



Home Blood Pressure Monitoring in Children and Adolescents: Systematic Review of Evidence on Clinical Utility

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Abstract

Purpose of Review For the accurate diagnosis and management of hypertension, out-of-office blood pressure evaluation using ambulatory (ABPM) or home monitoring (HBPM) is currently recommended. In children, there is considerable evidence on the clinical utility of ABPM, whereas the evidence on HBPM is limited. This systematic review presents (i) the benefits of HBPM in children; (ii) the evidence on normal range, diagnostic accuracy, and relationship with preclinical organ damage; and (iii) guidance for devices, monitoring schedule, and interpretation.

Recent Findings HBPM is a useful adjunct to the conventional office measurements for the evaluation of children with suspected or treated hypertension. HBPM is feasible in children and has good reproducibility, diagnostic accuracy and acceptability by users, and relatively low cost. Thus, it has greater potential for widespread and long-term use than ABPM, which is more expensive and often not available or not tolerated. Automated monitors that have been clinically validated specifically in children should be used with appropriate cuff size. HBPM for 7 days (minimum 3) with duplicate morning and evening measurements (minimum 12 readings) should be performed in children with suspected or treated hypertension before each office visit. Until more data become available, in case of diagnostic disagreement between office blood pressure and HBPM, treatment decisions should be based on ABPM.

Summary HBPM is clinically useful in children with hypertension. More research is needed on its clinical application, and more automated devices need to be clinically validated in this population.

Keywords Ambulatory blood pressure monitoring · Diagnosis · Masked hypertension · Out of office · Self-measurement · White coat hypertension

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Introduction

As in the adults, in children and adolescents, the accurate evaluation of blood pressure (BP) is a requisite for the reliable diagnosis and management of hypertension [1•, 2•, 3•, 4, 5]. Although the conventional office BP measurement, usually performed by a physician or nurse, is regarded as the standard method for hypertension evaluation, it is recognized that such measurements may be misleading and often lead to over- or underdiagnosis [1•, 2•, 3•, 4, 5]. This is mainly due to the white coat and the masked hypertension phenomena, which are common in adults and children, but also due to the poor reproducibility of office BP measurement and observer related factors and errors [1•, 2•, 3•, 4–6]. Thus, out-of-office BP evaluation is recommended for the confirmation of suspected hypertension, which is possible using ambulatory (ABP) or home BP (HBP) monitoring [1•, 2•, 3•, 4, 5].

Currently, guidelines recommend ABP monitoring as the gold standard method for diagnosing hypertension in adults and HBP monitoring as a reliable and useful alternative method [4, 5, 7, 8]. In children and adolescents, ABP monitoring has also gained a primary role for hypertension diagnosis, whereas the role of HBP monitoring remains controversial, mainly due to limited evidence on its clinical utility in the young population [1•, 2•, 3•]. However, HBP monitoring is being used in clinical practice for following children with hypertension, as shown in surveys in North America and Germany where 70% of pediatric nephrologists reported that they use HBP monitoring and regard such measurements as more reliable than the conventional office measurements [9, 10]. In the last 15 years, research data on using HBP monitoring in children are accumulating, which support its usefulness in clinical practice.

This systematic review (i) discusses the benefits from using HBP monitoring in children, (ii) presents the evidence on its normal range, diagnostic ability, and relationship with preclinical target organ damage, and (iii) provides practical guidance on preferred devices, the optimal measurement schedule, and the interpretation of readings.

Method

A systematic literature search was conducted independently by two investigators (ES and IB) at PubMed database using the following keywords: “(home blood pressure) AND children.” Eligible articles for inclusion were full-text articles in English that reported HBP data in children and adolescents. The initial PubMed search identified 501 articles, and 3 articles were also detected by handsearch. After excluding irrelevant studies, reviews, commentaries, letters, studies with overlapping populations, and studies not providing HBP data in children and adolescents, 10 studies compared HBP with daytime ABP [11•, 12–20], 4 provided data on the relationship of HBP with several indices of preclinical organ damage, [17,

19, 21, 22], 2 on the normal range of HBP [23•, 24•], and 9 on other clinical research questions [6, 25•, 26, 27, 28•, 29–32].

Feasibility, Advantages, and Disadvantages

HBP monitoring has similarities with ABP monitoring, as both methods obtain multiple BP measurements away from the office setting [33–36]. However, they have inherent differences, because HBP monitoring provides measurements in multiple days, weeks, or months and only at home and at sitting rest, whereas ABP monitoring is performed only for 24 h, during fully ambulatory conditions, at work/school, at home and during sleep, and in the sitting, standing, and also lying posture. Thus, these methods are rather complementary than competitive and provide different information on the individual’s BP profile and behavior. ABP monitoring appears to be more appropriate for initial diagnosis, as it requires no training and provides multiple and objective measurements within 24 h [7, 8, 33–36]. On the other hand, HBP monitoring is more appropriate for the long-term follow-up of subjects with treated hypertension, as it is more acceptable by users for repeated long-term use and less costly [7, 8, 33].

HBP monitoring is feasible and well accepted by children and their parents, as shown by its application in several studies in different countries which performed HBP monitoring for several days [11•, 12, 23•, 25•, 26, 33–37, 38•]. HBP monitoring can identify children with white coat and masked hypertension and with good diagnostic agreement with ABP monitoring [11•, 13, 25•].

Preliminary data suggest that, as in the adults [6–8], in children, HBP monitoring has superior reproducibility to office BP measurements and similar to that of ABP monitoring [15, 20]. This advantage is important for the reliable evaluation of out-of-office BP levels in clinical practice, but also in research, where the use of HBP monitoring increases the power of clinical trials and smaller sample size is required to reveal statistically significant BP changes than when using office measurements [6].

As mentioned above, HBP monitoring is more appropriate than ABP monitoring for repeated long-term use in treated hypertensives. Preliminary evidence shows that, as in the adults, children and adolescents prefer HBP than ABP monitoring, as they consider this method to cause less discomfort and minimal restriction of daily activities and sleep [22]. Additional advantages of HBP monitoring are its much wider availability and considerably lower cost than ABP monitoring, as well as the evidence from randomized controlled trials in adults that it improves hypertension control rate through the improvement of long-term adherence with antihypertensive drug treatment [7, 33].

HBP monitoring has several potential drawbacks. First, it does not allow the evaluation of the BP during night-time sleep which is a unique feature of 24-h ABP monitoring [1•, 2•, 3•]. However, as discussed below, novel low-cost HBP monitors equipped with specific software can take automated

measurements during night-time sleep, providing thereby a challenging alternative to ABP monitoring [22, 29]. Second, the automated electronic BP monitors require separate validation specifically in children, as they may have different accuracy than in the adults [39–41]. As discussed below, few electronic BP monitors have been successfully validated in children (www.stridebp.org) [40, 42]. Third, the availability of different cuff sizes of electronic devices for children and adolescents, which is necessary to accommodate the large range of arm circumference in the young population, is limited [1•, 7]. Fourth, studies in the adults showed frequent misreporting of HBP monitoring readings by patients (over- or underreporting), which can be avoided using devices with automated memory or PC-link capacity, or with HBP telemonitoring [43]. Last, the variability of HBP monitoring might induce anxiety in some children and their parents, resulting in frequent measurements, yet most of these cases are prevented with careful training and medical supervision.

Comparison with Office and Ambulatory Blood Pressure

Studies in normotensive children and adolescents showed similar levels of office BP with HBP, whereas in hypertensive children, office systolic (not diastolic) HBP appeared to be lower than office BP [16, 20, 23•, 25•, 36, 44]. A recent school-based study in 1024 adolescents showed that the second office BP measurement performed with an oscillometric device was comparable to 6-day HBP monitoring [30]. Interestingly, in children and adolescents, daytime systolic ABP appears to be considerably higher than HBP (Fig. 1) [11•, 12–20, 32, 33, 45] which contrasts findings in the adults showing similar values of daytime ABP with HBP [7]. This difference is probably due to the more intense physical activity during daytime in the young individuals and should be taken into account in the evaluation of out-of-office BP.

There is limited evidence on the reproducibility of HBP measurements in children and adolescents compared to office and ABP measurements, which showed similar results as in the adults [6], with HBP being superior to office BP and as reproducible as ABP [2, 15, 20]. This is probably due to the much larger number of BP readings obtained by ABP and HBP monitoring and the fact that these are taken in the usual environment of each individual.

Usefulness in Diagnosing Hypertension

Although office BP measurement remains the standard method for detecting and managing hypertension, in adults and in children, ABP monitoring is currently regarded as mandatory for most cases, mainly to identify white coat and masked hypertension and to evaluate BP during nighttime sleep [1•, 2•, 3•,

34]. There is accumulating evidence that in adults and in children, both the white coat and masked hypertension phenomena are common and there is considerable agreement between ABP and HBP in diagnosing such cases (Figs. 2 and 3) [11•, 13, 25•, 27, 33, 34, 46]. More specifically, two studies in children and adolescents suggested that there is good diagnostic accuracy of HBP in detecting white coat hypertension (by taking ABP as reference method), yet with relatively low sensitivity and positive predictive value in detecting masked hypertension [11•, 25•].

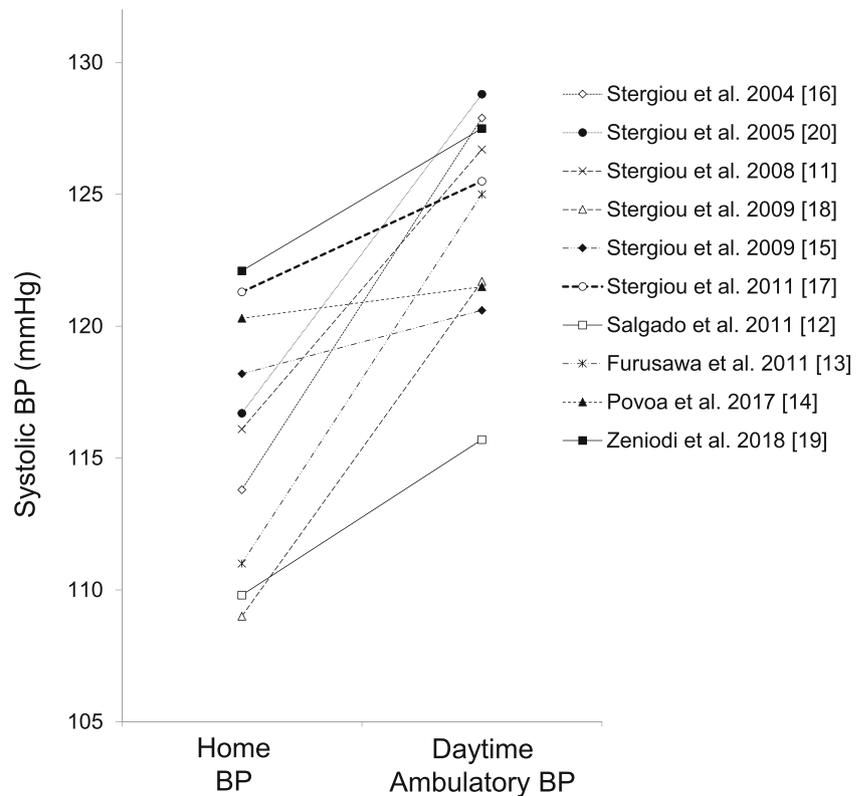
In the adults, HBP monitoring is currently recommended as a reliable alternative to ABP monitoring for diagnostic and treatment decisions in both untreated and treated subjects and has a primary role in long-term following of treated hypertensives [4, 5, 7, 8]. However, in children, the evidence on the clinical usefulness of HBP monitoring as primary diagnostic method in hypertension is limited and more data are needed. In addition, as mentioned above, the diagnostic ability of HBP for masked hypertension is uncertain. Thus, HBP monitoring might be used as a screening tool in children, or as a confirmatory out-of-office BP monitoring method after performing ABP monitoring, or when ABP monitoring is not available or not tolerated [34]. However, at present, the evidence is insufficient for diagnosis and treatment decisions in children to be based solely on HBP measurements. In children with office and HBP measurements suggesting the same diagnosis (e.g., normotension or hypertension), comfortable treatment decisions might be taken. In contrast, when office and HBP measurements disagree (suspected white coat or masked hypertension), then treatment decisions should be based on ABP monitoring.

Home Blood Pressure Normalcy

Ideally, the normal HBP range should be defined on the basis of its relationship with organ damage and cardiovascular events risk, as indeed it is the case in the adults [7, 8]. However, such data are not possible to obtain in children, and statistical criteria of HBP distribution and centiles values are used instead.

Two cross-sectional studies provided normalcy data for HBP values in children and adolescents [23•, 24•]. The Arsakeion School study in 778 apparently healthy children and adolescents in Greece provided percentile tables for HBP in boys and girls aged 6–18 years according to height and age (Table 1) [23•]. Another school study in 1024 adolescents (age 12–17 years) in Brazil provided percentile tables according to gender, age, and height [24•]. Both studies used electronic (oscillometric) upper-arm cuff HBP monitors clinically validated for BP measurement accuracy in children against standard auscultatory measurements [23•, 24•]. Fiftieth percentiles represent the BP level at the midpoint of the normal range, and 95th percentiles give the threshold of home hypertension [23•, 24•]. More data are needed in

Fig. 1 Studies comparing systolic home with daytime ambulatory blood pressure in children and adolescents



children to define the normal range and the threshold of hypertension based on HBP but also ABP measurements.

Association with Preclinical Organ Damage

In the adults, the prognostic ability of HBP has been demonstrated in outcome studies with hard endpoints of mortality and morbidity [7, 8]. In children, however, to obtain such data is unrealistic and surrogate endpoints of preclinical organ damage are used instead [1•, 2•, 3•, 38•, 47]. In adults, there is strong evidence

showing that both ABP and HBP give stronger associations than the conventional office measurements with several indices of pre-clinical organ damage at the level of the heart, the kidneys, and the arteries [4, 5, 7, 8, 33, 48]. In children, there is considerable evidence showing stronger association of ABP than office measurements with indices of preclinical organ damage, and particularly echocardiographic left ventricular mass index (LVMI) [1•, 2•, 3•, 38•].

In children and adolescents, the evidence on the relationship between HBP and preclinical organ damage is limited. A single study in children provided direct head-to-head comparison of ABP versus HBP in terms of their association with LVMI and arterial stiffness (pulse wave velocity) [17]. This study showed similar correlation coefficients for HBP and ABP with LVMI and in multivariate regression analysis, systolic HBP appeared to predict pulse wave velocity better than office BP or ABP measurements. A recent study in 218 young individuals showed that HBP and ABP provide similar correlations with LVMI, carotid intima-media thickness, and PWV [19]. More data are needed on the association of HBP with organ damage in children compared to office and ABP measurements.

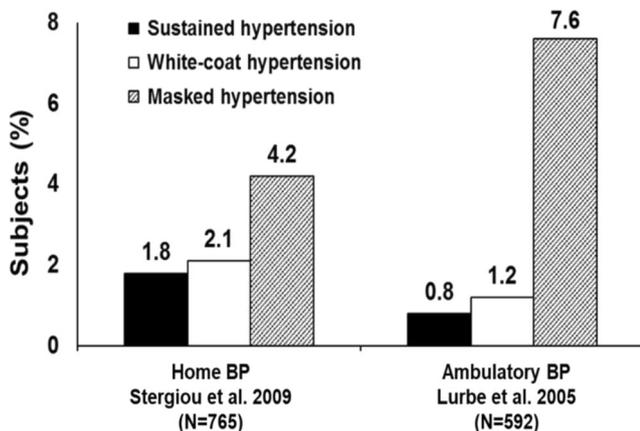
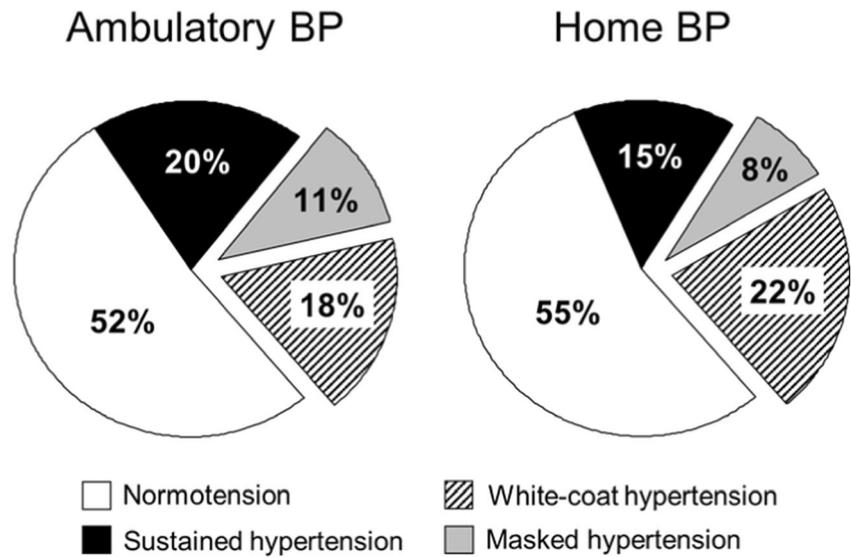


Fig. 2 Prevalence of white coat, masked, and sustained hypertension diagnosed by ambulatory or home blood pressure monitoring among healthy children and adolescents [27, 46] (with permission from [33])

Optimal Home Blood Pressure Monitoring Schedule

In adults, HBP monitoring using upper-arm cuff electronic (oscillometric) devices for 7 days (minimum 3 days) with

Fig. 3 Prevalence of white coat, masked, and sustained hypertension diagnosed by awake ambulatory or home blood pressure monitoring among children and adolescents referred to a hypertension clinic (BP, blood pressure; with permission from [11••])



duplicate morning and evening measurement is recommended for the evaluation of the home BP level, and the average of all readings is calculated without including the first day readings [4, 5, 7, 8, 33, 34]. A school-based study in Greece in 778 children and adolescents (about 30 boys and girls of each age year from 6 to 18 year) performed HBP monitoring for 3 days (minimum requirement in adults) with duplicate morning and evening measurements [23••], whereas other studies performed HBP monitoring for 6–7 days [11••, 26, 28••]. These data show the feasibility of wide application of HBP monitoring in children and adolescents.

The minimum schedule of HBP measurements has been investigated in a study in 100 children and adolescents, which showed that the reproducibility of 3-day HBP was superior to that of a single or 2-day HBP and that by averaging up to 12 readings (3 days), there was a progressive decline in average HBP, with no further decline thereafter [28••]. There was also a progressive decline in the HBP variability (SD), with little

change after the third day. Moreover, the association of HBP with ABP was improved by averaging up to 12 readings, with minor improvement thereafter. Thus, as in the adults [2••, 3••, 7, 8], a 7-day HBP monitoring schedule (at least 3 days with duplicate morning and evening measurement after 5 min sitting rest and 1 min between measurements—total of at least 12 readings) appears to be useful in the initial evaluation of untreated children with suspected hypertension and also in children with treated hypertension before each follow-up visit to the doctor.

Table 1 Normalcy tables for home systolic/diastolic blood pressure in children and adolescents by gender and height. Modified with permission from [23••]

Height (cm)	Boys		Girls	
	50th centile ^a	95th centile ^a	50th centile ^a	95th centile ^a
120–129	105/64	119/76	101/64	119/74
130–139	108/64	121/77	103/64	120/76
140–149	110/65	125/77	105/65	122/77
150–159	112/65	126/78	108/66	123/77
160–169	115/65	128/78	110/66	124/78
170–179	117/66	132/78	112/66	125/79
180–189	121/67	134/79	114/67	128/80

^a The 50th centile (midpoint of distribution) presents the usual home blood pressure, and the 95th centile the threshold for home hypertension

Devices for Home Blood Pressure Monitoring

The manual auscultatory office BP measurement is recommended by current guidelines as the reference method for diagnosing hypertension in children [1••, 2••]. However, 24-h ABP monitoring, which is regarded as the most reliable diagnostic method, can only be performed using automated electronic devices [3••, 48]. Electronic devices are also recommended for HBP monitoring, as they avoid the observer-induced errors of the manual auscultatory method and also prevent misreporting of HBP readings by users when devices with automated memory or CP-link capacity are used [7, 8]. More importantly, the evidence on the reference values of ABP as well as HBP measurements in children have been obtained exclusively using electronic (oscillometric) devices [1••, 2••, 23••].

Only electronic devices that have been clinically validated using an established protocol should be used [39, 40, 42]. It is important to mention that an electronic BP monitor which is successfully validated in adults may not be accurate in children, due to different structural and functional properties of their arterial walls, and separate validation in this population is necessary [40–42]. Only few of the electronic monitors

available on the market for office, ambulatory, or home BP measurements have been successfully validated in children (www.stridebp.org) [40, 42]. Only upper arm-cuff devices are recommended in children, as wrist-cuff devices have not been validated in this population [42, 49]. The availability of different cuff sizes to accommodate the wide range of arm circumference of children and adolescents is of major importance for the accurate BP measurement in the office and out of the office using the auscultatory or automated method.

Nocturnal Home Blood Pressure Monitoring

Nighttime BP during sleep is regarded as the most important aspect of the BP profile in predicting cardiovascular risk in the adults [48]. In children, nocturnal BP is particularly important in the presence of diabetes, nephropathy, and sleep apnea, and 24-h ABP monitoring is the gold standard method for its evaluation [1••, 2••, 3••]. Studies in children with type 1 diabetes have shown nocturnal hypertension and non-dipping assessed by ABP monitoring to be associated with microalbuminuria [18, 50, 51], carotid intima-media thickness [52], and LVMI [53].

Novel low-cost electronic HBP monitors which allow automated measurements during nighttime sleep have been developed [29, 53, 54]. Studies in the adults have shown that nocturnal HBP gives similar BP values and associations with preclinical organ damage with nocturnal ABP [53] and with similar agreement between methods in detecting non-dippers [29].

In children, there is scarce evidence on using HBP monitoring for evaluating BP during nighttime sleep. Preliminary data in children suggest that nocturnal HBP monitoring is feasible, it is preferred by children than nocturnal ABP, its levels are comparable to nighttime ABP and provide similar associations with indices of preclinical target organ damage [22].

Conclusions—Application in Clinical Practice

This systematic review suggests that, as in the adults, in children and adolescents, HBP monitoring is feasible and clinically useful. Despite the relatively limited published evidence and the several remaining research questions, HBP monitoring is already being used in children in clinical practice and appears to be a useful adjunct to the conventional office measurements for the evaluation of suspected or treated hypertension. HBP monitoring has several advantages, including good reproducibility, diagnostic ability, and acceptability by users and relatively low cost. Therefore, it has greater potential for widespread and long-term use than ABP monitoring, which is more expensive and often not available or not tolerated. Electronic upper-arm cuff monitors which have been

clinically validated in children should be used with appropriate cuff size. HBP monitoring for 7 days (not less than 3) with duplicate morning and evening measurements after 5 min sitting rest and 1 min between measurements (total of at least 12 readings) appears to be useful in the initial evaluation of untreated children with suspected hypertension and also for children with treated hypertension before each follow-up visit to the doctor. Until more data become available, in the case of disagreement between office and HBP measurements, the treatment decisions should be based on ABP monitoring. More research is needed on the clinical application of HBP monitoring in children, and more automated HBP measuring devices need to be clinically validated specifically in this population.

Compliance with Ethical Standards

Conflict of Interest The authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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