Interpretation of the 2024 International Society of Hypertension Position Paper on Technological Innovations in Blood Pressure Measurement and Reporting and Its Implications for China (Post-print)

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Abstract

Hypertension represents the leading modifiable risk factor for cardiovascular disease morbidity and mortality, and accurate blood pressure measurement is a critical factor in hypertension management. Conventional blood pressure measurement suffers from limitations including intermittency, static nature, and inability to capture readings during daily activities. While innovative blood pressure measurement technologies are rapidly being integrated into clinical practice, these technologies lack international consensus regarding validation of their accuracy, usability, acceptability, and reliability. Accordingly, this article convened relevant experts to interpret the latest "International Society of Hypertension Position Paper: Technological Innovations in Blood Pressure Measurement and Reporting", aiming to provide reference for community-based hypertension prevention and control in China.

Full Text

Interpretation of the 2024 International Society of Hypertension Position Paper on Innovations in Blood Pressure Measurement and Reporting Technology and Its Implications for China

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Abstract

Hypertension is the leading modifiable risk factor for cardiovascular disease morbidity and mortality, and accurate blood pressure measurement is a cornerstone of its management. Conventional blood pressure monitoring is limited by its intermittent and static nature, and its inability to capture readings during daily activities. Emerging blood pressure measurement technologies are rapidly being integrated into clinical practice; however, their adoption is hindered by the lack of international consensus regarding validation criteria for accuracy, usability, acceptability, and reliability. In response, this article convenes expert interpretation of the latest International Society of Hypertension Position Paper on Innovations in Blood Pressure Measurement and Reporting Technology, aiming to inform evidence-based recommendations for community-based hypertension prevention and control strategies in China.

Key words: Hypertension; Cardiovascular diseases; Blood pressure measurement technologies; Digital intervention; Guidelines interpretation

1. Background of the Position Paper

Cardiovascular disease is the leading cause of death and disease burden worldwide. Between 2009 and 2019, the number of people living with cardiovascular disease increased to 523 million, with steadily rising prevalence and disability-adjusted life years [1]. The *Chinese Guidelines for the Prevention and Treatment of Hypertension (2024 Revision)* [2] identifies hypertension as the primary modifiable risk factor for cardiovascular disease morbidity and mortality, emphasizing that accurate blood pressure measurement is critical for effective management.

Current guidelines rely on office, ambulatory, and home blood pressure readings, all of which are based on intermittent upper-arm cuff measurements taken under resting conditions. Although ambulatory monitoring provides more readings and information, the data remain limited and are subject to measurement errors from improper cuff positioning, cuff tightness, involuntary arm movements, and severe vascular stiffening [3-5]. These limitations underscore the need for new technologies that can measure blood pressure more precisely and provide continuous monitoring data.

China' s *14th Five-Year Plan for National Health* emphasizes the application of digital medical equipment in chronic disease management, calling for the development of low-cost, high-precision blood pressure measurement tools suitable for primary care settings, and promoting AI-assisted blood pressure data analysis to enhance abnormal value detection capabilities [6]. However, despite rapid advances in artificial intelligence and big data technologies, the swift emergence of new technologies presents both opportunities and challenges. In 2024, the International Society of Hypertension convened hypertension experts from 11 countries to develop the *Position Paper on Innovations in Blood Pressure Measurement and Reporting Technology* [7] (hereinafter referred to as the "Position Paper"), which aims to promote the standardized, safe, and reliable clinical application of new blood pressure measurement technologies. Currently, China lacks relevant consensus statements. Therefore, this article brings together experts in cardiology, information technology, general practice, emergency medicine, and evidence-based medicine to interpret this Position Paper, integrating cutting-edge developments in blood pressure measurement technology with the practical needs of China's primary care system to provide evidence-based decision-making references that are scientifically sound, operationally feasible, and cost-effective.

2. Blood Pressure Measurement Technology/Devices

2.1 Traditional Cuff-Based Blood Pressure Monitoring Technology

The core principle of traditional upper-arm cuff-based blood pressure measurement is the Korotkoff sounds method, discovered by Russian scholar Nikolai Korotkov in 1905. This technique involves wrapping a cuff around the upper arm, compressing the brachial artery, and then slowly releasing pressure while listening with a stethoscope for the characteristic friction and impact sounds synchronized with the pulse that indicate blood flow restoration [8]. These sounds originate from periodic turbulent vibrations of the arterial wall and directly reflect hemodynamic status. Although considered the gold standard, the Korotkoff method has subjective dependencies and limitations in patients with arrhythmias or vascular stiffening. Consequently, traditional mercury sphygmomanometers have been gradually replaced by electronic devices, though calibration of these instruments still relies on the Korotkoff method as the reference standard.

Currently, the oscillometric method is the core principle used in most clinical electronic blood pressure monitors. This approach involves inflating a cuff to

occlude brachial artery flow, then slowly deflating it while using high-precision pressure sensors to capture minute periodic pressure fluctuations caused by arterial pulsations. Specific algorithms then analyze these oscillometric signals to calculate blood pressure values [9]. However, these devices face clinical challenges including validation and calibration issues, limitations of both auscultatory and oscillometric methods, improper cuff sizing, and the lack of continuous data [10-12]. Therefore, noninvasive technologies that can seamlessly integrate into daily life are needed to enable better blood pressure management and more precise interventions, particularly given China' s large population and rapid aging trends. Table 1 summarizes these new technologies, which are detailed below.

2.2 Novel Blood Pressure Monitoring Technologies

2.2.1 Cuff-Based Blood Pressure Monitoring Technologies Cuff-Based Wrist-Worn Blood Pressure Monitors: Current wrist-worn cuff-based blood pressure monitors primarily use the oscillometric method, enhanced with sensor technology and algorithm optimization for convenient monitoring. The Position Paper mentions two such devices: the Omron HEM-9601T1 and a wrist blood pressure monitor from Huawei. These devices are particularly suitable for nocturnal blood pressure measurement with minimal sleep disturbance. One study of 50 patients demonstrated good agreement between upper-arm (Omron HEM-9700T) and wrist-worn (Omron HEM-9601T) devices, with a mean systolic blood pressure difference of only 0.2 $\pm$ 10.2 mmHg across 694 paired measurements over two nights [13]. Another Chinese study validated the accuracy of the HUAWEI WATCH for blood pressure monitoring in 85 patients, showing high consistency with mercury sphygmomanometer readings [14]. Regarding sleep disturbance, research presented at the 33rd European Hypertension Conference indicated that 90% of patients showed no electroencephalographic evidence of awakening during measurements with the Omron HEM-9601T [15]. However, wrist-worn devices remain susceptible to measurement errors from nocturnal arm movements and hydrostatic height differences between the wrist and heart level [16].

Finger-Cuff Blood Pressure Monitors Based on Vascular Unloading Technology: The vascular unloading technique, also known as the volume-clamp method, is a noninvasive approach that dynamically regulates external pressure to maintain constant arterial volume for indirect blood pressure measurement. First proposed by Czech physiologist Jan Penáz in 1973 and later improved by Wesseling et al. for the Finapres finger-cuff device in the 1980s, this technology became a milestone in continuous noninvasive blood pressure monitoring [17-19]. It works by adjusting finger-cuff pressure to maintain finger arteries at a constant volume, achieving zero transmural pressure where intra-arterial and extra-arterial pressures are equal [20]. Previous studies have validated the Continuous Non-invasive Arterial Pressure (CNAP) system based on this technology for use in emergency departments, demonstrating its ability

to more sensitively detect hypotensive events compared to intermittent oscillometric measurements while maintaining consistency with standard methods [21]. This technology is suitable for situations with rapid blood pressure changes but is not appropriate for precise blood pressure level assessment or hypertension diagnosis due to its high sensitivity to motion artifacts.

2.2.2 Cuffless Blood Pressure Monitoring Technologies Many wearable devices now use cuffless blood pressure monitoring technologies that generate readings without inflatable cuffs. These devices employ one or more combined techniques including photoplethysmography (PPG), pulse transit time (PTT), pulse arrival time (PAT), arterial tonometry, electrocardiography, ballistocardiography, impedance plethysmography, seismocardiography, and ultrasound, often requiring individual user calibration combined with artificial intelligence and machine learning [22-25].

Cuffless Wrist-Worn Blood Pressure Monitors: These devices estimate blood pressure by monitoring the correlation between pulse wave conduction characteristics and blood pressure, primarily through PTT, PAT, and multimodal signal fusion algorithms. Pulse waves are pressure waves generated when blood ejected during cardiac contraction impacts arterial walls. Their conduction velocity is directly related to vascular elasticity and blood pressure—when blood pressure increases, arterial wall tension increases, pulse wave velocity accelerates, and PTT shortens, with the reverse occurring when blood pressure decreases. PAT represents the time difference between the R-wave peak on an electrocardiogram and pulse wave arrival at a peripheral site. Precise measurement of PTT/PAT combined with algorithm optimization enables blood pressure estimation based on pulse wave analysis [26]. Pulse wave signals can be obtained through PPG and ultrasound technologies. The Position Paper mentions the Aktiia bracelet, Samsung Galaxy Watch, and Huawei Watch D as examples using this technology. However, cuffless wrist-worn devices still face challenges regarding calibration frequency, measurement accuracy, and systematic bias, though large cohort studies have begun using this technology [27,28].

Smart Rings: Smart rings measure blood pressure using PPG, an optical-based noninvasive physiological parameter detection technology that captures dynamic cardiovascular information by measuring blood volume changes. PPG works by illuminating the skin with LED light of specific wavelengths and detecting intensity changes in reflected or transmitted light. Since hemoglobin absorbs different wavelengths differently, periodic blood volume changes from cardiac pulsation alter light absorption, generating PPG signals containing both pulsatile and static components [26,29]. A 2024 prospective, single-arm, first-in-human trial evaluating smart ring accuracy found strong correlations with reference systolic ($r=0.94$, $P<0.001$) and diastolic ($r=0.95$, $P<0.001$) blood pressure measurements [27]. However, these devices rely on calibration with traditional cuff-based equipment, potentially introducing systematic errors, and the validation protocol did not follow the latest ESH guidelines specifically designed for

cuffless devices.

Smartphone-Based PPG Blood Pressure Monitoring: Smartphones can also acquire PPG signals for pulse wave analysis, typically using the LED flash adjacent to the camera. When a finger covers both the camera and flash, the device monitors reflected light changes to form a PPG waveform [30]. The OptiBP application described in the Position Paper uses this method, analyzing blood volume changes from light penetrating the fingertip, reflecting off tissues, and reaching the smartphone' s image sensor. Studies comparing OptiBP measurements with auscultatory reference values demonstrated accurate blood pressure measurement using this finger-based approach [31]. Similar applications have been launched in China, such as JD Health' s "mobile phone blood pressure measurement" and HealthSnap' s "contactless blood pressure measurement," which obtain PPG signals from fingers or facial measurements to derive blood pressure values. However, validation studies were conducted with participants seated and smartphones positioned at left ventricular level, without assessing the stability of calibration parameters over time [32]. Additionally, blood pressure measurements from facial PPG appear to have significant systematic errors [32].

Smartphone-Based Finger Oscillometry: Smartphone applications using finger oscillometry are under development, where users press a smartphone sensor (typically the camera area) to gradually compress the palmar arch artery with their finger. Built-in pressure sensors monitor applied finger pressure while optical sensors capture blood volume oscillation signals from arterial compression. When the artery is fully compressed, blood flow stops; as pressure gradually decreases, flow resumes and generates oscillatory waves. Machine learning models analyze oscillation amplitude characteristics across pressure changes to estimate systolic and diastolic blood pressure [33]. Research shows this method achieves accuracy within $±$3.3 mmHg for systolic and $±$5.6 mmHg for diastolic pressure compared to standard cuff devices, approaching the precision of finger-cuff oscillometry [33].

Ultrasound-Based Blood Pressure Monitoring: This technology measures blood pressure based on the Doppler effect and hemodynamic analysis, capturing blood flow signals noninvasively and converting them into blood pressure parameters through quantitative measurement of vascular diameter changes. The Position Paper notes its primary value lies in broad technical availability and the ability to assess other vascular functional or structural parameters. However, this field remains underdeveloped due to limited convenience compared to other cuffless technologies and lack of significant advantages over existing mature, portable cuff-based devices [34].

Continuous Blood Pressure Monitoring Technology: Continuous monitoring is defined as blood pressure readings output at intervals of $ $30 seconds, while intermittent monitoring uses intervals >30 seconds. Noninvasive continuous methods include tonometry, volume-clamp methods, and pulse wave analysis. These technologies are primarily relevant for situations with rapid blood

pressure changes, such as intensive care and anesthesia, and can also monitor rapid blood pressure fluctuations during sleep in patients with sleep apnea. However, daily life applications face challenges of low usability, patient discomfort, and calibration frequency requirements [35].

Blood Pressure Monitors with Specific Functions: Another innovation involves integrating additional functions beyond blood pressure measurement. Multi-sensor devices can simultaneously provide physiological, physical, or environmental data such as oxygen saturation, body temperature, ambient humidity, and atmospheric pressure. Furthermore, some automated nocturnal home blood pressure monitors can activate at preset times to enable unobtrusive nighttime blood pressure monitoring during sleep [36-38].

2.3 Validation of Novel Blood Pressure Monitoring Devices In 2018, the Association for the Advancement of Medical Instrumentation (AAMI), the European Society of Hypertension (ESH), and the International Organization for Standardization (ISO) jointly developed the universal AAMI-ESH-ISO standard (ISO 81060-2:2018) for validating automated cuff-based blood pressure measurement devices [39]. This standard applies only to automated cuff devices and not to cuffless technologies. However, the Institute of Electrical and Electronics Engineers (IEEE 2014), ISO (ISO 81060-3:2022), and the ESH Working Group on Blood Pressure Monitoring and Cardiovascular Variability have developed specialized validation protocols for cuffless devices. Currently, China has not issued national validation protocols or standards specifically for cuffless blood pressure devices. The *Chinese Expert Consensus on the Application of Smart Wearable Devices in Blood Pressure Management for Young and Middle-aged Adults* [40] recommends using smart wearable devices validated through international standards, and domestic enterprises must obtain medical device registration certification from the National Medical Products Administration (e.g., Class II medical devices) while meeting industry standards such as *Medical Electrical Equipment - Part 2-30: Particular Requirements for the Basic Safety and Essential Performance of Automated Non-invasive Sphygmomanometers* (YY 9706.230-2023), which require accuracy (error $ 5±$8 mmHg) and clinical safety. Table 2 presents validation protocols for novel cuffless blood pressure monitoring devices.

2.4 Reliability and Practicality of Novel Blood Pressure Monitoring Devices The market for novel blood pressure monitoring devices is growing rapidly. For any new device to serve clinical decision-making, it must meet three core criteria: accuracy, usability/acceptability, and reliability. Regarding accuracy, new devices must demonstrate equivalence to traditional cuff-based devices and validate derived metrics such as blood pressure variability, morning surge, and nocturnal dipping patterns, even in healthy monitoring populations. For usability and acceptability, human factors engineering principles must be applied to identify and reduce predictable operational errors [44], and acceptance among users and healthcare professionals must be validated, particularly since

the clinical value of parameters like blood pressure variability and morning surge remains uncertain. For reliability, reproducibility of continuous measurements over weeks to months is essential to assess long-term blood pressure fluctuations.

Existing studies show mixed results: some report significant differences between novel cuffless devices and traditional equipment [28,45-47], while others demonstrate acceptable agreement [48-50]. These discrepancies likely stem from methodological differences (e.g., sample sizes), insufficient ability of devices to track 24-hour blood pressure changes, and individual blood pressure variability. The Position Paper emphasizes that current regulatory oversight for these devices focuses primarily on safety rather than rigorous validation of clinical accuracy, necessitating multidisciplinary collaboration during device design and establishing cooperative mechanisms among regulators, scientists, manufacturers, and clinicians to unify validation concepts and protocols [51].

3. Benefits and Challenges of Novel Blood Pressure Monitoring Technologies

3.1 Benefits Novel blood pressure monitoring technologies, through wearable or cuffless devices, reduce data errors caused by cuff positioning and tightness. Techniques such as PTT, PAT, and PPG enable more accurate blood pressure measurement in individuals with large arm circumference, atrial fibrillation, and extreme blood pressure values. By acquiring multiple physiological signals, these technologies provide more comprehensive health assessments. Continuous monitoring with minimal user perception also yields more extensive blood pressure data. Overall, novel technologies offer potential benefits including overcoming limitations of traditional cuff methods, improving accuracy in special populations, enhancing nocturnal blood pressure monitoring, and providing more comprehensive data to inform community hypertension management and advance understanding of cardiovascular physiology and disease mechanisms.

3.2 Challenges The Position Paper enumerates current challenges for clinical application of novel blood pressure monitoring devices (Table 3). Before large-scale community implementation, these devices require randomized controlled trials to provide evidence of accuracy, usability, acceptability, and reliability. In China, clinical application of novel blood pressure measurement devices faces the challenges listed in Table 3. Future efforts must integrate comprehensive validation systems, tiered promotion strategies, enhanced physician-patient training, increased government funding support, and public-private partnerships to promote scientific dissemination and standardized application of novel devices.

4. Digital Interventions

Digital interventions involve applying digital technologies to achieve specific health goals. According to the 2023 Italian Society of Hypertension Position Paper, digital technologies include three categories: (1) mobile applications, smartphones, tablets, and advanced wearable devices; (2) medical technologies

including telemedicine platforms and instruments enabling clinical data sharing between patients and physicians; and (3) innovative medical devices with high-quality hardware and software capable of integrated analysis of large datasets [52]. Novel blood pressure monitoring technologies primarily fall into the first category. The Position Paper summarizes research evidence on digital interventions based on novel blood pressure monitoring technologies and identifies their transformative potential and associated challenges.

4.1 Research Evidence on Novel Blood Pressure Monitoring Technologies Novel blood pressure monitoring technologies can acquire and integrate multiple physiological signals, providing added value for risk assessment and treatment monitoring. A 2023 study used a wireless, wearable, noninvasive reflective PPG chest patch monitor to conduct high-frequency intermittent monitoring in 521 participants, collecting physiological parameters every five minutes including heart rate, oxygen saturation, respiratory rate, cuffless blood pressure, body temperature, and cardiac output. Based on these parameters, an expert panel developed a Multi-Parameter Real-Time Warning Score (MPRT-WS) for early detection of patient deterioration. Compared with the widely used National Early Warning Score (NEWS), MPRT-WS issued "high-risk" or "urgent" alerts 42.7 ± 49.1 hours earlier in 39 deteriorating patients, while NEWS identified only six high-risk cases [53]. Another study analyzing wearable PAT found that overnight mean normalized PAT correlated with arterial stiffness parameters at r=0.91, significantly higher than nocturnal blood pressure [54]. Research also suggests nocturnal pulse wave surges may be associated with left ventricular hypertrophy [35], and novel devices show advantages in diverse scenarios including heart failure patients, psychological stress, high-altitude environments, and acute stress situations [7].

The Position Paper highlights the advantages of novel blood pressure monitoring technologies for nocturnal home blood pressure monitoring. Automated timed home blood pressure monitoring (HBPM) is currently the only emerging technology validated through large-scale cross-sectional and longitudinal clinical studies. Research demonstrates that obtaining at least six nocturnal blood pressure readings using dedicated home blood pressure monitors correlates with subclinical organ damage and cardiovascular event risk at least as strongly as ambulatory blood pressure monitoring, independent of office and morning/evening home blood pressure [7]. In 2019, a Japanese research team published evidence from 2,545 participants showing that each 10 mmHg increase in nocturnal systolic blood pressure measured by HBPM at 2:00, 3:00, and 4:00 AM was associated with a 20.1% increase in cardiovascular event risk [55].

4.2 Impact of Digital Interventions Based on Novel Blood Pressure Monitoring Technologies on Healthcare Services Digital interventions can overcome healthcare access barriers in resource-limited regions while optimizing service efficiency, improving self-efficacy and adherence among hypertensive patients, and reducing healthcare costs, particularly for resistant hyper-

tension and high-risk populations. Integrating novel blood pressure monitoring technologies has the potential to enable hypertension and cardiovascular disease risk prediction, optimize personalized treatment pathways, and empower primary care. Figure 1 [Figure 1: see original paper] outlines digital interventions and technologies for hypertension management. However, implementation faces obstacles including the digital divide, socio-cultural barriers, and regional disparities, necessitating attention to localized adaptation [56-59].

In November 2017, the National Health Commission explicitly designated primary care institutions as the first line of defense in hypertension management [60,61]. By 2022, primary care facilities nationwide managed over 100 million hypertensive patients. The challenge lies in how to standardize, efficiently, and precisely manage these patients, achieve cardiovascular disease early warning, and reduce disease burden—areas where traditional primary care faces difficulties. Although novel blood pressure monitoring technologies have not yet been formally adopted by clinical experts, they have the potential to transform current hypertension prevention and control models. First, devices such as smart rings and wrist-worn monitors can simplify operational procedures, and continuous monitoring can improve detection rates of masked hypertension. Second, rapid development of internet information technology enables direct upload of blood pressure data and other real-time physiological signals to primary care public health platforms, facilitating remote monitoring and medication adjustment, automatic identification of abnormal signals with alerts to physicians, improved patient adherence, and optimized long-term management. Third, early intervention and timely complication management can reduce expenditure, and some novel technologies are low-cost, making them particularly suitable for financially constrained township health centers. Finally, general practitioners can individualize treatment plans based on blood pressure trends and other physiological signals while reducing human operation errors and improving data reliability. However, integrating novel blood pressure monitoring technologies into clinical decision-making faces numerous challenges requiring collaborative efforts from regulators, scientists, clinicians, and commercial companies to achieve full-chain digitalization of "screening-diagnosis-management-intervention" at the primary care level, ultimately contributing to the "Healthy China 2030" goals.

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