SciMedCentral

Journal of Family Medicine & Community Health

Research Article

Assessing Workflow, Satisfaction, and Potential Cost Reduction when Using a Cuffless Ambulatory Blood Pressure Monitor

Esther Hazan[1], Isabella Azarya[1], David Dvir[1], Viktoria Gonen[1], Gregory Ekhilevitch[1], Roei Merin[2], Arik Eisenkraft[2,3]* and Erez Carmon[1]

[1]Meuhedet Health Services, Israel

[2]Biobeat Technologies Ltd, Israel

[3]Institute for Research in Military Medicine, Hebrew University of Jerusalem, Israel

*Corresponding author

Arik Eisenkraft, Institute for Research in Military Medicine, Faculty of Medicine, The Hebrew University of Jerusalem, and the Israel Defense Force Medical Corps, POB 12272, 9112102 Jerusalem, Israel, Tel: +972-52-9210896

Submitted: 17 November, 2022

Accepted: 12 December, 2022

Published: 15 December, 2022

ISSN: 2379-0547

Keywords

- Non-Invasive Blood Pressure; Cuff less Blood Pressure; Remote Patient Monitoring; Hypertension; Patient Satisfaction; Ambulatory Blood Pressure Monitoring

Abstract

Background: Hypertension is a major risk factor for cardiovascular diseases. Ambulatory blood pressure monitoring (ABPM) is used for the diagnosis of hypertension; however, currently used devices have several drawbacks complicating their use and accuracy. We tested the workflow of a wearable photoplethysmography (PPG)-based cuffless device, when compared to the traditional cuff-based ABPM device.

Methods: Patients were recruited in a single community clinic and randomly assigned to either a cuff-based or a PPG-based 24-hour ABPM test. An assessment team recorded the time-to-complete each workflow component with each device. Questionnaires on user experience and workflow were filled by physicians, nurses, and recruited patients.

Results: Workflow assessment showed that it was faster with the PPG-based device than with the cuff-based device (301.17±58.39 seconds vs 1185±172.34 seconds on average, respectively). The PPG-based device received a higher score in all aspects when compared with the cuff-based device. The direct manpower cost reduction was 108,000 USD per year for 4,500 tests.

Conclusion: The PPG-based device has several advantages when compared to the traditional cuff-based ABPM device, potentially increasing both patient and medical staff satisfaction, and as a result, increasing compliance. This could help improve the diagnosis and treatment of hypertension in the community.

ABBREVIATIONS

ABPM: Ambulatory Blood Pressure Monitoring; BP: Blood Pressure; CI: Cardiac Index; CO: Cardiac Output; HBPM: Home Blood Pressure Monitoring; HR: Heart Rate; HTN: Hypertension; MHS: Meuhedet Health Services; OBPM: Office Blood Pressure Monitoring; PPG: Photoplethysmography; RR: Respiratory Rate; SpO2: Blood Oxygen Saturation; SV: Stroke Volume; SVR: Systemic Vascular Resistance

INTRODUCTION

Blood pressure (BP) has been routinely evaluated in clinical practice for more than a century, as a robust adjustable risk factor for cardiovascular disease. Hypertension (HTN) is a major risk factor for cardiovascular diseases, which are the leading cause of morbidity and mortality worldwide [1]. Moreover, at least 70% of American adults in their 60s and 70s have been diagnosed with hypertension, and adults 55 years and older with normal BP will have a 90% lifetime risk of developing hypertension [2,3,4]. The indications showing that HTN is the major global risk factor of morbidity and death and the benefits of BP lowering, has been based on upper-arm cuff BP measurement [5]. The upper-arm cuff BP measurement is recommended for office, home, and ambulatory BP measurement (ABPM) in clinical practice [5], and is the reference for assessing novel BP measurement technologies [6]. ABPM is frequently being used for the diagnosis of hypertension [7,8] since it is considered to provide a more comprehensive assessment of BP and allows identification of patients with distinct BP profiles [9-11]. The use of 24-hour ABPM is recommended to confirm the diagnosis of hypertension [12]. However, traditional ABPM devices have several drawbacks making their use complicated and influencing the accuracy of measurements, including cuff use discomfort, inappropriate cuff size, intermittent BP measurements in static conditions, and inaccuracies in measurements during daily activities and sleep [13-19]. An additional important issue is that automated arm cuff devices may not be readily available and not easily accessible especially in low-resource settings [20]. Despite efforts to reduce its prevalence, US hypertension control rates were recently shown to decline rather than improve [21].

Recently, several approaches based on sensors, signal processing, and algorithms embedded in wearable devices, have been developed to allow cuffless BP measurement [22-24], directed at providing a solution to the above issues. The potential of cuffless wearable devices is to record BP comfortably and continuously with minimal user intervention, providing detailed and unbiased information regarding circadian BP patterns and

variability during work and nighttime, without disturbing sleep [20].

As mentioned in the consensus statement by the European Society of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability [20], cuffless BP measurement technologies embedded in wearable devices may improve the awareness and early treatment of HTN in the general population, and may also facilitate self-monitoring of BP by patients with hypertension, thereby improving adherence to treatment and long-term BP control [23]. Clinical validation of cuffless BP devices is different and more complex than that for cuff-based devices, and standards developed for cuff BP devices are probably inadequate for cuffless devices. Cuffless wearable techniques are being proposed as the 'future of BP monitoring', and considerable effort is emerging in providing guidance for scientists and clinicians [25].

Despite the significant technical progress and some good agreement with conventional cuff-based BP measurement, mainly in static clinical conditions but also during daily living [26,27], the clinical adoption has been slow, mainly due to conservative approaches raising doubt and questioning its validity, while at the same time, at least for now, specific standardized guidelines of validation procedures are still being defined [28,29]. As cuffless BP measurement is a new method for BP evaluation, the normalcy thresholds for average cuffless BP values will probably need to be verified [20]. Moreover, cuffless BP devices will need to show that they provide benefits to patients on top of those provided by the currently recommended methods.

Based on the points raised earlier, this study aimed to test the feasibility and ease-of-use, as well as to assess the implications on health care providers' workflow, of a wearable cuffless 24-hour ABPM device, compared to a traditional cuff-based ABPM device.

MATERIALS AND METHODS

Study Overview

This prospective observational study included male and female patients above 18 years of age, suspected of having hypertension, referred by their general practitioners to a single clinic to have a 24-hour ABPM test. The participating nurses were highly skilled in operating traditional cuff-based ABPM devices. The study was approved by the Meuhedet Health Services (MHS) Institutional Review Board (approval number 2021-11-15), and as both devices are cleared for use by the Israel Ministry of Health for this indication, informed consent was exempt.

Study design and Outcome measurements

Following a referral by their physicians to an ABPM assessment unit and upon recruitment, patients were randomly assigned to use either a traditional cuff-based ABPM device or a photoplethysmography (PPG)-based chest patch device. An MHS assessment team was present in the clinic to collect data on the different components of the testing and method. This included recording the time it took to perform and complete each component, and the time to apply both devices (following a short period to allow for reaching a learning curve of at least three attachments of the chest patch by the nurses). Moreover, the team retrospectively contacted the participants – patients, nurses, and physicians – and collected their feedback regarding user experience.

The cuff-based ABPM device

The cuff-based ABPM device (SunTech Medical, Inc., Morrisville, NC, USA) is the standard device used by the MHS (Figure 1). It includes the device itself and a cuff, which is adjusted based on the size of the patients' arms. As with any other patient using this device, when patients participating in this study were assigned to the cuff-based ABPM test, the attending nurse admitted them into the ABPM system, provided an explanation about the test, connected the device to each patient, and assured correct cuff size. Next, patients were discharged home, and 24 hours later came back to the clinic to return the device. At that time, the nurses connected the ABPM device to a computer, downloaded the recordings, and transferred the gathered data for final analysis by experts in an analysis center of the MHS. When the analysis was completed, the test results and conclusions were sent from the analysis center to the initiating general practitioner. The report presented to the physicians included 24-hour, daytime, and nighttime analysis of BP and PR, the presence of dipping, histograms of measurements, and a table fully detailing all measurements taken during the session with time stamps. Several components are automatically generated, and expert physicians interpret some. The measurement rate was 20 minutes during the daytime, and 30 minutes during nighttime. This depicts the full workflow of the currently used cuff-based ABPM device.

The PPG-based chest patch device

The chest patch monitors used in this study (Figure 1; Biobeat Technologies Ltd., Petach Tikva, Israel) are based on reflective photoplethysmography (PPG) technology, in which part of the transmitted light is reflected from the tissues and detected by a photodiode detector positioned near the light source transmitter [26,27]. The disposable devices require a single calibration of the pulse rate (PR) and BP baseline using an FDA-cleared cuff-based device, and it collects multiple parameters, including non-invasive cuffless blood pressure (BP), heart rate (HR), blood oxygen saturation (SpO2), respiratory rate (RR), body temperature (all FDA-cleared and CE mark certified), as well as stroke volume (SV), cardiac output (CO), cardiac index (CI), and systemic vascular resistance (SVR) (also CE mark certified). The automatically-generated report presented to the physicians

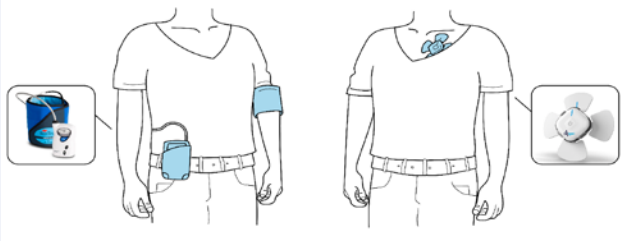

Figure 1 The blood pressure monitoring devices. Left - the currently-used traditional cuff-based ambulatory blood pressure monitoring device; Right - the disposable cuffless photoplethysmography-based chest patch device.

included 24-hour, daytime, and nighttime analysis of BP, PR, CO, SVR, data on dipping, histograms of measurements, and a table fully detailing all measurements taken during the session with time stamps. The measurement rate was 15 minutes during the whole monitoring period, including daytime and nighttime. Another form factor of the same device is a rechargeable wrist monitor [27], not included in this study, aimed for long-term monitoring. To date, this is the only cleared cuffless blood pressure monitoring device providing these features.

Questionnaires

Nurses, patients, and their primary physicians were contacted by phone retrospectively and asked about their user experience. Patients were asked about the chest patch only, while nurses and physicians were asked about both devices. The patients were asked to grade their satisfaction regarding the following aspects: how complicated was the device assembly; duration of the device assembly; convenience during daily use; aesthetics; irritation; ease while dressing; and general satisfaction. Patients were also asked about test cessation and if answered yes, what was the reason and whether they repeated and completed the test. In addition, they were asked about past use of the traditional cuff-based ABPM device, and if so, which device they would prefer now. The referring physicians' questionnaire included questions on the satisfaction rating of the final report, the data display, and its clarity. Nurses were asked about ease of attaching the devices; aesthetics of using the device; satisfaction with the time it takes to connect the device; the comfort of wearing clothes while using the device; ease of connecting the device to the MHS's computer systems; and general satisfaction of using the device. They were also asked if there were any technical difficulties leading to delays, disruption, or cancellation of the test. Except for this question, in all other questions among all users, the scores ranged from 1 (lowest score) to 10 (highest score).

Data collection and analysis

Evaluation of individual test costs was based on the time measurements obtained in this study and data retrieved from the MHS finance databases. For group comparisons (time measurements and questionnaires) non-parametric Mann-Whitney test was used. Paired samples t-test was used to compare the results from the nurses' questionnaires. Significance was achieved when the p-value was below 0.05 (two-tailed). Data presented as mean±SD. Statistical analysis was done using Graph Pad Prism 8.

RESULTS

For the assessment of workflow, four participants were assigned to the cuff-based ABPM device, and six patients were assigned to the PPG-based chest patch. Questionnaires were filled by 26 participants that were using the PPG-based chest patch devices (13 males, age 59.6±13.8 years, BMI 29.6±5.8 kg/m2), as well as 11 referring physicians, and 3 nurses. There were no adverse events from using the devices and none of them stopped the test. Table 1 show the results of the questionnaires provided to the medical teams and patients. Among nurses, the

Table 1: Results of the questionnaires.

P value	Chest patch	Cuff-based ABPM	Category/Item
a. Nurses			
ns	9.3±1.1	4.3±1.1	Ease of attaching the device?
0.04	10.0±0.0	3.7±2.3	A esthetics of using the device?
0.014	10.0±0.0	2.7±1.5	Satisfaction with the time it takes to connect the device?
0.05	0/3	3/0	Did you encounter technical difficulties leading to delays, disruption, or canceling of the test? (Yes/No)
0.001	10.0±0.0	1.3±0.6	Comfort of wearing clothes while using the device?
0.03	10.0±0.0	3.3±2.1	Ease of connecting the device to the HMO's computer systems?
0.014	10.0±0.0	2.7±1.5	General satisfaction of using the device?
b. Referring general practitioners			
ns	9.1±1.4	7.5±2.5	Satisfaction from the report
ns	9.2±1.4	7.6±2.5	Satisfaction from the presentation of the data and the parameters
Average±SD			**c. Patients (chest patches only)**
9.79±0.69			Complexity of device assembly (1 – severe, 10 – not at all)
9.41±2.06			Duration of device assembly and activation (1 – very long, 10 – very short)
9.33±1.16			Convenience in daily use (1 – not comfortable, 10 – very comfortable)
9.70±0.80			Aesthetics (1 – not aesthetic, 10 – highly aesthetic)
9.33±1.68			Local skin irritation (1 – very irritating, 10 – not at all)
9.91±0.39			Convenience while dressing (1 – not comfortable, 10 – very comfortable)
9.66±0.68			General satisfaction with the device (1 – not satisfied, 10 – very satisfied)

Category a. questionnaires provided to nurses on both of the devices; Category b. questionnaires provided to referring physicians on both of the devices; Category c. questionnaires provided to patients using the chest patch device. 1 – lowest score, 10 – highest score. ABPM, ambulatory blood pressure monitoring. HMO, healthcare management organization. PPG, photoplethysmography

PPG-based chest patch device received high scores (ranging between 9.3-10) in almost all categories, while the rating was significantly lower (ranging between 1.3-4.3) with the cuff-based ABPM device ($p<0.05$). Among physicians, a high satisfaction rate was found for data presentation and the automatically-generated final report (9.2 and 9.1 for the chest patch vs 7.6 and 7.5 for the traditional cuff-based device, respectively). When asking the patients, we found a high satisfaction rate from using the PPG-based chest patch device in all categories (ranging from 9.3-9.9). Other comments from patients were that connection and activation are short and simple, the chest patch is comfortable and does not protrude under the clothes, it does not awaken from sleep, is not cumbersome, and the fact there is no inflating cuff prevents stress and local pain as well as no issues of adjusting cuff size. Some disadvantages mentioned were that sometimes the chest patch interferes with the car belt, it requires shaving the chest hair, and since it is not water-proof patients cannot shower with the device. 17 patients had previous experience with the legacy cuff-based ABPM device, and they have all stated that they prefer using the PPG-based device.

The assessing the workflow and comparing the time to complete a single session, we found that connecting a patient to the PPG-based chest patch device took 301.258.4 seconds (average SD) and when using the cuff-based ABPM device it took 1185.0172.3 seconds ($p < 0.01$, Table 2). We did not include the time it took the cuff-based device to dry after cleaning it before the next use, which was around 20 hours per device. Moreover, with the traditional cuff-based ABPM device, the time from data acquisition until a final report was generated took 3 weeks on average, while with the PPG-based platform it was completed and uploaded to the web application within 2 minutes (data not shown).

The direct cost of manpower per test, including interpretation by an expert physician, the work of a technician, and the work of a nurse, was cut by 24 USD when using the PPG-based device. Assuming a yearly rate of 4,500 tests, it results in savings of 108,000 USD per year, looking only at the direct manpower cost saving.

DISCUSSION

Wearable cuffless BP monitoring devices have emerged as a novel approach to continuously measure BP, rather than single snapshot clinic measures that are subject to substantial variability [30]. Moreover, long-term BP readings are increasingly recognized to better relate to cardiovascular outcomes than cross-sectional readings [31].

The PPG-based device used in this study was already shown to provide accurate measurements when compared with a traditional cuff-based ABPM device [27]. When comparing the PPG-based chest patch devices with the currently-used traditional cuff-based ABPM devices we found several advantages. The PPG-based device is simple to use and user friendly, and easy to train and operate. Moreover, the satisfaction rate of patients, nurses, and physicians was high. As studies show the importance of nighttime measurements and their relation to cardiovascular morbidity and mortality [32], and the novel device provides measurements every 15 minutes during the whole 24-hour period [33,34], this could be regarded as another advantage. The automatically-generated report potentially allows for increased efficiency in terms of labor and analysis costs, as instead of waiting for up to 3 weeks to receive the final expert report, the automatically-generated report is available within several minutes after completion of the 24-hour session. The fact that the sensor is disposable eliminates the need for patients to return to the clinics. This feature was found to be especially important during the COVID-19 pandemic. Today, clinics that have traditional ABPM devices can perform a limited number of studies per day, based on the number of devices they have and their timely return after completion of a session by the patients. However, this could dramatically change when using the disposable PPG-based chest patch device, as the time-to-connect is shorter, there is no dependency on returning a device by the previous user (i.e., no waiting list), no need to download the collected data, nor cleaning the device and preparing it for the next patient. As shown in our results, the time to complete the workflow when using the PPG-based devices is significantly reduced when compared with the cuff-based ABPM devices. All of these translate into a substantial reduction of time for both the nurses and the patients, reducing further the costs of completing the 24-hour assessment. The PPG-based device has ranked high in simplicity and comfort, potentially improving patients' compliance to complete the test. This is especially important as the rates of hypertension rise while the rates of

Table 2: Time to complete the various components with each device.

Cuff-based ABPM (n=4)	Time	PPG-based chest patch (n=6)	Time	P-value
Patient admission	262.5±118.42	Patient admission	50.83±24.98	
Explanation about the device	105±57.45	Explanation about the device	77.33±20.26	
Connecting device on patient	165±75.50	Assuring cellular compatibility & downloading the app	64.16±12.81	
Entering patient's data into the system	97.5±28.72	Entering data into the app	37.50±6.89	
Patient admission upon return	165±30	Calibration of first measurement	60.00±0.00	
Downloading data into the computer	75±30	Shaving and attaching the patch	11.33±10.23	
Washing the cuff and putting batteries in charger	315±30			
Total time in seconds (without drying)	1185.0±172.3	Total time in seconds	301.2±58.4	0.005

Time measurements are presented as mean±SD in seconds. Drying of the cuff took 20 hours, and was not included in this analysis. ABPM, ambulatory blood pressure monitoring.

patients' compliance decline [21]. By using a simple, wireless, and cuffless disposable device, healthcare systems could now provide a better adjusted and an earlier therapeutic intervention, changing the timeline of home ABPM tests to the timelines we are used to when we get laboratory blood tests. Moreover, since the device is not causing any stress or discomfort, it allows repeated ABPM assessments, helping not only with the diagnosis of HTN but potentially also with adjusting treatment in the long run. Such a device can also help with enhancing equal access to health care, as every person with the same health need can be given an equally effective chance of receiving the appropriate treatment.

Even though the currently-used cuff-based ABPM devices have helped with the diagnosis of HTN over the years, they still have several disadvantages leading to low compliance and adoption by patients [35], who need to be diagnosed or reassessed, as the repeated cuff inflation is in many cases painful, and disrupts the everyday routine, including sleeping time [36]; the cuff size should be well adjusted to the arm in order to avoid inaccuracies of BP measurements; the dependance on returning the device back on time for the next person to use it often results in a long waiting list that in most countries last for several weeks and months, delaying the diagnosis and proper treatment, as well as further reduction in compliance due to the need to return to the clinic; measurements are collected every 20-30 minutes, and when considering artifacts and misreading, this might result in a limited amount of data to provide accurate assessment of day-time and night-time averages; the whole process of connecting a patient, downloading the data and preparing the device for the next patient is considered a cumbersome and lengthy workflow for nurses; and they are costly [30], Unlike the ABPM test, the home and office BP monitoring (HBPM and OBPM, respectively) provide only few day time measurements.

Both modalities provide an infrequent snapshot of BP measurements during day-time only, missing the morning surge and any night-time measurements [30]. By that, they miss the night time measurements which is more linked with HTN-related cardiovascular morbidity. As both are based on cuff measurements, there is still the need to adjust the cuff size and it involves inconvenience and painful measurements, and regarded as tedious for patients. Patients must arrive to the clinic to have the OBPM test, and preferably – have it while they are alone in a silent room [37,38]. This takes time and reduces the compliance. HBPM relies on the compliance of patients to keep good and proper record of their measurements, perform the measurement properly, and assuring proper cuff size. HBPM devices' use is infrequent and associated with low acceptability [30]. On top of the previously-mentioned barriers to use, there are issues of not remembering to use it, and it is hard to position and use independently. All of these issues lead to underestimation of the real burden of HTN, and lack of proper assessment of treatment efficiency and success.

Cuffless BP devices provide automated out-of-office BP readings without any cuff disturbance or user awareness; measurements are taken more frequently, providing more data points for a better assessment of BP during the 24-hour session, and especially during the night; it is a disposable, single use device, potentially reducing or eliminating the waiting lists, and with no need to return it to the clinic after use; and as demonstrated in the current study, the nurses' workflow has been cut in more than a half when using this platform. This is expected to increase patients' compliance, as already being shown in the questionnaires performed within the current study. A recent study [30], explored patient attitudes towards the use of a cuffless device compared to classic methods. This included semi-structured audio-recorded interviews with participants, and discussed several points raised during the study, such as the finding that the classic 24-h monitoring was associated with low acceptability, annoyance, sleep disturbance and functional limitation. Conversely, participants reported high usability and comfort with the cuffless wearable device, similar to the findings in the current study, stating it was simple, practical, convenient, more comfortable, less intrusive, less bulky, did not impact lifestyle, did not affect sleep, and was easy to use.

The PPG-based device enabled direct manpower cost reduction of 24 USD per test, and a total of 108,000 USD per year. However, one should also consider other costs that will probably be also reduced, including mainly logistical components, as well as the elimination of waiting lists, and the fact that patients will not need to return the devices to the clinics. These parameters were not quantified in the current study and should be looked at in future assessments.

CONCLUSIONS

To conclude, we found the disposable PPG-based chest patch advantageous over the traditional cuff-based ABPM device, showing that it is well tolerated by patients, simple to use, and with the automatically-generated report could serve as the next generation of ABPM assessment. The substantial decrease in time required by the nurses is also of high importance, helping to ease the burden especially during this time, with increased burn-out of nursing staff all over the world. Moreover, the reduction in direct costs is also considered as an advantage, especially when the costs of health care keep rising. Further studies will look at the effect of the device on cost reduction beyond what we show here, as well as on treatment adherence, and clinical outcome.

Although the exact role of cuffless BP devices is yet to be recognized in clinical practice, patients already express unequivocal preference for such devices compared to legacy cuff-based devices.

LIMITATIONS OF THE STUDY

A major limitation of this study is the small number of participants, and despite the quite conclusive results, future studies will need to include larger numbers of participants in order to substantiate our findings. Another important aspect would be adding a clinical outcome end point, showing whether indeed compliance is higher, and whether the cuffless technology allows proper control of HTN, at least as good as what we curently show using the cuff-based devices.

AUTHOR CONTRIBUTIONS

Conceptualization, A.E. and E.C.; methodology, A.E. and E.C.; formal analysis, E.H., A.E. and E.C.; investigation, E.H., I.A., D.D., V.G., G.E., R.M. and E.C.; resources, A.E. and E.C.; data curation, E.H.,

A.E. and E.C.; writing—original draft preparation, E.H., A.E. and E.C.; writing—review and editing, all authors; visualization, A.E.; supervision, A.E. and E.C.; project administration, A.E.; funding acquisition, A.E., and E.C. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of the Meuhedet Health Services (MHS) (protocol code 2021-11-15, date of approval November 15, 2021).

Informed Consent Statement

Patient consent was waived as both devices are cleared for use by the Israel Ministry of Healthy for this indication.

Data Availability Statement

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

R.M. and A.E. are employees of Biobeat Technologies Ltd. The remaining authors declare no conflict of interest.

REFERENCES

1. Wierzejska E, Giernaś B, Lipiak A, Karasiewicz M, Cofta M, Staszewski R. A global perspective on the costs of hypertension: a systematic review. Arch Med Sci. 2020; 16: 1078-1091.
2. Vasan RS, Beiser A, Seshadri S, Larson MG, Kannel WB, D'Agostino RB, et al. Residual lifetime risk for developing hypertension in middle-aged women and men: The Framingham Heart Study. JAMA. 2002; 287: 1003-1010.
3. Whelton PK. The elusiveness of population-wide high blood pressure control. Annu Rev Public Health. 2015; 36: 109-130.
4. Pena-Hernandez C, Nugent K, Tuncel M. Twenty-Four-Hour Ambulatory Blood Pressure Moni-toring. J Prim Care Community Health. 2020; 11: 2150132720940519.
5. Stergiou GS, Palatini P, Parati G, O'Brien E, Januszewicz A, Lurbe E, et al. 2021 European Soci-ety of Hypertension practice guidelines for office and out-of-office blood pressure measurement. J Hypertens. 2021; 39: 1293-1302.
6. Stergiou GS, Alpert BS, Mieke S, Wang J, O'Brien E. Validation protocols for blood pressure measuring devices in the 21st century. J Clin Hypertens (Greenwich) 2018; 20: 1096-1099.
7. Krause T, Lovibond K, Caulfield M, McCormack T, Williams B, Guideline Development Group. Management of hypertension: summary of NICE guidance. BMJ. 2011; 343: d4891.
8. Grossman, E. Ambulatory blood pressure monitoring in the diagnosis and management of hyper-tension. Diabetes Care. 2013; 36: S307-S311.
9. Higashi Y, Nakagawa K, Kimura M, Noma K, Hara K, Sasaki S, et al. Circadian variation of blood pressure and endothelial function in patients with essential hypertension: a comparison of dip-pers and non-dippers. J Am Coll Cardiol. 2002; 40: 2039-2043.
10. Maio R, Perticone M, Sciacqua A, Tassone EJ, Naccarato P, Bagnato C, et al. Oxidative stress impairs endothelial function in nondipper hypertensive patients. Cardiovasc Ther. 2012; 30: 85-92.
11. Anstey DE, Muntner P, Bello NA, Pugliese DN, Yano Y, Kronish IM, et al. Diagnosing Masked Hypertension Using Ambulatory Blood Pressure Monitoring, Home Blood Pressure Monitoring, or Both? Hypertension. 2018; 72: 1200-1207.
12. Boffa RJ, Constanti M, Floyd CN, Wierzbicki AS, Guideline Committee. Hypertension in adults: summary of updated NICE guidance. BMJ. 2019; 367: l5310.
13. Aylett M, Marples G, Jones K. Home blood pressure monitoring: its effect on the management of hypertension in general practice. Br J Gen Pract. 1999; 49: 725-728.
14. Beevers G, Lip GY, O'Brien E. ABC of hypertension. Blood pressure measurement. Part I-sphygmomanometry: factors common to all techniques. BMJ. 2001; 322: 981-985.
15. Solá J, Proença M, Chételat O. Wearable PWV technologies to measure Blood Pressure: eliminat-ing brachial cuffs. Annu Int Conf IEEE Eng Med Biol Soc. 2013; 2013: 4098-40101.
16. Schoot TS, Weenk M, van de Belt TH, Engelen LJ, van Goor H, Bredie SJ. A New Cuffless De-vice for Measuring Blood Pressure: A Real-Life Validation Study. J Med Internet Res. 2016; 18: e85.
17. Ruzicka M, Akbari A, Bruketa E, Kayibanda JF, Baril C, Hiremath S. How Accurate Are Home Blood Pressure Devices in Use? A Cross-Sectional Study. PLoS One. 2016; 11: e0155677.
18. Shin J, Kario K, Chia YC, Turana Y, Chen CH, Buranakitjaroen P, et al. Current status of ambu-latory blood pressure monitoring in Asian countries: A report from the HOPE Asia Network. J Clin Hypertens (Greenwich). 2020; 22: 384-390.
19. Asayama K, Fujiwara T, Hoshide S, Ohkubo T, Kario K, Stergiou GS, et al. Nocturnal blood pressure measured by home devices: evidence and perspective for clinical application. J Hypertens. 2019; 37: 905–916.
20. Stergiou GS, Mukkamala R, Avolio A, Kyriakoulis KG, Mieke S, Murray A, et al., European So-ciety of Hypertension Working Group on Blood Pressure Monitoring and Cardiovascular Variability. Cuffless blood pressure measuring devices: review and statement by the European Society of Hyper-tension Working Group on Blood Pressure Monitoring and Cardiovascular Variability. J Hypertens. 2022; 40: 1449-1460.
21. Muntner P, Shimbo D, Carey RM, Charleston JB, Gaillard T, Misra S, et al. Measurement of Blood Pressure in Humans: A Scientific Statement From the American Heart Association. Hyperten-sion. 2019; 73: e35-e66.
22. Bard DM, Joseph JI, van Helmond N. Cuff-less methods for blood pressure telemonitoring. Front Cardiovasc Med. 2019; 6: 40.
23. Mukkamala R, Yavarimanesh M, Natarajan K, Hahn JO, Kyriakoulis KG, Avolio AP, et al. Eval-uation of the accuracy of cuffless blood pressure measurement devices: challenges and proposals. Hypertension. 2021; 78: 1161–1167.
24. Mukkamala R, Stergiou GS, Avolio AP. Cuffless blood pressure measurement. Annu Rev Biomed Eng. 2022; 24: 203-230.
25. Solá J, Delgado-Gonzalo R. Handbook of cuffless blood pressure monitoring: a practical guide for clinicians, Researchers, and Engineers. Book. 2019.
26. Nachman D, Gepner Y, Goldstein N, Kabakov E, Ishay AB, Littman R, et al. Comparing blood pressure measurements between a photoplethysmography-based and a standard cuff-based manom-etry device. Sci Rep. 2020; 10: 16116.
27. Nachman D, Gilan A, Goldstein N, Constantini K, Littman R, Eisenkraft, A, et al. 24-hour Am-bulatory Blood Pressure Measurement using a Novel Non-Invasive, Cuff-less, Wireless Device. Am J Hypertens. 2021; hpab095.

28. IEEE standard for wearable cuffless blood pressure measuring devices. IEEE Std 1708-2014. 2014: 1-38.

29. IEEE standard for wearable, cuffless blood pressure measuring devices- amendment 1. IEEE Std 1708a-2019. 2019: 1-35.

30. Gnanenthiran SR, Liu H, Tan I, Chan J, Schlaich MP, Schutte AE. Cuffless blood pressure de-vices: the gap between patient acceptability and need for validation. J Hypertens. 2022; 40: 2317-2319.

31. Chung SC, Pujades-Rodriguez M, Duyx B, Denaxas SC, Pasea L, Hingorani A, et al. Time spent at blood pressure target and the risk of death and cardiovascular diseases. PLoS One. 2018; 13: e0202359.

32. Yang WY, Melgarejo JD, Thijs L, Zhang ZY, Boggia J, Wei FF, et al., International Database on Ambulatory Blood Pressure in Relation to Cardiovascular Outcomes (IDACO) Investigators. Asso-ciation of Office and Ambulatory Blood Pressure With Mortality and Cardiovascular Outcomes. JAMA. 2019; 322: 409-420.

33. di Rienzo M, Grassi G, Pedotti A, Mancia G. Continuous vs intermittent blood pressure meas-urements in estimating 24-hour average blood pressure. Hypertension. 1983; 5: 264-269.

34. Mena LJ, Maestre GE, Hansen TW, Thijs L, Liu Y, Boggia J, et al., International Database on Ambulatory Blood Pressure in Relation to Cardiovascular Outcomes (IDACO) Investigators. How many measurements are needed to estimate blood pressure variability without loss of prognostic in-formation? Am J Hypertens. 2014; 27: 46-55.

35. Atzenhoefer M, Mangan Mary J, Moreno Ana Cristina P, Dalmar A, Nfor T, Allaqaband S, et al. Secular trend of ambulatory blood pressure monitoring use at St. Luke's Medical Center. J Am Coll Cardiol. 2020; 75: 1888–11888.

36. Unger T, Borghi C, Charchar F, Khan NA, Poulter NR, Prabhakaran D, et al. 2020 International Society of Hypertension Global Hypertension Practice Guidelines. Hypertension. 2020; 75: 1334-1357.

37. Stergiou G, Kollias A, Parati G, O'Brien E. Office Blood Pressure Measurement: The Weak Cornerstone of Hypertension Diagnosis. Hypertension. 2018b; 71: 813-815.

38. Asayama K, Ohkubo T, Imai Y. In-office and out-of-office blood pressure measurement. J Hum Hy-pertens. 2021; Mar 30: 1-9.