Interpretation of the 2024 Expert Consensus on Arterial Pressure, Structure, and Function Assessment (Post-print)

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Abstract

Assessment of arterial pressure, structure, and function constitutes an important component of cardiovascular health management. In recent years, various non-invasive evaluation techniques have been applied in clinical practice; however, the usage details, advantages, and limitations of these technologies remain unclear. In view of this, an international expert panel in the cardiovascular field formulated the Expert Consensus on Assessment of Arterial Pressure, Structure, and Function in September 2024, which respectively examined the most commonly employed techniques in arterial assessment, with particular emphasis on elaborating the reference values for each category of technology and their application value in clinical practice. This article provides an interpretation of this consensus, aiming to organize and propose arterial evaluation methods adapted to China' s current stage, thereby offering clinical recommendations for comprehensive cardiovascular health management in China.

Full Text

Interpretation of the 2024 Expert Consensus on Blood Pressure Measurement and Assessment of Arterial Structure and Function

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Abstract Assessment of arterial pressure, structure, and function forms an essential part of cardiovascular health management. In recent years, multiple non-invasive assessment techniques have been adopted in clinical practice; however, specific implementation details, advantages, and limitations of these techniques remain unclear. To address this, an international panel of cardiovascular experts developed the Expert Consensus on Assessment of Arterial Pressure, Structure, and Function in September 2024. This consensus reviews the most widely utilized arterial assessment techniques, detailing reference ranges for each method and their clinical utility. This article provides an interpretive analysis of the consensus document, aiming to synthesize and propose arterial evaluation approaches suitable for China' s current healthcare landscape. The objective is to deliver clinical recommendations for comprehensive cardiovascular health management in China.

Keywords Cardiovascular diseases; Arterial pressure; Arterial structure; Arterial function; Expert consensus; Interpretation

Cardiovascular disease remains the leading cause of death globally, with health assessment and prevention representing the most cost-effective management strategies [1]. Assessment of arterial pressure, structure, and function is fundamental for predicting cardiovascular events and managing cardiovascular health [2]. However, existing arterial pressure measurement methods have various limitations, and improper measurement settings or timing may lead to missed or erroneous diagnoses [3]. Furthermore, techniques for evaluating arterial structure and function lack standardization, such as ankle-brachial index, cardio-ankle vascular index (CAVI), and intima-media thickness [4-7]. To clarify the application conditions and limitations of these technologies, the Expert Consensus on Blood Pressure Measurement and Assessment of Arterial Structure and Function (hereinafter referred to as "the Consensus") was published in the *Journal of Hypertension* on September 9, 2024. This consensus integrates the latest evidence to define appropriate scenarios for arterial pressure measurement and standardize methods for assessing arterial structure and function, with particular emphasis on their advantages, limitations, indications, normal values, and practical clinical applications to enhance the precision of cardiovascular health evaluation and risk prediction. Currently, China lacks corresponding guidelines or consensus systematically addressing the standardization and application scenarios of arterial pressure, structure, and function assessment. Given the Consensus' s important role in standardizing arterial evaluation in China, our research team has conducted this interpretation for peer reference. Our team comprises clinical cardiologists, general practitioners specializing in cardiovascular medicine, evidence-based methodology experts, and guideline development methodology specialists, with no conflicts of interest with the original consensus development team.

1 Main Content of the Consensus: Arterial Pressure Assessment

1.1 Office Blood Pressure, Home Blood Pressure Monitoring, and Ambulatory Blood Pressure Monitoring

Office blood pressure measurement is the most commonly used method for screening, diagnosing, treating, and following up patients with hypertension, with the most extensive research and evidence base. Hypertension classification, treatment initiation thresholds, and therapeutic targets are all based on this approach [2-3,8-10]. However, reliance on office blood pressure alone often leads to "white coat hypertension" and "masked hypertension," and errors are common when using manual auscultatory devices [2-3,8-11], resulting in overtreatment or undertreatment of hypertension. Office measurement methods include manual auscultation, electronic sphygmomanometers, and unattended automated office blood pressure measurement. Office blood pressure measurement has important limitations because values obtained in specific clinical settings differ significantly from real-life conditions. Additionally, office blood pressure cannot identify blood pressure variations occurring outside the clinic during wakefulness or sleep [3]. Unattended automated office blood pressure refers to self-measurement by patients in a room without staff present [3], with results typically lower than traditional measurements (approaching daytime ambulatory blood pressure), reducing but not eliminating white coat and masked hypertension phenomena; however, the threshold for defining office hypertension remains unclear [2-3,8]. Moreover, unattended automated office blood pressure measurement is not feasible in many clinical settings. In addition to seated measurements, patients with hypertension should also have standing blood pressure measured when orthostatic hypotension symptoms occur, particularly in elderly individuals and those with neurodegenerative diseases (such as Parkinson' s disease or dementia) or diabetes [2].

Compared with office blood pressure measurement, out-of-office blood pressure measurement better captures individuals' true blood pressure status during daily activities, including 24-hour ambulatory blood pressure monitoring [12] or home blood pressure monitoring [13]. Home blood pressure monitoring or 24-hour ambulatory blood pressure monitoring demonstrates stronger reproducibility, with values more strongly correlated with hypertension-mediated organ damage and better predictive of cardiovascular events and mortality [2-3]. Combined use of these methods can diagnose white coat hypertension and masked hypertension. Twenty-four-hour ambulatory blood pressure monitoring can identify nocturnal hypertension, daytime hypertension, and abnormal blood pressure variability, with a recommended repeat interval of at least 2-3 months, or 1 year for those with stable blood pressure [2-3,12].

1.2 Central Arterial Blood Pressure

Due to the structural and functional properties of arterial vessels, pressure pulses generated by left ventricular ejection in the proximal aorta typically increase in amplitude as they propagate peripherally. Invasive measurements have revealed that central and peripheral arterial diastolic pressures are nearly identical, so waveform changes are primarily related to differences between central and peripheral systolic pressure [14-15], with a difference ranging from 0-30 mmHg (1 mmHg = 0.133 kPa) and an average difference of 12 mmHg [14]. In clinical settings, central arterial blood pressure is usually estimated using pulse wave velocity and waveform morphology.

Current blood pressure-lowering strategies are based on office measurement of brachial artery blood pressure, which can reduce cardiovascular risk but cannot completely reverse the risk of hypertension-related morbid events [2]. Assessing only brachial artery blood pressure without considering the impact of central blood pressure on cardiovascular events may lead to overtreatment or undertreatment. Numerous studies have focused on central arterial pressure as a stronger predictor of hypertension-related end-organ damage, cardiovascular events, and cardiovascular mortality. Central arterial pressure-based antihypertensive therapy may represent a future direction for antihypertensive strategies requiring investigation. However, due to inconsistent diagnostic and prognostic data and lack of clear cutoff values to distinguish normal from high central arterial pressure in broader populations, central arterial pressure measurement is not recommended as a fundamental indicator for hypertension clinical management. Current clinical applications target young patients with isolated systolic hypertension, where peripheral blood pressure is disproportionately elevated compared to central blood pressure [2]. On the other hand, central arterial pressure and other parameters, such as augmentation index and wave reflection index, are used in research to describe the pathophysiological mechanisms of many diseases and related therapeutic approaches. Therefore, central arterial pressure measurement is currently essentially limited to clinical research and specialized centers.

2 Arterial Structure Assessment

2.1 Carotid Artery Intima-Media Thickness (CIMT) and Plaques

CIMT can be quantified through carotid ultrasound. The 2023 European Society of Hypertension (ESH) guidelines state that increased CIMT at the carotid bifurcation can be considered a marker of early-stage atherosclerosis [3]. CIMT predicts cardiovascular disease risk, with CIMT $>$ 0.9 mm considered abnormal; CIMT $>$ 1.5 mm, local thickness increase of 0.5 mm, or local thickness increase exceeding 50% of surrounding levels suggests carotid plaque [3]. The 2021 European Society of Cardiology (ESC) clinical practice guidelines for cardiovascular disease prevention state that due to lack of methodological standardization and lack of added predictive value for cardiovascular disease, intima-media thickness is not recommended for risk assessment [16]. Compared with CIMT, carotid plaque has greater prognostic significance for cardiovascular events. The 2018 and 2023 ESH guidelines recommend carotid ultrasound for patients with carotid bruits, prior transient ischemic attack history, cerebrovascular disease, or evidence of other vascular diseases to screen for severe carotid stenosis and asymptomatic plaque or stenosis in patients with confirmed vascular disease in other locations [2].

2.2 Retinal Microcirculation

The eye provides an ideal window for observing microvascular changes in the pathophysiology and treatment of cardiovascular and metabolic diseases. Retinal vessel assessment primarily involves funduscopic examination in patients with risk factors such as diabetes or hypertension. Fundoscopy can detect hemorrhages, microaneurysms, exudates, and cotton wool spots (grade 3), as well as papilledema or macular edema (grade 4); these changes are reproducible and predictive of mortality. Grade 1 and 2 lesions such as arteriolar narrowing or arteriovenous nicking have lower reproducibility and predictive value. Retinal microcirculation examination is an excellent marker and prognostic tool for hypertension and other cardiovascular and metabolic diseases, applicable to large-scale population cohort studies or clinical trials evaluating the impact of pharmacological or nutritional interventions on cardiometabolic diseases.

3 Arterial Function Assessment

3.1 Blood Pressure Variability

Research shows that blood pressure variability includes short-term variations within 24 hours (via 24-hour ambulatory blood pressure monitoring) [17], medium-term fluctuations from home blood pressure measurements (self-monitored home blood pressure), or long-term variability from office blood pressure changes. Increased blood pressure variability may predict the development, progression, and severity of cardiac, vascular, and renal organ damage, as well as cardiovascular events and mortality [18-19]. Blood pressure variability indicators include frequency, dispersion, sequence, and instability. However, which blood pressure variability methods, parameters, and indicators are most effective and reproducible for risk prediction remains controversial, and there is no consensus on whether blood pressure variability should be incorporated into clinical practice [13,20-21]. Currently, this is limited to research and specialized hypertension centers but can be used for evaluating patients with specific characteristics.

3.2 Ankle-Brachial Index

The ankle-brachial index is the ratio of systolic blood pressure measured at the ankle to that measured at the brachial artery. Ankle-brachial index measurement is simple, non-invasive, time-efficient, and low-cost; it is used for diagnosis and monitoring of lower extremity artery disease (LEAD) and for assessing systemic atherosclerosis progression and cardiovascular risk [22-24].

Ankle-brachial index measurement is indicated for patients with clinical suspicion of LEAD and asymptomatic patients at risk for LEAD. LEAD should be suspected in patients with LEAD symptoms (intermittent claudication), other symptoms (rest/exercise lower limb ischemia), non-healing lower limb wounds, or signs suggestive of LEAD (absent pulses, arterial bruits). Asymptomatic patients at risk for LEAD include those with cardiovascular disease or other atherosclerosis, age > 65 years, high cardiovascular risk, diabetes, chronic kidney disease, heart failure, or aortic aneurysm. An ankle-brachial index ≤ 0.90 diagnoses LEAD, while an index > 1.40 indicates increased arterial stiffness. An ankle-brachial index < 0.90 or > 1.40 is an independent predictor of other cardiovascular risks and mortality.

3.3 Pulse Wave Velocity (PWV)

PWV is the speed at which a wave (pressure) propagates along an arterial segment. Currently, multiple devices can calculate PWV at a single measurement point using arterial pulse wave analysis [25]. Arterial wall properties vary considerably from the aortic root to smaller peripheral arteries, and PWV including the aortic segment is a strong predictor of cardiovascular risk. Increased carotid-femoral pulse wave velocity (cfPWV) and brachial-ankle arterial segment (baPWV) are independent risk factors for cardiovascular disease [26-27].

Following the publication of the arterial stiffness consensus, Western countries have adopted cfPWV as the gold standard for assessing arterial stiffness [28]. cfPWV research has been conducted primarily in Western countries, using simultaneous (Complior device) or sequential (SphygmoCor CVMS device) application of sensors at the carotid and femoral arteries, with operators recording pulse pressure. However, high-quality pulse pressure recordings require substantial operator expertise, thus limiting widespread clinical application. Asian countries preferentially use baPWV. Studies have found that in patients without peripheral artery disease, baPWV is associated with premature aging and cardiovascular risk [27]. baPWV may slightly diminish the aortic contribution to PWV values, but its advantage lies in greatly simplified measurement procedures. Moreover, measurement devices can typically also measure ankle-brachial index to assess peripheral artery disease, providing a two-in-one examination, such as the Omron VP1000 and MESI mTABLET ABI systems.

Increased PWV occurs in the early stages of hypertension, with arterial stiffness increasing before hypertension development. Furthermore, compared with traditional risk-based scores, cfPWV or baPWV can more accurately classify cardiovascular risk, an advantage particularly significant for young patients at low or intermediate risk. According to the 2023 ESH Hypertension Guidelines, PWV is included as a basic screening tool for assessing hypertension-mediated organ damage [2]. A baPWV $\geq$ 18 m/s and cfPWV $\geq$ 10 m/s are recommended as thresholds for determining hypertension-related target organ damage. However, factors such as limited equipment availability, high costs (ranging from 100,000 to 350,000 RMB), and constrained medical resources may restrict implementation.

3.4 CAVI

CAVI is a non-invasive indicator developed in Japan for assessing the structural and functional stiffness of the arterial tree from the aortic origin to the ankle [29]. Its characteristic is independence from instantaneous blood pressure values, enabling more stable reflection of arterial structural stiffness. CAVI is influenced by multiple factors, including arteriosclerotic disease, cardiovascular risk factors, and arterial smooth muscle contraction and relaxation [30-32]. CAVI records electrocardiograms, phonocardiograms, pulse waveforms at the brachial and ankle arteries, and brachial systolic and diastolic blood pressure through the automated VaSera device (Fukuda Denshi, Japan). It calculates PWV via formula and finally computes the CAVI value based on electrocardiogram, phonocardiogram, pulse waveform, and blood pressure data. The VaSera device' s built-in algorithm automatically completes the calculation and directly displays the CAVI value.

The prospective CAVI-J study in Asian populations showed that individuals with CAVI $\geq$ 9.5 had increased risk of cardiovascular events and all-cause mortality [4]. The multicenter prospective TRIPLE-A study in European populations demonstrated that the optimal CAVI threshold for predicting increased cardiovascular morbidity in subjects $\geq$ 60 years was 9.25 [33]. CAVI is an indicator of overall arterial stiffness independent of blood pressure levels at the time of measurement, is easy to measure, is almost operator-independent, and is a reproducible method for assessing arterial structure and function. It can serve as an indicator for predicting and evaluating cardiovascular disease and risk factors in daily clinical practice. However, CAVI is currently used mainly for cardiovascular prevention and clinical disease in Asia, and its clinical application in Western countries requires more data support.

4 Strengths and Limitations of the Consensus

The Consensus provides a comprehensive, integrated assessment approach covering multiple methods for evaluating blood pressure, arterial structure, and function, including office blood pressure measurement, home blood pressure monitoring, ambulatory blood pressure monitoring, blood pressure variability, ankle-brachial index, PWV, CIMT, and retinal microcirculation. This offers clinicians and researchers a comprehensive perspective for thorough cardiovascular health assessment. Furthermore, some recommended techniques, such as home blood pressure monitoring and ankle-brachial index screening, are low-cost, high-benefit, simple to operate, and well-supported by evidence, making them suitable for widespread clinical application.

The limitations of the Consensus include that some technologies (such as central arterial pressure, cfPWV, and CAVI) involve high equipment costs and require specialized operation, making them difficult to popularize in medical institutions in developing countries and limiting their clinical applicability. Some indicators, such as blood pressure variability, although clearly associated with target organ damage, lack high-quality evidence for intervention thresholds. Emerging technologies like CAVI show potential in early diagnosis of cardiovascular disease, but their clinical application still requires support from more randomized controlled trials. Future efforts need to reduce costs and simplify operations through technological innovation and conduct multi-population studies to strengthen evidence and enhance clinical utility.

5 Implications for Clinical Practice and Guideline Development in China

China currently lacks corresponding guidelines or consensus systematically addressing blood pressure measurement and assessment of arterial structure and function. This Consensus comprehensively standardizes blood pressure measurement techniques and arterial structure and function assessment methods, providing precise, individualized cardiovascular risk management tools for clinical practice in China while offering multidimensional references for decision-making and guideline development regarding blood pressure measurement and arterial structure and function assessment.

Establishing a set of well-adapted, localized evaluation indicators is crucial. We recommend that when developing relevant guidelines in China, priority should be given to assessment methods with high cost-effectiveness, low technical difficulty, and high-level evidence. For example, office blood pressure measurement and home blood pressure monitoring, due to their low cost and simple operation, are suitable for widespread promotion in primary healthcare settings in China.

Our consensus interpretation team recommends constructing a standardized assessment framework from three dimensions—arterial pressure, structure, and function—to provide a comprehensive, actionable evaluation system for clinical practice. For arterial pressure assessment, we recommend selecting office blood pressure, home blood pressure monitoring, or 24-hour ambulatory blood pressure monitoring based on the specific problems to be addressed and timing, using them synergistically to optimize hypertension screening, diagnosis, treatment, and follow-up. For arterial structure assessment, we recommend carotid ultrasound and retinal microcirculation examination as early evaluation indicators of vascular health. For arterial function assessment, we recommend ankle-brachial index as an indicator for evaluating peripheral artery disease and arterial stiffness.

This Consensus provides a scientific framework for arterial pressure, structure, and function assessment by integrating global evidence and comprehensively discussing multiple assessment techniques, enabling clinicians to more thoroughly understand patients' cardiovascular health status and achieve early intervention and personalized treatment. Future research should further optimize these assessment methods, requiring integration with localized research, policy support, and technology popularization, and explore their application effects in different populations to promote the standardization and precision of cardiovascular health assessment and achieve comprehensive upgrading of cardiovascular disease prevention and control.

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