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BP measurement techniques: Clinical review and update

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Abstract

Increased blood pressure (BP) damages multiple organs. Diagnosis, treatment, and prevention of end-organ require regular, accurate BP measurement. BP was predominantly recorded using the mercury-based-sphygmomanometer. Recently, oscillometric-based devices have been invented and are commonly used worldwide.

BP measurement methods are broadly divided into Office-based and out-of-clinic (home). The patient at home or workplace conducts home BP measurement, either intermittently (Non-ambulatory BP monitoring [NABPM]) or continuously (Ambulatory BP Monitoring [ABPM]). Despite the variety of BP measurement methods, the ABPM method is the best method of BP recording, especially in unstable (liable) BP readings. NABPM is conducted less frequently in the nighttime, whereas ABPM is conducted day and night and gives more frequent stable BP records. In ABPM, the mean of the measurements is automatically calculated and stored for later use or sent directly to the physician. Furthermore, some people may have an increase in BP at nighttime or loss of the dipping BP character, which increases the risks of high BP complications. Hence, in this comprehensive review, we will discuss the different methods of BP recording, their advantages and disadvantage, and their differences. Scopus, EMBASE, PubMed, Google, and Google Scholar were searched for the related reviews and original articles cited for BP measurement methods and techniques.

Keywords: ABPM; NABPM; BP measurement; Office-based; Home-based; White coat hypertension

1. Introduction

BP is rationally expressed as systolic BP/diastolic BP mmHg. Systolic BP is a pressure exerted on systemic arteries walls during the left ventricular contraction that corresponds to the ejection phase of the cardiac cycle. In contrast, diastolic BP is the pressure exerted on systemic arteries during left ventricular relaxation (relaxation phase of the cardiac cycle).

Common hypertension complications include coronary heart disease, heart failure, myocardial infarction, cardiac arrhythmias, peripheral artery disease, chronic kidney disease (CKD), cognitive impairment, and stroke. Therefore, high BP confirmation is required to prevent these complications.

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The mean ambulatory blood pressure monitoring (ABPM) records represent the BP measurements more precisely than clinic-office BP and non-ambulatory- BPM (NABPM) records. Nasothmio et al. reported that in resistant hypertensive patients, NABPM home-based records were not significantly different from ABPM records. However, NABPM is essential to differentiate between the hypertension phenotypes and normotensive subjects [1]. It was reported that ABPM readings give higher reproducibility, are not subjected to digit preference, and easily exclude the insignificant rise of BP measurement due to surroundings [2].

BP measurement accuracy needs a good, calibrated machine and the correct time for recording. For a long time, BP measurement was conducted in clinics. However, recently due to the availability of new automatic machines, BP recording can be performed in other places such as pharmacies, homes, and workplaces. The importance of accurate BP records has led the health authorities to revise the BP measurement methods, looking for the best and the more straightforward method. Therefore, reviewing the known BP records methods and understanding the based techniques, their advantage, and disadvantages are essential to determine the best method of BP measurement in medical practice. To achieve this aim, we searched for review and original articles published in Scopus, Google Scholar, EMBASE, and PubMed, using different keywords and text phrases (ambulatory BP measurement, BP recording, techniques of BP recording, oscillatory BP recording, physiology of hypertension, cardiac cycle physiology, diagnosis of hypertension, home BP measurement, dipping BP, etc.). Then, the team summarized and wrote this comprehensive clinical review article.

2. Blood variability detection and its significance

BP records are different during the 24 hours. It is reported that BP is lower during sleeping time and higher at waking up in the morning by about 10-20 mmHg [3]. The higher BP records during the daytime may be due to the increased activity and stress during working hours. It has been noted that BP records are higher at 6 AM and midday, increasing the prevalence of cardiovascular disease (CVD) complications [4]. The pattern of diurnal variation is usually preserved even in hypertensive patients; however, some hypertensive patients may lose their diurnal BP reduction at night (non-dipper), as in some CKD patients, autonomic neuropathic diseases, and preeclampsia-associated High BP.

A strong link between non-dipper high BP and an increased rate of cardiovascular system (CVS) events and related morbidity, and mortality [5], increasing death rate due to CVS complications by 20% [6]. Furthermore, Ingelsson et al. reported that an increase in nighttime diastolic BP by 9 mmHg is accompanied by a 25% increase in congestive heart failure risk among elderly patients [7]. Furthermore, early detection of non-dipper BP pattern at nighttime is an essential predictor for CVS complications prevention [8].

2.1. Blood Pressure Measurement

2.1.1. General considerations

BP recording is measured by medical personnel, listening and sensing the change in the blood gush sound or by palpating arterial pulsation while reducing the pressure on an occluded artery. The auscultatory method is achieved by auscultating the sound change after reducing the cuff pressure. The palpatory method is performed by palpating the radial or brachial artery pulsation during cuff deflation after increasing cuff-balloon pressure more than systolic BP by at least 30 mmHg. These two methods are still used; however, they are not as frequently used as before. The cuff pressure is usually increased and decreased manually, although recently, new machines can do that automatically.

The new devices are oscillometric devices that can measure BP by recording arterial wall logarithmic oscillation and blood flow in the arteries, transforming them into recordable numbers. These BP recording devices were invented and are progressively developed and validated to obtain BP recording in the office-clinics and at home during the last 40 years. BP recording is a routine practice that is usually recorded before the patient enters to see a doctor. Most of the time, clinicians confirm the BP reading by themselves, especially when the patient has complaints suggestive of hypertension. Despite the strict recommendations of the issued guidelines of BP measurement, proper methodical procedures for BP measurement are not usually firmly applied [9] as in (table 1), producing misleading BP records [10]. The typical sequence of BP recording is illustrated in figure 1.

BP must be measured from the two arms at the first visit. If there is>10 mmHg difference between the two arms' records, causes such as peripheral vascular disease should be excluded first [11]. In the case of an unrecognized cause of the BP discrepancy between the two arms, the higher side record is usually taken as a real BP measurement because even one side's high records are associated with an increased rate of CVS events and death [12].

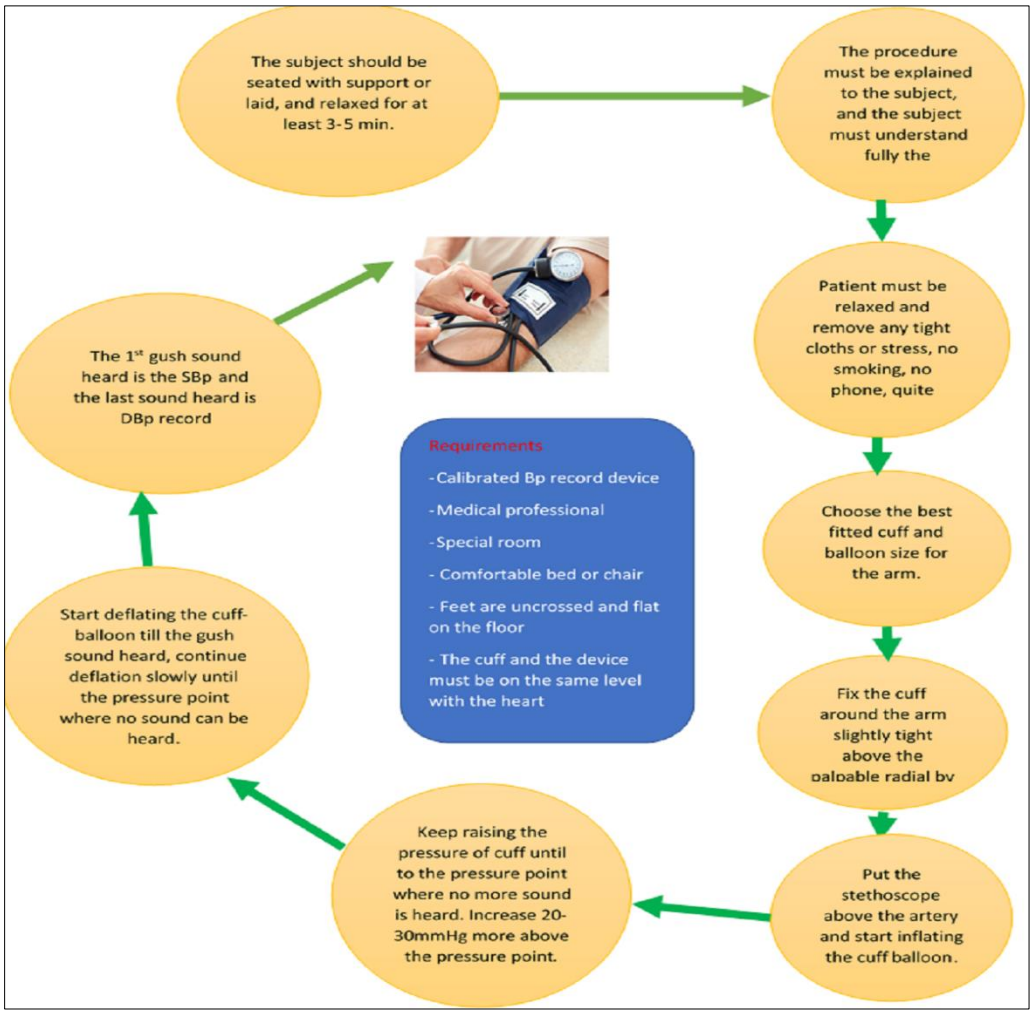

Figure 1 Typical sequences of BP measurement

Table 1 Requirement of BP measurement

BP measurement place	**Office of physician or nurse office**
Condition of place	Quite a room with a temperature between 36.5-37.5oC
Patient status	Before BP recording: No cigarette smoke, no caffeine drinking, and no exercise (even walking) for 30 min; empty urinary bladder; the subject must be seated and relaxed for at least 3–5 min
Machine	Oscillometric machines must be validated.
Patient and the personnel	Patients and staff must not communicate before, during, or between measurements. The patient's arm must be rested at the heart level, his back must be supported, and his legs uncrossed.
Cuff and Balloon	-The cuff and its balloon should be individualized according to arm circumference. -Cuff balloon should cover 75–100% of the arm circumference -Electronic devices' cuffs, see the instruction booklet of the device
BP Measurement Protocol	Three records must be taken a minute apart during each visit, and at least a mean of the two stable records is taken.
	If the 1st BP record is <130/85 mmHg, no more re-measurements are mandatory. Hypertension can be approved if 2-3 office-based records of BP≥140/90 mmHg.

At least two measurements of BP should be done in every office visit 1-2 minutes apart, and if the second reading is higher than the 5 mmHg difference, then a third reading or more readings are needed till stable reading is obtained. Furthermore, in the case of high BP first records, multiple records of BP are required when there are not any features of end-organ damage before diagnosing hypertension. A minimum of three times BP records over a week to confirm pathological high BP; however, Hartet al.t al concluded that a more extended period is required to obtain the entire BP record [13].

2.1.2. Cuff placement and specifications

cuff-placement

Cuff must be fixed 2-3 cm above the cubital fossa with accurate direct contact with skin, and the cuff balloon should be on the radial artery [14]. The arm has to be supported at the heart level [15], while the unsupported arm may lead to about 10-12 mmHg higher BP readings than the actual BP value [16]. The patient must sit quietly for at least 30 minutes before measuring BP [17]. Other factors that might increase BP, such as urinary bladder distension, talking, and background noise, must be ruled out [14]. Despite all these recommended precautions, about 20-30% of normotensive subjects still have higher BP readings that can put them unnecessarily in the hypertension category [18]. This type of hypertension was named white coat or isolated office hypertension. The white coat hypertension must be considered first, especially if there is no evidence of hypertension end-organ manifestation. It should be excluded before starting treatment by NABPM or ABPM BP recording method [19].

Cuff size

Cuff must be correctly sized [20]. Smaller-sized cuffs and small cuff-balloon need higher pressure to occlude the brachial artery, leading to a higher systolic BP record by about 10-50 mmHg, especially in obese patients. American Heart Association recommended the applicable cuff and balloon size for different arm circumference ranges (Table 2) [14].

Table 2 Arm circumference and Proposed cuff size

Arm circumference (cm)	Cuff name	Size (cm^2)
22-26	Small adult cuff	12 x 22
27-34	Adult cuff	16 x 30
35-44	Large adult	16 x 36
45-52	Adult thigh	16 x 42

2.1.3. Length of the cuff and cuff-balloon

it was reported that the cuff-balloon size must be ≥ 80%, and its width should be > 40% of the arm circumference [14].

3. Types of devices used in BP measurement

3.1. Manual auscultatory BP measurement devices

This method was previously used for BP measurement; however, it is still used in many countries. It is conducted by a conventional Riva-Rocci sphygmomanometer [21]. The mercury-based sphygmomanometer is withdrawn from clinical practice in developed countries due to mercury toxicity risk. The auscultatory BP measurement method needs excellent hearing ability, trained personnel, and periodic supportive revision courses for medical professionals to eliminate and minimize BP recording discrepancies [22].

Currently, a mercury-based sphygmomanometer is rarely used in clinical settings and research projects; however, it is still an essential method to calibrate newly non-mercury-based devices such as aneroid manometers [23]. Systolic BP is the pressure when the first blood gush sound (Korotoff phase I) is heard. The stethoscope is usually put lightly over the brachial artery because a tightly laid stethoscope or between the cuff-balloon and the skin may lead to blood turbulence, causing a lower diastolic BP record by about 10-15 mmHg. Cuff-balloon must be trimmed slowly by 2 to 3 mmHg per second [24]. As cuff-balloon pressure is decreased, at a particular measurement of force, the sound is muffled (stage IV), and then after about 10 mmHg reduction of the intra-balloon pressure, the sound disappears (phase V), which corresponds to the diastolic BP record in adult [14]. The palpatory method depends upon the loss of pulsation beyond

the inflated sphygmomanometer and the reappearance of the arterial pulse during pressure reduction. This method will enable just the detection of systolic BP with lesser accuracy. It is advisable to recognize the systolic BP by palpation to exclude the potential deficits of the palpatory auscultatory gap. At the same time, the Korotkoff sounds transiently disappear unnoticeably as the cuff is deflated. Korotkoff sounds may appear and disappear and then reappear again, which may give the wrong BP record, mainly when BP recording is conducted by unwell-trained personnel. The palpatory method is also performed in severely shocked patients.

3.2. Oscillometric BP devices

Office Bp measurement method method	Home Bp measurement method	Continues AMBPM
- Bp is measured at the nurse or Dr's office. - Patient should be seated, rested, No smoking, no phone calls and comfortable, and feet are uncrossed and flat on the floor.	- Bp is recorded by the patient seated at home two to three time at different times of the day. - General requirement and conditions should be applied.	- Bp is recorded during the day every 15 min, every 30 mins at night.
Advantages		
- Bp records are strongly associated with CVS events and complications.	- Detect and differentiate between hypertension phenotypes as white coat and masked HTN. - Bp records are strongly associated with CVS events and complications & outcome.	- Detect and differentiate between hypertension phenotypes. - Bp records are strongly associated with CVS events and complications & outcome. - Detection of Bp variability, night non-dipping, and the effect of daily activities.
Disadvantages		
- Needs medical professional attendance. - Can give higher Bp records. - Bp record does not corresponds to the actual Bp variability. - Is not the typical method for hypertension phenotype differentiation.	- Does not need medical professional attendance - Costly - Patient bias - Needs patient training - Need good patient compliance	- The devices are not widely available - Costly - Disturb patients especially at night. - Need good patient compliance
Reliability to Bp measurement and outcome		
- Is not strongly reliable for diagnosis of hypertension in doubtful cases. - - is not the typical method to differentiate between the hypertension phenotypes	- Good for the diagnosis of doubtful hypertension cases. - -Can be used to diagnose or exclude masked and/or white coat hypertension. - Correlated well with CVS outcome.	- Typical method for detecting abnormalities in daily Bp variability. - Excellent method to detect non-dipping Bp pattern. - Is certainly well correlated with CVS outcome, other end-organ damage.

Figure 2 Description, advantages, disadvantages, and reliability of the main three BP measurement methods

Oscillometric BP measurement is the currently used method for BP measurement worldwide, especially in developed countries. Oscillometric devices are supplied by an electronic sensor that detects arterial pressure oscillation, and its cuff balloon usually inflates and deflates automatically. Algorithmic oscillatory propriety is the primary mechanism of detecting the BP measurements by these devices. These devices are provided with sensors in the cuff that can see the specific algorithm and oscillometric pulse waves, typically during cuff-balloon deflation. Some new devices also detect oscillations during the inflation of the cuff balloon [5,25]. These devices were invented and used in 1876 [24].

Conditions that lead to arteries wall elasticity loss or reduce arteries compliance, such as atherosclerosis, diabetes, CKD, and aging, give inappropriate BP recordings by oscillometric devices. Furthermore, cardiac arrhythmia, which affects the oscillatory waves' strength and character, can provide abnormal BP records [25]. Moreover, these types of machines are easily breakable and frequently physically damaged. Frequent validation of the devices and maintenance are

commonly required to maintain their accuracy and perfection. Standard measures such as patient positioning, BP cuff size, arms level, appropriate cuff-balloon size, etc., should be strictly applied (table 1).

The varied models of oscillometric devices use different algorithms [26]. However, oscillometric commercial devices, intra-arterial, and Korotkoff auscultatory BP records did not reveal significant differences [27]. Automatic oscillometric machines can be used in the clinic, either with or without personal medical attendance [28]. It was reported that BP readings are higher by about 9 mmHg in systole readings and about 7 mmHg in diastole readings in the presence of the medical personal [29]. This increase in BP readings with the personnel's presence made one reporter recommend automatic BP recording while the patient is alone [30]. In contrast, a study reported no significant differences in BP readings, either with or without the presence of medical personnel [31]. Recently, it was noted that the attended and unattended BP values are equally correlated with organ damage in hypertensive patients [32].

3.3. Blood pressure measurement methods according to the site

3.3.1. Hospital-office-based method.

BP measurement is conducted in the clinic office either by the attended medical professional personnel or by the patient alone.

3.3.2. Attended office-based BP measurement.

This type of BP measurement can be conducted manually and by an automatic device. BP measurements in the clinic office should be multiple, on different days and at times of the day. It is better if the BP record is taken in the same room and by the same person every time. Each visit must have at least two or three readings of BP, and an average of at least two stable readings is considered. When the BP measurement is ≥ 140/90 mmHg, at least two readings of BP are required before labelling the subject as a hypertensive person. As stated in table 1, the office should be quiet with a comfortable temperature. Patients must be relaxed as recommended or lying on a comfy couch, the mid-arm should be at the heart level, the feet should be flat and uncrossed [15], and the device is well validated with a proper cuff and cuff-balloon size [33].

3.3.3. Unattended office BP measurement

Automatically, the BP is measured multiple times while the subject is seated or lying down comfortably on a couch in the office alone. This type of BP measurement is needed to exclude the high BP records that might occur due to the attendance of medical personnel. It is required when treatment is necessary to be initiated for subjects who have high BP records in the clinic but have normal records at home, for example [34].

3.4. BP measurement at home

The patient conducts this BP measurement method outside the clinic (home and workplace). The patient can measure the BP while unattended by a medical professional at home or during work, and even when sleeping, usually using fully automatic devices. This method is recommended to have multiple, more frequent BP readings. These various records help to eliminate BP records inaccuracies due to external environmental factors [35].

There are two methods to determine BP at home and workplace: ABPM and NABPM. These two methods were not used earlier to diagnose hypertension, but they are recently more frequently used to diagnose borderline hypertensive cases and follow-up BP control after starting treatment. Recording BP by ABPM & NABPM at home and workplace minimizes BP record errors due to conditions such as stress, presence of medical staff, and place change. Measuring BP by these methods represents BP records changes that usually occur during daily activities [36] and sleep.

3.4.1. Ambulatory BP monitoring (ABPM)

ABPM is usually done 24 hours, although some patients may need longer hours of BP monitoring. The device is typically standardized to record BP every 15 to 20 minutes during the daytime and at night, every 30 to 60 minutes [37]. However, Wolak et al. reported that six to eight hours of ABPM might be enough if the full 24-hour BP recording is not applicable [38]. When ABPM is used, hypertension is diagnosed if the subject has a mean BP record during 24 hours ≥ 125/75 mmHg, average daytime BP ≥ 130/80 mmHg, or moderate nighttime BP ≥ 110/65 mmHg [38].

3.4.2. Non-Ambulatory home BP Monitoring (NABPM)

Measuring BP must be done frequently and at different times and places. The patient is given a fully automatic device and is taught how to use the device by expert personnel. The records are then collected, the mean of the BP records is

taken, and BP final record is established. This method is usually conducted in the daytime rather than at nighttime because it disturbances patient sleep and sleeping patterns that may negatively affect BO records.

The ABPM measurement method is superior to the NABPM regarding BP records variance and outcome, while the former obtains BP records more frequently during daytime and sleeping time [39]. These two methods are used in uncontrolled hypertensive patients who need adding a third BP lowering therapy to rule out white coat hypertension [6]. Furthermore, ABPM & NABPM methods are required in borderline cases. ABPM & NABPM are not considered interchangeable, while the daytime readings do not differ significantly between the two methods [40]. There is evidence that lower high ABPM & NABPM BP readings are associated better with end-organ damage than higher office-BP-readings [41]. NABPM & ABPM methods are better than office BP measurement in the early detection of hypertension and its late complications [42]. However, it has been reported that the systolic BP readings are generally not significantly different when measured at the office or at home by the NABPM method [43].

The differences in BP recording between ABPM and NABPM are vague in clinical practice. However, ABPM might be more acceptable to detect non-dipping, white coat, and masked hypertension because, by ABPM, BP can be measured at night and during sleep. In contrast, NABPM is better for following hypertension control. The best advantage of the recent ABPM &NABPM devices is that they can be directly connected via a wireless connection to medical professionals. Patients' BP can be monitored, and the antihypertensive doses can be managed accordingly.

There are some concerns from health providers and insurance companies about medical professionals' abilities to deliver the proper techniques and enough information about automatic oscillatory machines to patients. Additionally, insurance companies are not all willing to pay patients' device costs. All these facts and others limit these devices' use at home and sometimes even in health centres in some countries [44].

3.4.3. Penaz-finger cuff BP measurement method

This method is used in hospitals, especially in intensive care units but can be used at home for BP recording. A photo-electronic BP recording was possible by detecting blood volume and flow at the finger. At one finger, arterial pulsation can be appreciated by a photo-plethysmograph beneath the finger cuff, driving a servo-loop that quickly alters cuff pressure to maintain the output constant by keeping the artery closed partially. The arterial pressure wave is well represented by the pressure oscillations in the finger cuff. Compared to records of brachial artery pressure, it was shown that this method is legitimate and can reliably measure systolic and diastolic BP [46]. Finometer and Portapres recorders are two types of finger-cuff devices that can be inflated for up to two hours without influencing blood flow [45]. AMBP records for 24 hours can be obtained by this method, but the Portapres are heavy, and it might be distressful to some patients [45].

3.4.4. Ultrasound BP measurement method

Ultrasonic BP recording has become a significant focus in the noninvasive assessment of BP for the last decades [46]. Installed ultrasonic sensors can detect and transmit the reflected ultrasonic waves of brachial artery movement during systole and diastolic [26]. Using ultrasound recording for BP as a replacement for the oscillometric BP or continuous noninvasive BP recording method is increasingly coming into focus. The ultrasound method offers several advantages over the oscillometric and continuous BP recording methods for deep tissue penetration and using different multiple arterial sites [47]. This method is better, especially in infants and young children [48] and patients with indistinct Korotkoff sounds, as in muscular atrophy-diseased patients. Although the ultrasound BP recording method is not widely used, especially in everyday clinical practice in adults, it can assess the ankle-brachial index.

4. Conclusion

Mercury sphygmomanometer is considered the gold standard for office blood pressure measurement and was universally used due to the worldwide ban on mercury-based devices, decreasing the frequency of usage of devices. Oscillometric automatic BP recording devices have become more widespread and are commonly used.

BP measurement methods are quickly advanced processes during the last 20 years. As advancements in BP measurement methods and devices improve, researchers and medical professionals face new challenges. The quality of BP measurement in clinical practice is not satisfactory, despite the recommendations of the new guidelines to adhere to the recommended methods and the recording conditions. It has been thought that the inconsistency of the office BP reading might be due to factors unrelated to the patient, such as infrequent device standardization, poorly prepared technician/clinician due to lack of training, and re-training supportive courses. Therefore, new research projects are required to study these issues.

Although ABPM and NABPM devices have been available for quite a reasonable period, there are questionable conflicting data about their efficiency in diagnosing hypertension and monitoring its control. New multicentre studies are urged to clarify this matter to improve the understanding and assess which method is superior to the other.

ABPM seems the best method to record BP and diagnosis of hypertension, especially in borderline cases; however, its superiority is not clinically evident. Therefore, further larger-scale projects are required.

Compliance with ethical standards

Disclosure of conflict of interest

The authors have no conflict of interest in this topic.

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