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REVIEW

Blood pressure measurement in pediatric population: comparison between automated oscillometric devices and mercury sphygmomanometers—a systematic review and meta-analysis

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Abstract

With the progressive elimination of mercury column devices for blood pressure (BP) measurement in children and adolescents, valid alternatives are needed. Oscillometric devices provide a replacement without mercury, are fully automated, and have excellent reliability among evaluators. Here, the goal was to test the accuracy of automatic blood pressure monitor devices compared to the mercury sphygmomanometer for BP measurement in children and adolescents. Electronic databases are EMBASE, MEDLINE (PubMed), SCOPUS, and Web of Science. We selected 8974 potentially eligible articles and two authors independently. We separately reviewed 370 full papers. Potentially eligible articles were selected according to the following criteria: (a) articles published in Portuguese, English, and Spanish; (b) screening of titles; (c) screening of abstracts; and (d) retrieval and screening of the full article to determine whether it met the inclusion criteria. We included 45 articles for analysis, 28 of which were selected for meta-analysis. The systolic BP measured by automatic blood pressure monitors presents 1.17 mmHg on average (95% CI 0.85; 1.48); for diastolic BP, it produced −0.08 mmHg (95% CI −0.69; 0.54) compared with a mercury sphygmomanometer. There is high heterogeneity between studies (> 90%) in the meta-analysis, partly explained by the device model, study environment, and observer training. Only articles that reported BP measurement by both methods were included.

Conclusion: Automatic blood pressure monitors have strong measurement validity when compared with the mercury column. Thus, these can be safely used in blood pressure measurements of children and adolescents in clinical and epidemiological studies.

What is Known:

- *The "gold standard" for indirect BP measurement is the mercury sphygmomanometer.*
- *The accuracy of the automatic device is critical to any blood pressure measurement method.*

What is New:

- *Oscillometric or automatic devices can be a suitable alternative to auscultation for initial screening, consistent with current pediatric guidelines.*
- *The automatic devices compared to the mercury column have a good validity of measurements, which can be used in blood pressure measurements of children and adolescents in clinical and epidemiological settings, provided that international protocols are followed.*

Keywords Blood pressure · Pediatric population · Hypertension · Validity

Abbreviations

AHA	American Heart Association
BP	Blood pressure
DBP	Diastolic blood pressure
EHS	European Hypertension Society
HHS	British Hypertension Society
PRISMA	Preferred Reporting Items for Systematic Review and Meta-analysis
PROSPERO	International Prospective Register of Systematic Reviews
SBP	Systolic blood pressure

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Introduction

Studies indicate that arterial hypertension is a major public health problem, even in the pediatric population, affecting approximately 11% of children and adolescents worldwide [1–3]. Children with hypertension may have health complications such as left ventricular hypertrophy, altered macro- and microvasculature, and decreased cognitive function[3]. Given that blood pressure (BP) follows from childhood to adulthood, high BP in children is a significant concern and calls for early detection and intervention to prevent future cardiovascular consequences [4, 5].

It is recommended that children aged at least 3 years old should have their BP measured routinely [6, 7]. The "gold standard" for BP measurement in the past has been the mercury sphygmomanometer [8]. In recent years, with the increasing concern that mercury is contaminating the environment and developing electronic/digital equipment to measure blood pressure, many health institutions have replaced the mercury manometers with other equipment [9]. However, removing mercury manometers from healthcare facilities has created problems and unforeseen challenges to accurately measure blood pressure [10], especially in the pediatric population.

Oscillometric devices are a more convenient alternative because measurements are fully automated, do not require specialized training, have good reliability between evaluators, and have become the gold standard for BP measurements in adults in clinical settings [11]. The verification and recognition of the quality of the devices used in the pediatric population are essential for their legitimacy and reliability; therefore, these devices must be evaluated according to the validation standards by international scientific societies, such as the American Heart Association (AHA) and the British Hypertension Society (BHS) [12]. However, uncertainty remains regarding the accuracy of oscillometric devices for use in this children and adolescent population, given the limited view of proprietary algorithms that support the systolic and diastolic blood pressure (SBP and DBP, respectively) estimates, as well as concerns about automatic cuff overinflation [13, 14].

Therefore, the objective was to estimate the accuracy of blood pressure oscillometric and aneroid monitors when compared against mercury sphygmomanometers for BP measurement in children and adolescents.

Methods

Systematic review

This systematic review was conducted and prepared following the preferred reporting items for systematic reviews and meta-analysis (PRISMA). Our systematic review is registered in the PROSPERO (International Prospective Register of Systematic Reviews) CRD42018110330, in which, at the date of this publication, there was no article on this topic.

Electronic search

The searches were carried out on the electronic databases EMBASE, MEDLINE, SCOPUS, and Web of Science for articles published until February 15, 2020.

The following descriptors and reading terms for medical subjects (MeSH) were used as search terms in the databases and divided into two independent lists, one for children and one for adolescents:

Children list "early childhood" OR child OR childhood OR children OR preschool OR preschoolers OR pediatric OR paediatric, "blood pressure" OR "arterial pressure" OR "blood pressure determination" OR hypertension "blood pressure monitor" OR "continuous sphygmomanometer" OR sphygmomanometers OR monitor OR "automatic monitor" OR oscillometry.

Adolescents list adolescence OR adolescents OR youth OR teen OR teenager, "blood pressure" OR "arterial pressure" OR "blood pressure determination" OR hypertension, "blood pressure monitor" OR "continuous sphygmomanometer" OR sphygmomanometers OR monitor OR "automatic monitor" OR oscillometry.

Two investigators examined the articles and performed data sorting, data extraction, and quality assessment in an independent and paired manner. Discrepancies between reviewers were resolved by consensus, and in the third reviewer, discrepancies resolved in the debate were consulted. The relevant articles were obtained in full and assessed for eligibility and exclusion criteria.

Eligibility criteria

Cross-sectional studies involving healthy children and adolescents aged 3 to 19 years were included, covering a wide range of measurement configurations: clinical, school environments, research, and others.

The studies had to include an oscillometric device with an arm cuff used to measure blood pressure, following international guidelines for BP measurement in the pediatric population. As a reference standard and comparison measure, a mercury sphygmomanometer was used simultaneously with the oscillometric device.

The inclusion criteria were: study population composed of children and adolescents (3–19 years old), original

research study, and a study carried out with objective measures (oscillometric apparatus × mercury column).

Studies in which the participants had specific diseases (hypertension, diabetes, dyslipidemia, kidney disease, etc.) were excluded. Articles that were not in Portuguese, English, or Spanish, and conference papers or books were excluded. Also, articles that only presented one method of measuring blood pressure were excluded. These criteria were established to increase comparability between studies.

Tracking and extracting data

Potentially eligible articles were selected according to the following criteria: (a) articles published in Portuguese, English, and Spanish; (b) screening of titles; (c) screening of abstracts; and (d) retrieval and screening of the full article to determine whether it met the inclusion criteria if the abstract did not provide sufficient data or was not available.

The articles were screened by two authors (Araujo-Moura K and Souza GL), independently and in pairs; the results were compared, and a predefined form of extraction was used. If any disagreement occurred, the article was assessed by a third reviewer (Luz MG).

The reference management software EndNote Web was used, where articles were saved, and duplicate articles were excluded. When the studies did not meet the eligibility criteria, the reason for exclusion was documented in a table.

Risk of bias assessment

After an initial calibration exercise, the author KAM assessed the risk of bias of included studies, and ACFM collaboratively reviewed and solved disagreements between them through discussion. We used a modified version of the Cochrane risk of bias tool [15] that is designed to assess to risk of bias of observational studies. Each potential source of bias was graded as low, high, or unclear risk. The criteria for judging a high risk of bias included selection bias, blindness (outcome and exposure), reporting bias, flawed measurement of both exposure and outcome, and failure to develop and apply appropriate eligibility criteria.

Meta-analysis

Summary measurement data items

The authors collected data independently for each study methodology in terms of study characteristics (author, year, and place of publication), sample (sample size, age group, healthy versus clinical sample), device type (oscillometric × aneroid), blood pressure measurement configuration (clinic, school, research, and others), observer training, financing source, and whether it was a validation study. For validation studies, the protocol was observed as the "Association for the Advancement of Medical Instrumentation" (AAMI), the "British Hypertension Society" (BHS), or the "European Hypertension Society, International Protocol" (EHS).

We extracted the mean difference in SBP and DBP between the oscillometric device and the mercury sphygmomanometer for the main BP results. If the mean difference was not reported, it was calculated from the group means reported for the oscillometric device and the mercury column. In some cases, the results were reported only by subgroups and not by the entire study sample; in these cases, we estimated the unweighted groups' averages for the whole of the sample.

Inclusion criteria

Studies included in the systematic review process to be included in the meta-analysis should have statistical information: mean, standard deviation or standard error, and sample size for both measurement methods, "automatic monitors," and "mercury column." The standard error (SE) of the mean difference was extracted. If the mean difference was not reported, we calculated it from the 95% confidence intervals (95% CI) of the mean difference or the SD of the mean difference. If neither was reported, we calculated the SE from the SD for the mean of each group.

Statistical analysis and meta-analysis

We used the Stata 15 program for all statistical analyses. The "metan" command in Stata was used to calculate the grouped effect estimates for the mean difference in BP (95% CI), first using a random-effects model (high heterogeneity indicated by I^2 75%).

We stratified the meta-analysis by subgroups (publication, monitor type, setting, and guideline) due to the heterogeneity found (high heterogeneity indicated by $I^2 \geq 75\%$). We constructed forest graphics for each subgroup analysis. We generated a funnel plot and the Egger test to evaluate our data set for the likely presence of bias (small study effect), plotting the mean difference on the *x*-axis and SEM difference on the *y*-axis.

Results

Literary search

The PRISMA flowchart of the bibliographic search is provided in Fig. 1. The bibliographic search produced 14,127 potentially eligible information titles, 7151 articles for children, and 6976 for adolescents.

After applying the inclusion and exclusion criteria from the search for children and excluding duplicates, 30 potentially eligible articles were included. The main reasons for exclusion were related to specific diseases and only one method of measuring blood pressure. For adolescents, after applying the inclusion and exclusion criteria and removing duplicates, 15 potentially eligible articles were included for evaluation, with the main reasons for exclusion being the study population and only one method of measuring blood pressure. When the information from the two searches was concatenated, 45 articles were included in the data's quantitative analysis. To complete the meta-analysis, 28 studies were used in total: 11 of children, eight of adolescents, and nine articles with children and adolescents included in the same survey.

Some articles required searches in addition to the database. For this, an e-mail was sent to the authors seeking information. Of the six e-mails sent, we did not obtain responses from any author, and articles awaiting those responses were excluded.

Characteristics of eligible studies

The descriptions of the 44 studies included are presented in Table 1. The studies were carried out in several countries, the majority being in the USA (37.78%), Asia (17.78%), Europe (20.0%), Brazil (13.33%), South America (Argentina, Brazil, Chile, Colombia, Peru, and Uruguay, 4.44%), Canada (2.22%), Australia (2.22%), and a country that was not identified (2.22%). The assessment of risk of bias of included studies is presented in Supplementary file 7. Developing and/or applying appropriate eligibility criteria were appropriate in 32.8% studies. The three studies have not reported the outcome objective extensively [16–18]. Finally, there were numerous significant differences in the characteristics of data reported consistently for the outcome of interest; there was no suspicion of no other biases reported in 6.3% of the studies, which might imply a high risk of bias [19–21].

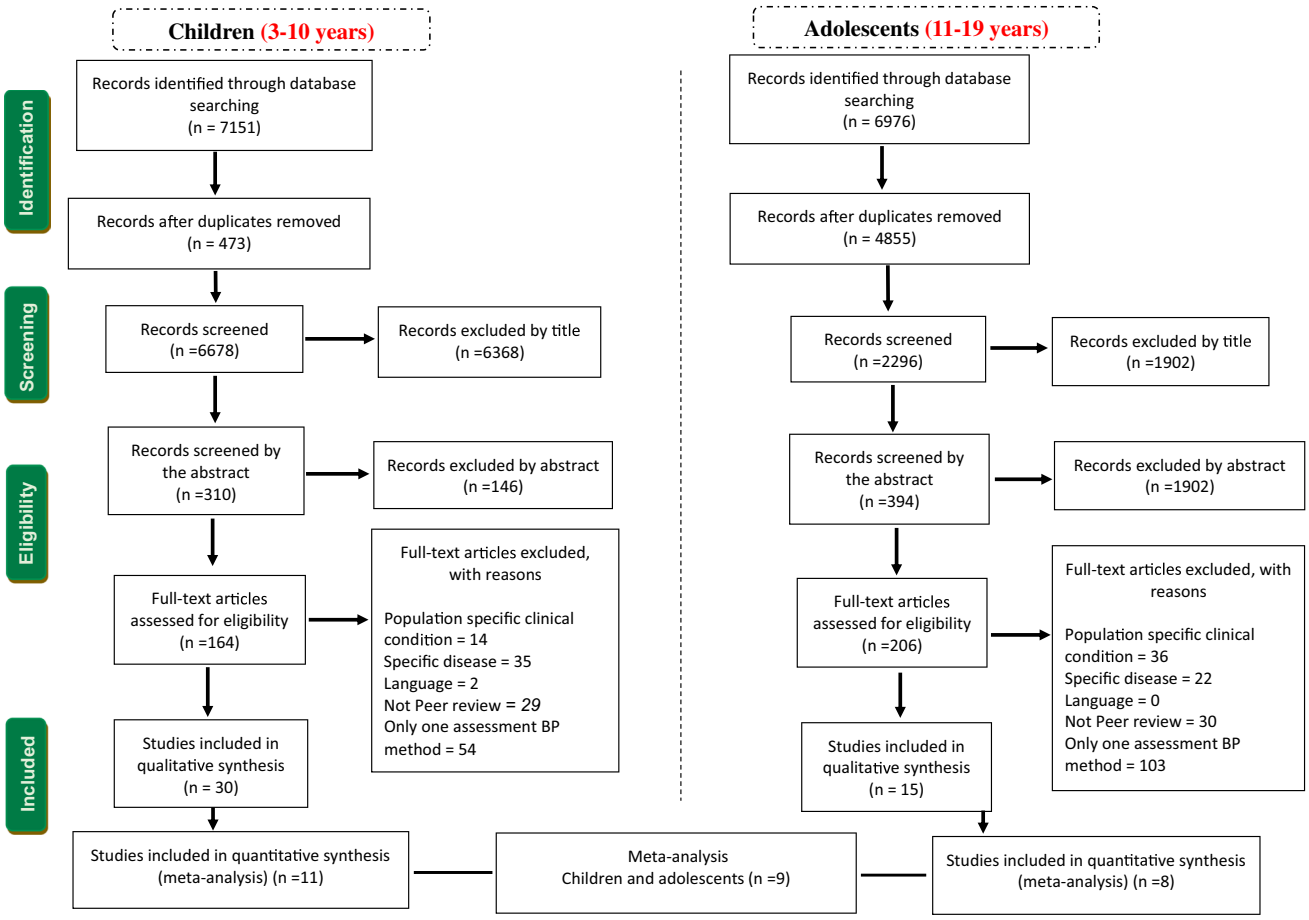

Fig. 1 Literature search PRISMA flow diagram

Meta-analysis

Figure 2 shows the meta-analysis results for systolic (Fig. 2A) and diastolic (Fig. 2B) blood pressure. For SBP, the oscillometric devices produced significantly higher measurements than mercury sphygmomanometers. There was heterogeneity between the studies, with the effects of individual studies ranging from −5.0 to 6.40 mmHg (Fig. 2A). In the DBP, the standard error of measurement by oscillometric devices was not significantly different compared with the mercury sphygmomanometer, with estimates of the effects of individual studies ranging from −5.0 to 8.10 mmHg (Fig. 2B).

In order to understand and investigate the heterogeneity found, samples were split into subgroups. In Fig. 3A, our results show that in the type of monitor stratification, there were significant differences between the groups, suggesting that the oscillometric monitor brand can influence the measurements. As shown in Fig. 3B, the stratification by setting shows a statistically significant difference between the groups' epidemiological environments (free-living) and clinical environments (clinic). When we stratified the subgroups by guideline (Fig. 3C), the results show that in those studies where there were no reports of which type of international guideline was used, the standard error of measurement was more significant compared to the articles which detailed the methodology used.

Subgroup analyses were also performed to assess DBP. In Fig. 4A, the stratification by type of monitor shows a significant difference between the Dinamap, Omron, and Other groups, with estimates of individual effects ranging from 4.83 to −14.65. When stratified by setting (Fig. 4B), as well as in SBP, there are no significant differences between the "free-living" and "clinic" groups in DBP, indicating that the measurement is valid in both epidemiological and clinical settings.

Analysis of the guideline subgroup (Fig. 4C) demonstrates significant differences between the groups evaluated, meaning that those studies which did not report the protocol followed according to the international guidelines obtained a greater standard error of measurement compared to the studies which reported and described the guideline adopted in the article (AAMI, BHS, and EHS).

Figure 5A, B show the funnel plots to assess the mean differences in blood pressure levels between measurement methods. For SBP, there is symmetry in the distributions of the mean differences between the methods, varying between 0 and 10 mmHg, and, according to the Egger test, there are no effects of small studies (SBP bias 0.48; $p = 0.727$). However, the DBP results have asymmetry in the distributions of the mean differences between the methods, indicating a possible publication bias; according to the Egger test, this publication bias does not derive from small studies (DBP bias 1.27; = 0.917)

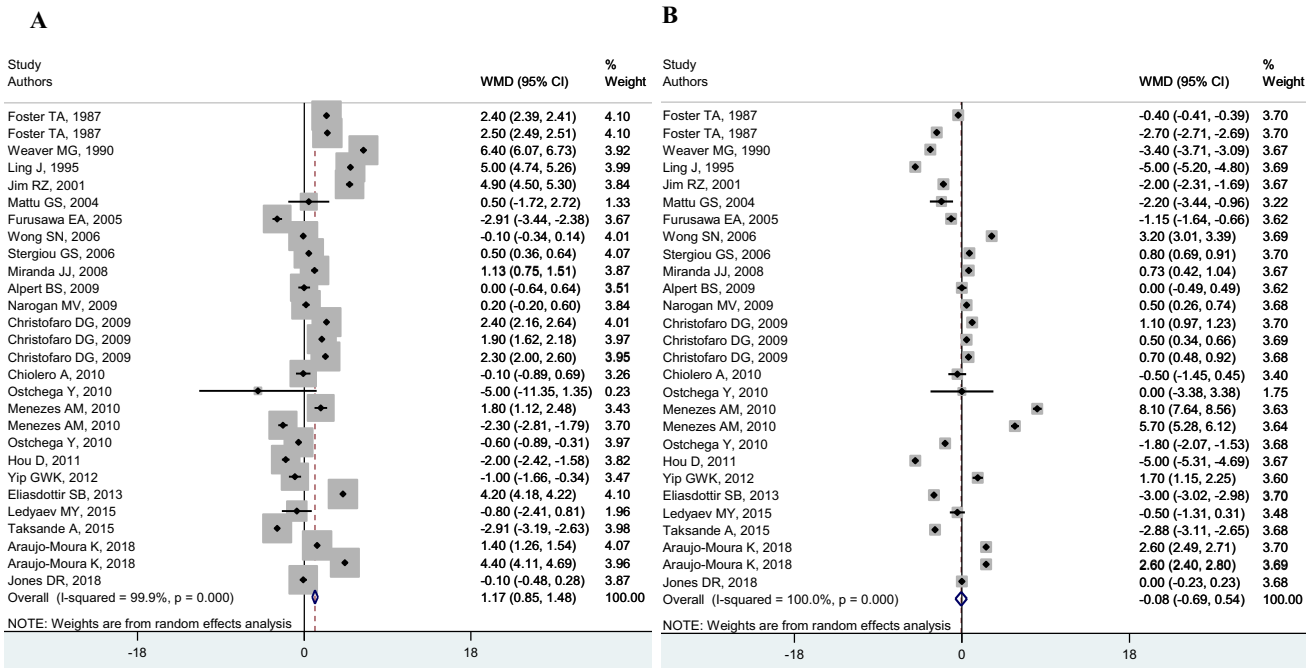

Fig. 2 Forest plot for systolic blood pressure (**A**) and diastolic blood pressure (**B**) in studies that used oscillometric devices

Table 1 Characteristics of reviewed and included studies

Author	Survey center	Publication year	*n*	Age range (years)	Setting	BP monitor		Guideline (validation)	Meta-analysis	
Foster TA, 1987	USA	1987	3217	5–17	Free-living	Unspecified	No information			**Included**
Foster TA, 1987	USA	1987	2978	5–17	Free-living	Unspecified		No information		**Included**
Weaver MG, 1990	USA	1990	81	10–13	Free-living	Dinamap		No information		**Included**
Ling J, 1995	USA	1995	85	> 1–16	Free-living	Unspecified		AAMI		**Included**
Ling, J. 1995	USA	1995	85	1–16	Clinic	Unspecified		AAMI		
Barker ME, 2000	UK	2000	55	5–10	Free-living	Dinamap		BHS		
Barker ME, 2000	UK	2000	47	5–10	Free-living	Omron		BHS		
Jim RZ, 2001	Australia	2001	61	8–13	Clinic	Dinamap		BHS		**Included**
Park MK, 2001	USA	2001	7208	5–17	Free-living	Dinamap		BHS		
Mattu GS, 2004	Canada	2004	36	3–18	Clinic	Unspecified		BHS		**Included**
Furusawa EA, 2005	Brazil	2005	60	12–21	Clinic	Omron		BHS		**Included**
Redwine KM, 2005	USA	2005	112	6–17	Clinic	Unspecified		BHS		
Wong SN, 2006	China	2006	132	5–15	Clinic	Dinamap		BHS		
Stergiou GS, 2006	Greece	2006	197	6–16	Free-living	Omron		EHS		**Included**
Miranda JJ, 2008	London	2008	97	2–12	Free-living	Omron		No information		**Included**
Alpert BS, 2009	USA	2009	15	3–12	Clinic	Unspecified		AAMI		**Included**
Midgley PC, 2009	Scotland	2009	764	4–8	Free-living	Omron		No information		
Narogan MV, 2009	Russia	2009	85	4–15	Free-living	Unspecified		BHS		**Included**
Christofaro DG, 2009	Brazil	2009	84	10–15	Free-living	Omron		BHS		**Included**
Christofaro DG, 2009	Brazil	2009	81	10–15	Free-living	Omron		BHS		**Included**
Christofaro DG, 2009	Brazil	2009	81	10–16	Free-living	Omron		BHS		**Included**
Chiolero A, 2010	USA	2010	30	8–10	Free-living	Dinamap		EHS		**Included**
Ostchega Y, 2010	USA	2010	90	13–19	Free-living	Omron		BHS		**Included**

Table 1 (continued)

Author	Survey center	Publication year	*n*	Age range (years)	Setting	BP monitor	Guideline (validation)	Meta-analysis	
Menezes AM, 2010	Brazil	2010	60	14–15	Free-living	Omron	BHS		**Included**
Menezes AM, 2010	Brazil	2010	60	14–15	Free-living	Omron	BHS		**Included**
Ostchega Y, 2010	USA	2010	90	13–19	Clinic	Omron	AAMI		**Included**
Alpert BS, 2011	USA	2011	111	3–12	Clinic	Unspecified	BHS		
Hou D, 2011	China	2011	86	2–18	Free-living	Omron	No information		**Included**
Kamath N, 2011	India	2012	1475	5–16	Free-living	Unspecified	No information		
Lee CG, 2011	South Korea	2011	45	7_17	Clinic	Dinamap	EHS		
Alpert BS, 2012	USA	2012	41	> 8	Clinic	Unspecified	AAMI		
Yip GWK, 2012	China	2012	65	5–15	Clinic	Unspecified	BHS		**Included**
Lee CG, 2012	South Korea	2012	861	7–18	Clinic	Dinamap	BHS		
Eliasdottir SB, 2013	USA	2013	979	9–10	Free-living	Unspecified	No information		**Included**
Luyan W, 2014	China	2014	64	> 18	Free-living	Unspecified	BHS		
Redwine KM, 2015	USA	2015	112	6–17	Free-living	Unspecified	BHS		
Ledyaev MY, 2015	Russia	2015	30	5–15	Clinic	Unspecified	BHS		**Included**
Taksande A, 2015	India	2015	100	3–15	Free-living	Omron	No information		**Included**
Meng LH, 2016	China	2016	35	4–19	Clinic	Omron	AAMI		
Dong J, 2017	China	2017	87	3–12	Clinic	Unspecified	AAMI		
Beime B, 2017	Germany	2017	33	3–12	Free-living	Unspecified	EHS		
Araujo-Moura K, 2018	South America *	2018	191	3–10	Free-living	Omron	BHS		**Included**
Araujo-Moura K, 2018	South America *	2018	127	11–18	Free-living	Omron	BHS		**Included**
Jones DR, 2018	USA	2018	111	6–18	Clinic	Unspecified	BHS		**Included**
Kollias A, 2018	USA	2018	37	3–12	Clinic	Unspecified	AAMI		

AAMI Association for the Advancement of Medical Instrumentation, *BHS* British Hypertension Society, *EHS* European Society of Hypertension

*South American countries:Argentina, Brazil, Chile, Colombia, Peru, Uruguay

Discussion

The aim of this research was to systematically review the accuracy of oscillometric devices and aneroid sphygmomanometers to measure blood pressure in children and adolescents. We included 9219 children and adolescents in our meta-analysis; the oscillometric devices showed an overestimation of SBP in 1.17 mmHg when compared with a mercury sphygmomanometer. There was no significant difference for DBP measures. Our meta-analysis found that oscillometric devices present a valid alternative to the mercury sphygmomanometer, and there was a high degree of heterogeneity in quantifying the validity of automatic monitors for children and adolescents.

The BP automatic monitors have to submit a validation process to meet a minimum standard of precision and to facilitate comparison between monitors [12]. The validation protocols (i) are composed of specific instructions on measurement settings and observer training; (ii) should be applicable for samples with representative ranges of low to high BP in adults; and (iii) should provide values that are more comparable with the values obtained from the mercury sphygmomanometer [13, 14]. Therefore, this equipment must be evaluated according to the validation standards required by international protocols, such as the American Heart Association (AHA), the British Hypertension Society (BHS), and the Europe Society Hypertension (ESH) [22–24].

According to the guidelines of the European Society of Hypertension for the pediatric population, the reference values accessible to define the categories of SBP were obtained by the auscultatory method; the reference values for oscillometric devices are notably higher compared to the auscultatory ones; more recent studies are oriented to develop reference values using oscillometric devices. However, great heterogeneity of studies and measurement methods does not allow or hinder the grouping of information and data [25, 26].

Protocol validation data suggests that oscillometric devices generally appear to perform better for SBP than for DBP in pediatric populations [27]. However, not all automatic monitors present the same results when used simultaneously on the same patient [28]; therefore, it is crucial, for adequate BP measures, to keep in mind the specific type of device when determining its suitability. Differently auscultatory measurement, oscillometric devices measure oscillations using the cuff as a transducer to determine mean arterial pressure. Thus, the device uses its own algorithm to calculate average BP directly from the point of maximum oscillation; neither PAS nor PAD are directly measured but rather calculated using an algorithm based on a supposed relationship between oscillations. As there are several brands of oscillometric devices, there is no standard device, as the algorithms vary between them [26, 29].

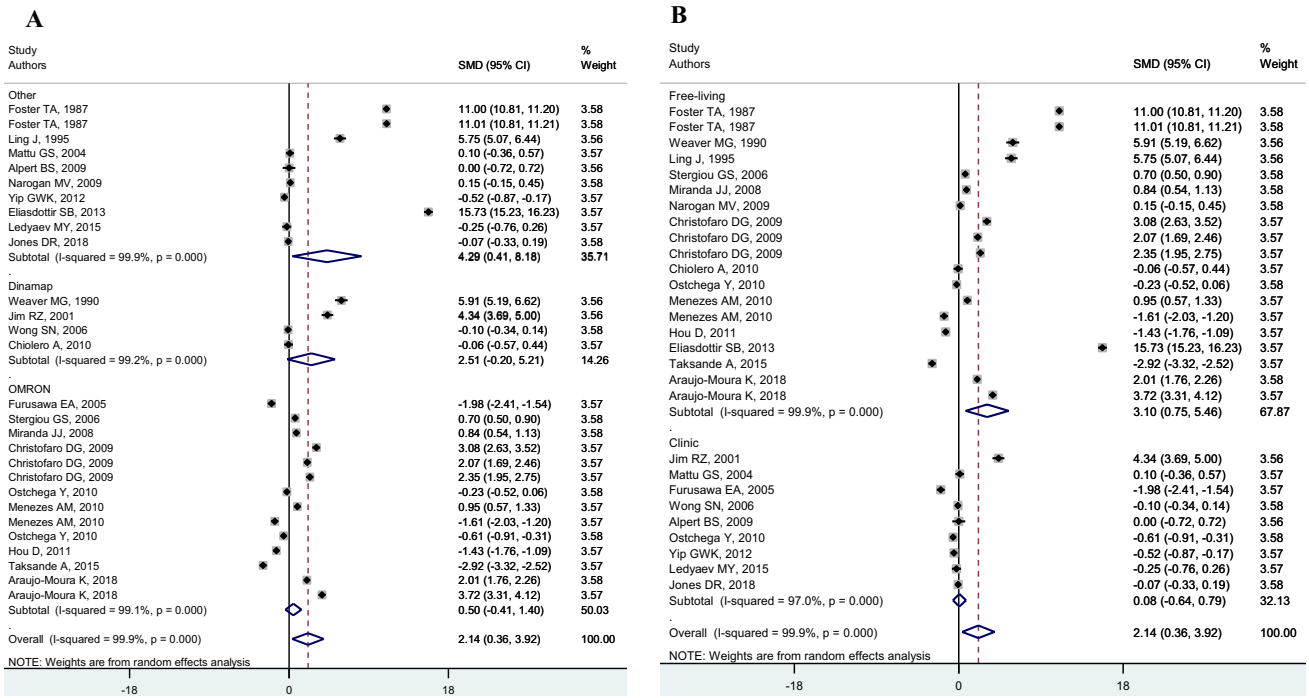

Fig. 3 Subgroup analysis systolic blood pressure (SBP). (**A**) Stratified by BP monitor (**B**) stratified by setting SBP, (**C**) stratified by guideline. AAMI, Association for the Advancement of Medical Instrumentation; BHS, British Hypertension Society; ESH,European Society of Hypertension

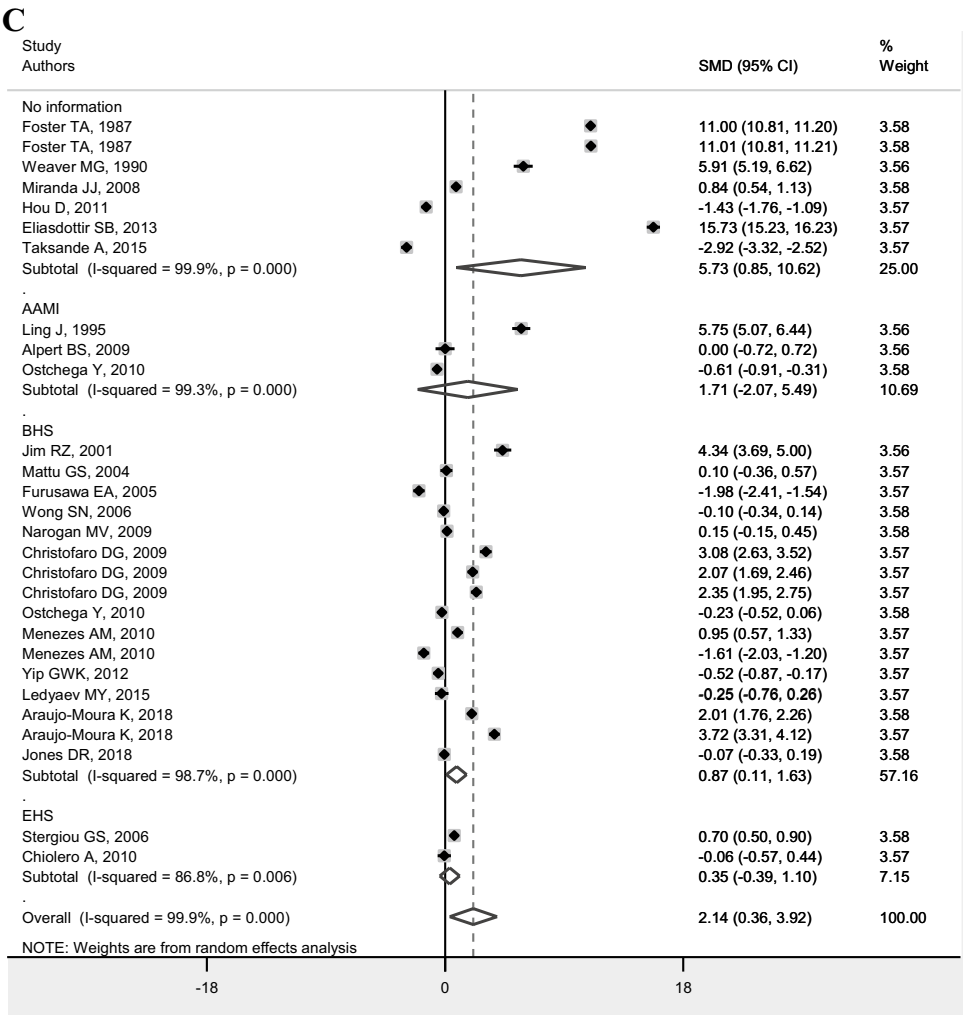

Fig. 3 (continued)

One of the benefits and attractive alternatives to using oscillometric devices is the fact that they request minimal training of the observer and show low inter-observer variability [7], which makes these devices particularly useful for population screening and large-scale research studies. On the other hand, given the recommendations for the use of oscillometric devices in adults in clinical practice, this use can generate a loss of technical ability among health professionals with respect to auscultatory methods [30].

The potential advantages of oscillometric devices over conventional sphygmomanometry are significant. They are easy to use, thus eliminating the need for highly trained personnel, they avoid the preference and bias of terminal digits related to the previous knowledge of the registered BP, and these devices, if accurate, can improve the measurement accuracy and substantially reduce the sample size required in clinical trials of hypertension [31–33]. However, it is important to emphasize that the HBP diagnosis by an oscillometric automatic monitor in children should be confirmed by auscultatory BP measurement by mercury column as recommended by the American Academy of Pediatrics and European Society of Hypertension [25, 26, 34].

As for the type of manufacturer and the study configurations, the included studies used a wide range of oscillometric devices included in our meta-analysis. Among them, the Omron models were used more frequently, followed by Dinamap and others. The type of manufacturer is an essential factor concerning the accuracy of oscillometric devices. The Omron model, for example, has the validation of several of its devices for measuring BP in the pediatric population; the model HEM-7200 can correctly classify an individual as free from disease, and the inter-observer variability is automatically controlled by the device, which is not the case for auscultatory methods [12, 32]. Dinamap, on the other hand, is a popular choice for BP measurement in clinical settings but has received considerable criticism regarding its inaccuracy in adult measurements and is therefore not used as often in the pediatric population [33, 35].

Studies carried out in the free-living environment, which mainly include schools, significantly overestimated the BP measured by oscillometric devices compared to the mercury sphygmomanometer. It is necessary to recognize that school-based BP measurements are generally less controlled due to the school setting, which can cause an additional contributing factor when assessing the accuracy of oscillometric devices. For good BP measurements using the auscultatory method, a quiet environment is necessary with technical skills and specific training [7, 30, 31, 36, 37].

Substantial methodological differences may clarify the unexplained heterogeneity between the studies examined. The results can be impacted by significant variation within the samples that were different for both methods. For example, the oscillometric apparatus may be more accurate in older adolescents, in which BP is more similar to that of adults. Future studies on the validation of oscillometric devices should design their studies within the validation protocols' parameters and report detailed factors such as study environment, observer training, and study population [33, 38].

In the DBP measurements, there was some asymmetry between the studies, which may be indicative of publication bias [36]. Possible explanations for this result include the fact that the measurement of DBP in the pediatric population through the auscultatory method is more challenging due to physiological factors [30].

The first sound (K1) designates systolic blood pressure, and the disappearance of all sounds (K5) designates diastolic blood pressure in a pediatric population. Korotkoff sounds can be heard up to close to 0 mmHg [33], and the muffling of sounds (K4) should be considered as the diastolic pressure in these circumstances. Therefore, we highlight the potential risk that K5 may not occur in small children, and heartbeats can be heard until the cuff deflates completely at level zero [30, 33]. Recommendations on the use of K4 or K5 as DBP for children and adolescents have changed considerably over time. Although the examiner's training can strongly influence the evaluation of K4 and K5, the literature suggests that K4 should be used as an indicator of DBP in children and adolescents, since it has less inter-observer variability and is predictive of hypertension in adults [35]. Therefore, the publication bias found for DBP is indicative that research with average differences above 10 mmHg is not being published due to the little validity of automatic devices and with unfavorable results [39, 40]. We only included articles that reported BP measurement by both methods. Another possible limitation is that our review tested the validation of automatic monitors in "healthy" populations, so the results should be interpreted with caution for pediatric populations with some clinical condition, e.g., chronic kidney disease, hypertension.

According to the US Preventive Services Task Force, the evidence to support screening for hypertension in the pediatric population is insufficient, there are still many gaps in the critical evidence that leads to an understanding of the benefit of the screening potential for hypertension in this population, and the harmony between benefits and damages

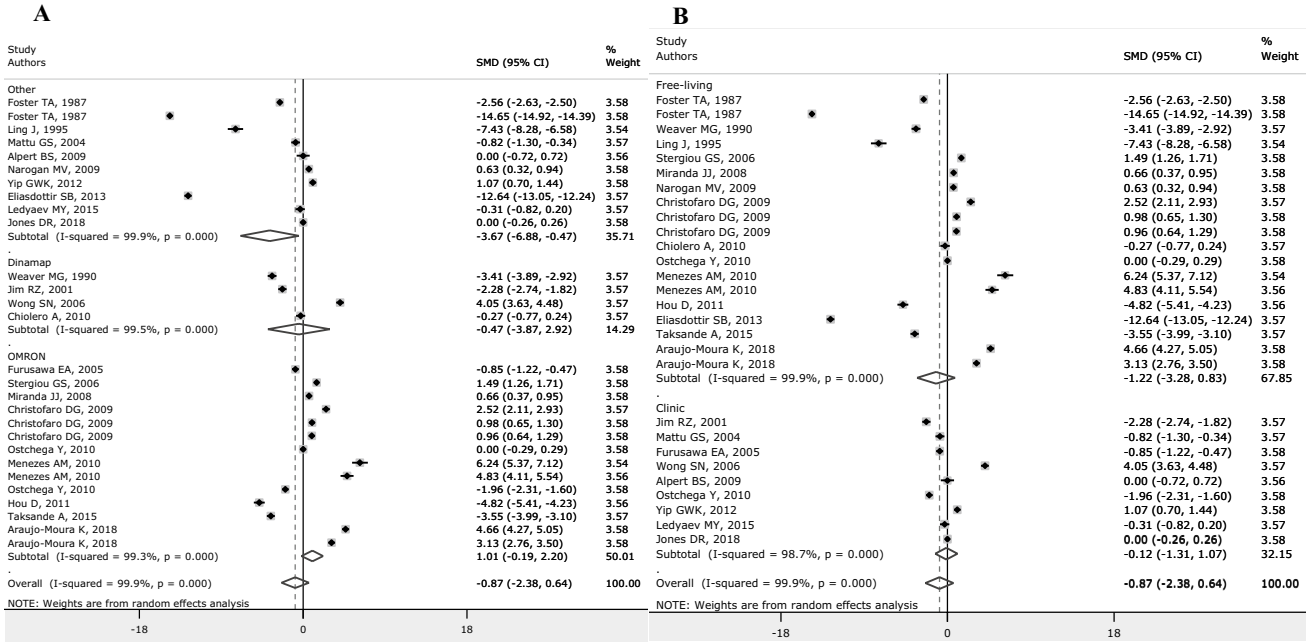

Fig. 4 Subgroup analysis diastolic blood pressure (DBP). (**A**) Stratified by BP monitor (**B**) stratified by setting DBP, (**C**) stratified by guideline. AAMI, Association for the Advancement of Medical Instrumentation; BHS, British Hypertension Society; ESH, European Society of Hypertension

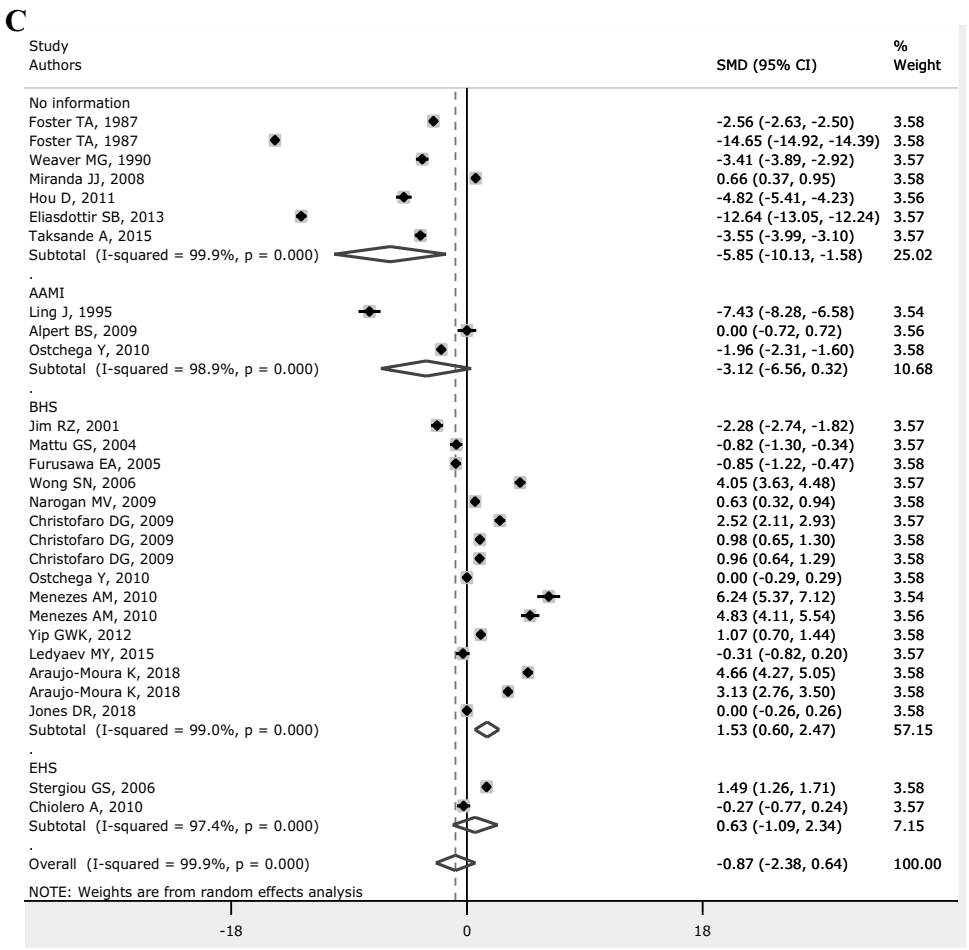

Fig. 4 (continued)

cannot be delimited [41]. Thus, the AHA, NHLBI, and the American Pediatric Association, recommend measuring blood pressure at least once a year for each medical care of children aged 3 to 18 years, where the necessary equipment must be considered when selecting the device, considering account advantages and disadvantages [25, 26, 42, 43].

Among the devices for screening hypertension, oscillometric devices are devices validated for children and

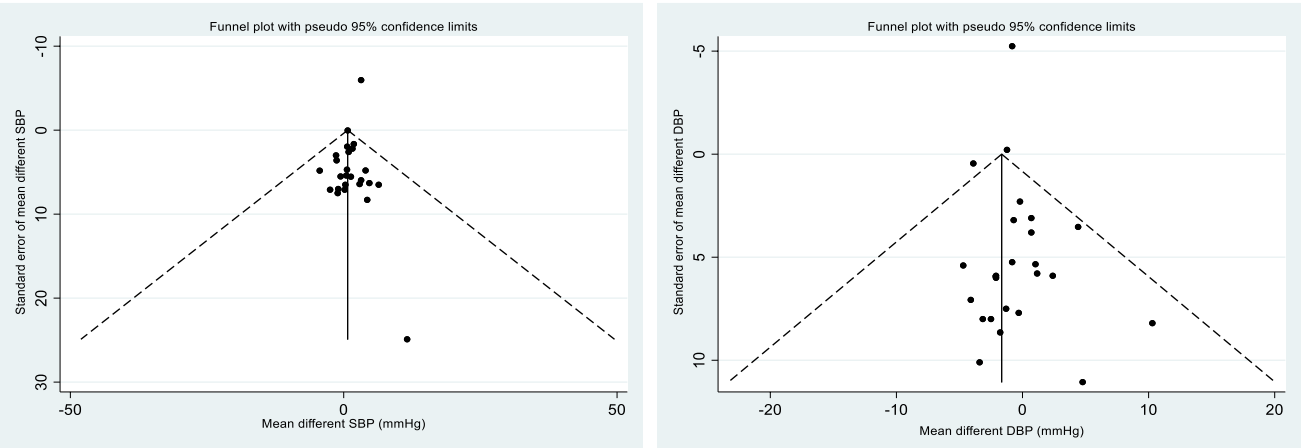

Fig. 5 Funnel plot for SBP and DBP in studies that used oscillometric devices: plotted are mean differences between devices (oscillometric-mercury) by SEM difference for individual studies (circles).The vertical line indicates the pooled effect estimate from the random-effects model

adolescents, in which they replaced sphygmomanometers in clinical practice because they are more environmentally friendly, easier to use, and eliminate potential sources of errors. In addition to clinical practice, these devices are beneficial in situations where the auscultatory method is challenging. They can assist in the accurate diagnosis of AH, in addition to reducing the effect of the white coat and masked AH, they are less susceptible to errors, in addition to being able to use appropriately sized cuffs [25, 26, 44, 45].

Conclusion

Since most children with hypertension are asymptomatic, regular BP screening is essential. Oscillometric or automatic devices can be a suitable alternative to auscultation for initial screening, consistent with current pediatric guidelines. The automatic device compared to the mercury column has a good validity of measurements, which can be used in blood pressure measurements of children and adolescents in clinical and epidemiological settings, provided that international protocols are followed. Further validation protocols are needed which are specifically designed for pediatric populations (or have validated adult protocols), preferably without reliance on mercury sphygmomanometers as the reference standard.

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Author contribution MSc PhD Keisyanne de Araujo-Moura conceptualized and designed the initial study. In addition, she designed the data collection instruments, performed the initial analysis, wrote the initial manuscript, and revised the manuscript. Dr. Augusto César Ferreira de Moraes conceptualized and designed the initial study. He coordinated and supervised the data and critically reviewed the manuscript for content. Bs Letícia Gabrielle Souza and Bs Gabriele de Luz Mello searched the articles and extracted the data. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

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Availability of data and material The data generated and analyzed during the current study were extracted from published paper and are available in several scientific journals. The dataset used in the meta-analysis is available from the corresponding author upon reasonable request.

Declarations

Ethics approval This article is a systematic review and does not contain participating humans or animals evaluated by the authors, and because of this reason, our institution does not require that it be approved by the ethics committee. Meanwhile, the protocol was approved by the PROSPERO committee on the protocol (CRD42018110330).

Conflict of interest The authors declare no competing interests.

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