WCHT was defined as normal BP measured by ABPM among CBPM/HBPM positive whereas MHT was defined as high BP by ABPM among CBPM/HBPM negative(16).

Data extraction

Two reviewers (AK and TA) independently extracted the data including study's characteristics (i.e. study setting, study design), study participants (i.e. mean age, percent male, and underlying disease), study and standard tests (i.e. types, measurement device, time and duration of measurement, and cut-offs for HT diagnosis). Numbers of true positive, false positive, true negative, and false negative for each diagnostic test were extracted.

Risk of bias assessment

Risk of bias assessments were done independently by 2 reviewers (AK and TA) using the Quality of Diagnostic Accuracy Studies - 2 (QUADAS-2)(17) including patient selection, index test, reference standard, and flow/timing domains. Each domain consists of two sections, i.e., risk of bias and applicability. Risk of bias comprised 3 items (i.e., information used to support the risk of bias judgment, signaling questions, and judgment) which was judged as low, high, or unclear. Applicability was judged as low, unclear, or high risk according to whether the study did or did not match the review question.

Statistical analysis

Diagnostic performances of CBPM/HBPM versus ABPM (i.e., sensitivity, specificity, area under receiver operating characteristic(ROC) curve, LR^+/LR^- , and DOR) were estimated for individual studies. These were then pooled using a bivariate mixed-effect regression model taking into account the different BP thresholds. In addition, the hierarchic summary ROC(HSROC) curve was estimated and plotted if applicable (number of studies ≥ 4); this was classified as low, moderate, or high accuracy if the HSROCs were $0.5 < x < 0.7$, $0.7 \leq x \leq 0.9$, and $0.9 < x \leq 1$, respectively(18).

Proportions of WCHT and MHT were separately pooled using a random-effect model if heterogeneity was present; otherwise a fixed-effect model was applied. Heterogeneity was assessed using a Q test ($p < 0.1$) and the I^2 statistic ($> 25\%$). Potential sources of heterogeneity (i.e. mean age, sex, study settings, types of ABPM, numbers of repeated BP measurements) were explored by adding variables one by one in a meta-regression model. If the variables could decrease I^2 or τ^2 , subgroup analysis was performed accordingly.

Publication bias was examined by Deek's funnel plot(19). If there was asymmetry, a contour-enhanced funnel plot was further explored to distinguish whether an asymmetrical funnel was due to heterogeneity or publication bias. All statistical analyses were performed with STATA version 15.0 (StataCorp, College Station, Texas). P-values < 0.05 were considered statistically significant for all tests except for heterogeneity and Egger's tests, where a P-value < 0.10 was used.

Results

Searching from Medline and Scopus databases identified 1,104 and 1,224 articles, respectively. After deleting duplications, 1460/1,693 studies were screened by screening titles and abstracts. A total of 233 full articles were reviewed and 58 studies met inclusion criteria and were finally included in the review. Among the included studies, 50(10, 12, 20-67), 4(68-71), and 4(7, 72-74) studies assessed CBPM, HBPM, and both CBPM and HBPM performances, respectively (see Figure 1). Their characteristics are described in Table 1. Among the 58 studies, 32 and 26 studies recruited participants from hospital and community settings, respectively. Most studies included general population, whereas 4 studies included specific populations, e.g., white-collar workers(26, 67), male football players(41), and male military workers(38). Twenty-one studies included participants who had not been prior diagnosed with HT, whereas 37 studies included both participant who had or had not been diagnosed with HT.

Risk of bias assessment

Results of risk of bias assessment are presented in Additional Table 1. Almost all CBPM studies (94.44%) were low risk in all domains of applicability. Eight(21, 32, 39, 40, 45, 51, 53, 58) (16.7%) and 7 (12.9%) studies(31, 35, 42, 47, 50, 56, 59) were high and unclear bias in selection of study subjects. Fifty-two studies(10, 12, 20-32, 34-39, 41-67, 71, 72, 74) (96.3%) applied the index/study test before the reference standard, but with unclear explanation of blinding. Thirty-eight studies (70.4%) were high or unclear risk of bias in flows and timing because they did not report the time interval between the study test and the reference standard, or they also excluded subjects with invalid test results or those lost to follow up. All HBPM studies were low risk of bias in all domains of applicability. Six studies (75%) applied the index test before the reference standard without blinding information, and 4 studies (50%) were high risk of bias in their flow and timing.

Pooling CBPM diagnostic performances

Among 54 CBPM studies, 31 studies (7, 10, 12, 20-35, 41, 59-67, 72, 73) reported 2x2 table data which could be assessed for diagnostic performance, while 7 (36-40, 42, 43) and 16 (44-58, 71) studies reported data for only positive and negative CBPM respectively (see Table 1).

Among the 31 studies with 2x2 data, 29 (7, 10, 12, 21-35, 41, 59-64, 67, 73, 74) and 1 (20) studies used a cutoff threshold of $\geq 140/90$ and $\text{DBP} > 95$ mmHg for diagnosis of HT. The cut-offs of ABPM were 125-130/79-80 for 24-hr (12, 27, 32-34, 59, 60, 62-64, 74) and 135-140/85-91 mmHg for day-time/awake (7, 20-26, 28-31, 35, 61, 66, 67, 73). The mean age ranged from 28 to 62 years and percent male ranged from 35% to 100% (see Table 1).

These 2x2 data ($n = 66,767$) were used for pooling diagnostic characteristics of CBPM versus ABPM, see Additional Table 2. The pooled sensitivity and specificity were 70% (95% CI: 63%, 76%; $I^2 = 98.56\%$) and 81% (95% CI: 73%, 87%; $I^2 = 99.47\%$) with high heterogeneity, see Figure 2 a-b. Pooled LR+ and LR- were 3.67 (95% CI: 2.69, 5.00; $I^2 = 99.35\%$) and 0.37 (95% CI: 0.31-0.44; $I^2 = 98.57\%$), see Additional Figure 1. These diagnostic characteristics all require setting a threshold and trading off sensitivity for specificity or LR+ for LR-, hence they must be judged in pairs. For example, given a pretest probability of HT of 44%, the post-test probability was increased to 74% if CBPM was positive, or reduced to 23% if CBPM was negative (see Fagan's plot Figure 3a). Alternatively, a single measure of diagnostic performance, i.e., the DOR was 9.84 (95% CI: 6.82, 14.20; $I^2 = 100\%$), see Additional Figure 1c. The HSROC reflects diagnostic performance across the entire range of possible threshold values; in this case, the pooled HSROC was 0.81 (95% CI: 0.72, 0.88) indicating moderately good discrimination for judging presence of HT (Additional Figure 2a). Deek's funnel plot showed no evidence of publication bias (Additional Figure 3a).

Subgroup analysis

Subgroup analyses were performed by types of ABPM, age group (< 50 and ≥ 50 years), percent males ($< 50\%$ and $\geq 50\%$), number of repeated measurements of CBPM (1, 2-5 times), setting of studies (community and hospital-based), and type of patients (no HT, mixed HT with non-HT). The degrees of heterogeneity (I^2) did not decrease for each sub-group of these factors (Additional Table 3), but performances of CBPM improved in some sub-groups including age group ≤ 50 year, percent male $\leq 50\%$, and community-based setting with the LR+ of 5.1 (95% CI: 3.0, 8.7), 5.8 (95% CI: 3.5, 9.8), and 6.0 (95% CI: 3.9, 9.3), respectively.

Pooling HBPM diagnostic performances

Eight HBPM studies (7, 68-74) reported 2x2 data (Additional Table 4) with cutoff threshold of 135/85 (68-72, 74) ($N=6$) and 140/90 (7, 74) ($N=2$) mmHg and measurement duration about 3 to 7 days, see Table 1. Mean age and percent male ranged from 48.1 to 51.8 years and 46.5% to 54.9% respectively. Among them, 4, 3, and 1 studies applied 24-hr ABPM, day/awake ABPM, and multiple periods, respectively.

The overall pooled sensitivity and specificity were respectively 74% (95% CI: 66%, 80%; $I^2 = 95.52\%$) and 83% (95% CI: 76%, 89%; $I^2 = 90.20\%$), see Figures 2 c-d. The pooled DOR, LR+ and LR- were 13.73 (95% CI: 8.55, 22.03; $I^2 = 99.99\%$), 4.36 (95% CI: 3.04, 6.27; $I^2 = 75.06\%$), and 0.32 (95% CI: 0.25, 0.41; $I^2 = 94.34\%$), see Additional Figure 4 a-c. Again, given a pretest-probability of 44%, a positive HBPM would result in a post-test probability of 77%, while a negative HBPM would reduce the probability to 20% (Figure 3b). The pooled HSROC was 0.85 (95% CI: 0.82, 0.88), again suggesting moderately good discrimination, see Additional Figure 2b. Sub-group analysis could not be performed due to the small number of included studies. Deek's funnel plot indicated no evidence of publication bias, see Additional Figure 3b.

Pooling prevalence of WCHT and MHT by CBPM

Seven (36-40, 42, 43) and 16 studies (44-58, 65) reported only data of WCHT and MHT, see Table 1. These studies were then combined with 31 CBPM studies with 2x2 data above, yielding a total of 38 and 47 studies for pooling proportions of WCHT and MHT respectively. Among the 38 studies with WCHT, time of ABPM measures were 24-hr ($N=13$), day-time/awake ($N=23$), and multiple periods ($N=2$). Among the 47 studies with MHT, ABPM measures were 24-hr ($N=13$), day-time/awake ($N=24$), and multiple times ($N=7$), both 24-hr and daytime ($N=4$), and daytime and nighttime ($N=1$).

Data for the 38 ($n = 32,685$) and 47 ($n = 47,713$) studies for WCHT and MHT are provided in Additional Tables 5 and 6. The pooled proportions of WCHT and MHT were 0.28 (95% CI: 0.25, 0.32) and 0.27 (95% CI: 0.22, 0.31) with corresponding I^2 of 97.64% and 99.36% respectively, see Figures 4a and 4b. Subgroup analyses were performed, but none of the co-variables could decrease the degree of heterogeneity (see Additional Table 7). However, subgroup of repeated measures of CBPM 4-5 times and 24-hr ABPM could respectively reduce the pooled WCHT from 0.28 to 0.23 (95% CI: 0.16, 0.31) and 0.23 (95% CI: 0.18, 0.28). Likewise, repeated CBPM measure could reduce the pooled MHT from 0.27 to 0.15 (95% CI: 0.10, 0.19) whereas the 24-hr ABPM conversely increased the prevalence to 0.33 (95% CI: 0.22, 0.43).

Pooling prevalence of WCHT and MHT by HBPM

Eight HBPM studies were included for pooling WCHT ($n = 1,979$) and MHT ($n = 1,939$), see Additional Table 4. The pooled prevalence of WCHT and MHT were 0.17 (95% CI: 0.11, 0.22) and 0.30 (95% CI: 0.19, 0.42) with the corresponding I^2 of 88.62% and 97.32%, see Figures 4 c-d.

Discussion

The findings suggest that diagnostic performances of HBPM were slightly higher than those of CBPM. The pooled sensitivity, specificity, DOR, LR+, and area under ROC for HBPM were respectively 74%, 83%, 13.73, 4.36, and 0.85%, while these corresponding values for CBPM were respectively 70%, 81%, 9.84, 3.67, and 0.81%.

To date, there has been only one relevant meta-analysis published in 2011 (8), which included fewer studies than ours (i.e., 7 versus 31 for CBPM and 3 versus 8 for HBPM). Overall sensitivities found in our study were lower than the previous review (i.e., 70% vs. 75% for CBPM and 74% vs. 86% for HBPM), while the specificities were higher (i.e., 81% vs. 75% for CBPM and 83% vs. 62% for HBPM). Our pooled estimates are more precise than the previous review, which was

limited by the small number of included studies. In addition, our results indicated that roughly 28% of those who are positive on CBPM may have WCHT and roughly 27% of those who are negative on CBPM may have MHT. The prevalence of WCHT and MHT were approximately 17% and 30% when using HBPM.

The percent WCHT was lowest when comparing CBPM with 24-hr ABPM (23%), while the percent MHT was highest when comparing CBPM with 24-hr ABPM (33%). This reinforces the belief that 24-hr ABPM yields the best for detecting HT because it can capture the nighttime and morning surge BP. Therefore, the actual WCHT in the clinical practice might be lower than that found in our study (28%), which most of the studies compared CBPM with daytime ABPM. The number of repeated measurements of CBPM also affected the diagnostic performances, i.e., there was a lower WCHT and MHT if repeatedly measuring CBPMs over 4-5 visits.

Our results also found that the percent WCHT was lower in HBPM than CBPM (17% versus 28%), in other words, a diagnosis of HT by CBPM alone could lead to misclassify patients who actually do not have hypertension. This is an important issue for diagnosis and treatment of hypertension because previous evidence from meta-analyses found a similar risk of cardiovascular disease between those with WCHT and normotension(75-77). Unnecessary treatments of WCHT have several disadvantages including potential adverse drug events and costs. Measuring BP in the patient's own environment using HBPM could reduce stress and decrease over-diagnosis of HT. Although HBPM could decrease WCHT, implementing HBPM for screening HT in the general population may carry significant budget implications, particularly in low and middle income countries.

An automated office blood pressure measurement (AOBPM), in which clinic BP is measured when patient is unattended sitting in a quiet room, might be an alternative if ABPM cannot be applied as for evidences from the recent meta-analyses (78, 79). These evidences showed that BP measured by AOBPM was not different from BP measured by awake/daytime ABPM, but it was significantly different when compared to CBPM which was measured by physicians or nurses. Therefore, the AOBPM may be another option to enhance diagnostic performance of CBPM in routine clinical practice.

In contrast to WCHT, detection of MHT is important for CVD prevention. Our results found that prevalence of MHT was high in both normal CBPM (27%) and HBPM (30%). Thus, ABPM is still necessarily for confirming the diagnosis of MHT. Nonetheless, screening all individuals with normal CBPM or HBPM is impractical; so prioritizing people who are high risk of CVD to screen with ABPM is important. Several approaches have been used for identifying such high risk individuals. For instance, Veira et al(50) suggested that people with prehypertension by CBPM (systolic BP = 120-139 mmHg and/or diastolic BP = 80-89 mmHg) should be referred for ABPM to screen MHT. However, the false positive rate of this approach was as high as 40% and the authors concluded that high-normal BP from CBPM alone might not be appropriate for prioritizing people to screen for MHT.

Another method is CVD risk-based approach using known CVD risk factors such as male sex, smoking, obesity, and diabetes. However, results from Colantonio et al. indicated that considering metabolic syndrome did not provide higher prediction of MHT than using clinic BP alone(80). Therefore, future research about the strategies to identify individuals at high risk of MHT is needed.

Our study has some strengths. We estimated the diagnostic performance of CBPM and HBPM relative to ABPM by additionally pooling data from 31 and 8 studies with prevalence of WCHT and MHT. However, our study has some limitations. Firstly, our pooling was based on high heterogeneity across studies, particularly for pooling prevalence of WCHT and MHT. Although, we attempted to explore the sources of heterogeneity by performing subgroup analyses according to age group, sex, and types of ABPM. None of them was identified as a source of heterogeneity. A small number of HBPM studies was available compared to the number of CBPM studies, and estimation of diagnostic performance yielded imprecision, so results need to be updated when more studies are available, or individual patient data (IPD) meta-analysis should be considered to allow for more sub-group analysis of specific factors. Although most included studies had low risk of bias in subject selection and index test, most of them (70.4% for CBPM and 50% for HBPM) had high risk of bias in flow and timing due to long/unclear time interval between performing index and standard tests. The long interval may lead to misclassification of disease due to improvement or worsening of the BP condition(17). For instance, patients with high BP by CBPM/HBPM may be prescribed anti-hypertensive drugs to lowering BP before performing ABPM. This might underestimate the diagnostic performance of CBPM and HBPM. Finally, we did not identify relevant studies from grey/unpublished databases. Although there was no evidence of publication bias suggested by Deek's funnel plot(19) for both pooled estimates of CBPM and HBPM, publication bias could be not ruled out and overestimated diagnostic accuracy of CBPM and HBPM might be present. However, some previous systematic review and meta-analyses found that including unpublished studies might affect less on overall estimates, so they should not change the overall findings(81, 82). All of these limitations might distort generalizability of our findings, thus applying our results in clinical practice should be considered individually.

Conclusion

In conclusion, diagnostic performances of HBPM were slightly higher than the performance of CBPM. However, the prevalence of MHT was high in both negative HBPM and CBPM. Therefore, ABPM is still necessary for confirming the diagnosis of HT, especially in people who are highly suspected with MHT.

Abbreviations

ABPM; ambulatory blood pressure measurement, AHA; American Heart Association, BP; blood pressure, CBPM; clinic blood pressure measurement, CI; confidence interval, CKD; chronic kidney disease, CVD; cardiovascular diseases, DBP; diastolic blood pressure, DM; diabetes mellitus, DOR; diagnostic odds ratio, HBPM; home blood pressure measurement, HT; hypertension, LR; likelihood ratio, MHT; masked hypertension, NM; normotension, QUADAS-2; Quality of Diagnostic Accuracy Studies – 2, ROC; receiver operating characteristic, SBP; systolic blood pressure, SD; standard deviation, SE; standard error, WCHT; white coat hypertension

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: All data generated or analysed during this study are included in this published article and its Additional information files.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: AK, TA and AT were responsible for designing the study. AK and TA were responsible for searching the databases, selecting the studies, and extracting the data. AK, TA, and AT analyzed the data. AK and TA drafted the manuscript. CD, AT, UC, and JA critically revised the manuscript.

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Table

Table 1: **Characteristic of included studies**

Author (Year)	Country	Setting	Type of population	Previous HT	Taking anti-HT drug	Mean age (year)	%Male	CBPM; HBPM cut-off (mmHg)	No. repeated measure CBPM (day interval)	Measurement duration for HBPM (day)
<i>Studies with complete 2x2 diagnostic results of CBPM only</i>										
Brueren M. 1995(20)	Netherlands	Health care	Outpatient	Non-HT	No	47	51.13	95(DBP)	3 (-)	-
Botomino A. 2004(21)	Switzerland	Community	General population	Mixed	Unspecified	53.7	42	140/90	1	-
Ungar A. 2004(22)	Italy	Health care	General population	Mixed	No	60	48.8	140/90	1	-
Ohkubo T. 2005(23)	Japan	Community	General population	Mixed	Mixed	61	40	140/90	1	-
Fagard R. 2007(24)	EU-countries	Community	General population	Mixed	No	39	46.1	140/90	1	-
Wang G. 2007(25)	China	Community	General population	Mixed	Mixed	(18 – 86)	54.3	140/90	1	-
Trudel X. 2009(26)	Canada	Community	White-collar workers	Non-HT	No	44	38.8	140/90	1	-
Ishikawa J. 2010(27)	Japan	Community	General population	Mixed	No	59.9	52.7	140/90	1	-
Maseko M. 2011(28)	South Africa	Community	General population	Mixed	Unspecified	43.9	35.6	140/90	1	-
Afsar B. 2013(29)	Turkey	Health care	Outpatient	Mixed	Unspecified	57.46	67	140/90	1	-
Berge H. 2013(41)	Norway	Community	Male professional football players	Mixed	No medication	28.1	-	140/90	1	-
Alwan H. 2014(30)	Germany	Community	General population	Mixed	Mixed	48	49	140/90	1	-
Conen D. 2014(10)	Europe, South America and Asia	Community	General population	Mixed	No	45.74	48.48	140/90	1	-
Aihamsi K. 2015(31)	Oman	Health care	Outpatient	Mixed	Mixed	46.15	-	140/90	-	-
Rhee M. 2015(12)	Korea	Community	General population	Mixed	Unspecified	46.7	35.9	140/90	1	-
Mutlu S. 2016(32)	Turkey	Health care	General in-patient	Mixed	Mixed	44.4	54.4	140/90	-	-
Scuteri A. 2016(33)	Italy	Community	General population	Mixed	Mixed	48.93	39.88	140/90	-	-
Melgarejo J. 2017(34)	Europe and Asia	Community	General population	Mixed	No	-	-	140/90	1	-
Fujita H. 2018(35)	Japan	Community	General population	Non-HT	No	-	51.5	140/90	-	-
Erdogmus S. 2018(62)	Turkey	Health care	General population	Mixed	Mixed	55	42.3	140/90	1	-
Sheppard J.P. 2018(66)	U.K.	Health care	General population	Mixed	Mixed	52.8	46.2	NA	1	-
Bhattarai M. 2019(59)	Nepal	Health care	General population	Non-HT	Mixed	43.82	55	140/90	1	-
Cai P. 2019(60)	China	Health care	General population	Non-HT	No	61.8	48.5	140/90	1	-
Kaul U. 2019(63)	India	Health care	General population	Mixed	Mixed	NA	NA	140/90	1	-
Michaud A. 2019(64)	Canada	Health care	Outpatient	Mixed	Unspecified	51.9	54	140/90	NA	-
Trudel X. 2020(67)	Canada	Community	Worker	Mixed	Mixed	44.6	40.2	140/90	1	-
Calvo-Vargus C. 2003(61)	Mexico	Health care	General population	Mixed	Mixed	54.7	82.2	140/90	1	-
<i>Studies with complete 2x2 diagnostic results of HBPM only</i>										
Almeida A. 2012(68)	Brazil	Health care	General population	Mixed	Mixed	50.6	-	135/85	-	5

Author (Year)	Country	Setting	Type of population	Previous HT	Taking anti-HT drug	Mean age (year)	%Male	CBPM; HBPM cut-off (mmHg)	No. repeated measure CBPM (day interval)	Measurement duration for HBPM (day)
Park J. 2017(69)	Korea	Health care	Outpatient	Mixed	Unspecified	51.8	46.5	135/85	-	6
de Almeida, 2014(70)	Brazil	Health care	Outpatient	Mixed	Mixed	50.6	46.8	135/85	-	3
Rhee M.Y., 2018(71)	South Korea	Health care	General population	Non-HT	No	52.2	47.1	135/85	-	7
<i>Studies with complete 2x2 diagnostic results of both CBPM and HBPM</i>										
Stergiou G 2000(7)	Greece	Health care	Outpatient	Mixed	No	48.4	54.9	140/90; 140/90	5 (14 - 21 days)	6
Hanninen M 2010(73)	Finland	Community	General population	Mixed	Mixed	49.1	47.9	140/90; 135/85	4(-)	7
Zhang L 2015(72)	Belgium	Health care	General population	Mixed	No medication or wash out period >2 weeks	50.6	51.1	140 (SBP); 135/85	3 (7 days)	7
Ntineri A. 2019(74)	Greece, U.K., Finland	Health care	General population	Mixed	Mixed	53.8	52.6	140/90	3	-
<i>Studies with positive CBPM studies only</i>										
Hoegholm A. 1999(36)	Denmark	Community	General population	Mixed	No medication or wash out period >5 weeks	47.7	46.9	140/90	3 (7 days)	-
Martinez M 1999(37)	Spain	Health care	General population	Non-HT	No medication or wash out period >3 weeks	52	47.8	140/90	3 (7-14 days)	-
Gan S 2003(38)	Singapore	Community	Male military conscripts	Mixed	Unspecified	20	100	140/90	2 (14 days)	-
Tunckale A. 2004(39)	Turkey	Health care	General patient	Non-HT	No medication or wash out period >4 weeks	-	-	140/90	3	-
Shimbo D. 2009(40)	U.S.A.	Health care	Outpatient	Mixed	No medication	52.5	46	140/90	2 (30 days)	-
Pengkeaw P. 2014(42)	Thailand	Health care	Outpatient	Mixed	No medication or wash out period >4 weeks	42.29	74.2	140/90	1	-
Mancia G.2015(43)	Italy	Community	General population	Unspecified		-	-	140/90	2 (-)	-
<i>Studies with negative CBPM only</i>										
Schoenthaler A 2010(44)	U.S. (African or Latino)	Community	General population	Mixed	No medication	35.9	39	120/80	3 (14 days)	-
Viera A 2010(45)	U.S.	Community	General population	Non-HT	No medication	49	44	140/90	1	-
Bacaksiz A. 2013(46)	Turkey	Health care	Outpatient	Non-HT	No medication	35.8	51.1	140/90	1	-
Sobrinho J. 2013(47)	Spain	Community	General population	Non-HT	No medication	43.1	44.7	140/90	1	-
Franklin S 2013(48)	Europe Japan	Community	General population	Non-HT	Mixed	-	-	140/90	1	-
Larsen T 2014(49)	America	Health care	Outpatient	Non-HT	No medication	49.8	47	140/90	3 (-)	-
Viera A 2015 (50)	America	Health care	Outpatient	Non-HT	No medication	47	39	140/90	1	-
Trachsel L 2015(51)	Switzerland	Community	General population	Non-HT	No medication	42.8	-	140/90	1	-

Author (Year)	Country	Setting	Type of population	Previous HT	Taking anti-HT drug	Mean age (year)	%Male	CBPM; HBPM cut-off (mmHg)	No. repeated measure CBPM (day interval)	Measurement duration for HBPM (day)
Redmond N. 2016(52)	America,	Community	General population	Mixed	Mixed	59.1	30.7	140/90	1	-
Viera A 2016(53)	America	Health care	General population	Non-HT	No medication	48	40	140/90	1	-
Piantanida. E 2016(54)	Italy	Health care	General population	Non-HT	No medication	46.3	-	140/90	1	-
Booth III J 2017(55)	America	Health care	Outpatient	Non-HT	No medication	-		140/90	1	-
Anstey D 2017(56)	America,	Community	General population	Mixed	Mixed	56	35.7	140/90	1	-
Ozkan S. 2018(57)	Turkey	Health care	Outpatient	Non-HT	No medication	58.8	25.1	140/90	-	-
Gun T. 2018(58)	Turkey	Health care	Outpatient	Non-HT	No medication	55	46.5	-	1	-
Salazar M. R., 2019(65)	Argentina	Health care	Outpatient	Mixed	Mixed	51.4	40.7	140/90	-	-

ABPM; ambulatory blood pressure measurement, CBPM; clinic blood pressure measurement, DBP; diastolic blood pressure, HBPM; home blood pressure measurement, HT; hypertension, SBP; systolic blood pressure

Figures

Figure 1

Flow chart of study selection

Figure 2

Pooled sensitivity and specificity of clinic and home blood pressure measurements compared with ambulatory blood pressure measurement

Figure 3

Fagan's plot of clinic and home blood pressure measurements compared with ambulatory blood pressure measurement

Figure 4

Pooled proportion of white coat hypertension among positive clinic/home blood pressure measurements and masked hypertension among negative clinic/home blood pressure measurements

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