STUDY OF METHODS FOR ASSESSING VASCULAR RIGIDITY AND PREDICTING CARDIORENAL COMPLICATIONS IN PATIENTS WITH ISCHEMIC HEART DISEASE AND TYPE 2 DIABETES AFTER MYOCARDIAL REVASCULARIZATION

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Abstract
Interest in sphygmometry is particularly high in the context of comorbid conditions such as diabetes mellitus, obesity, chronic kidney disease, and metabolic syndrome. These conditions are accompanied by accelerated vascular aging, inflammation, and endothelial dysfunction, which makes the assessment of vascular stiffness extremely important [8]. For example, in patients with type II diabetes, increased ABI is detected significantly more often and at earlier stages than in individuals without diabetes, and is an independent predictor of adverse outcomes [9]. Thus, sphygmometry is becoming an integral part of a comprehensive approach to the management of such patients.

Keywords: coronary heart disease, diabetes mellitus, sphygmometry, chronic kidney disease

Introduction. Cardiovascular disease (CVD) remains the leading cause of morbidity and mortality worldwide, despite significant advances in diagnosis and treatment [1]. According to the World Health Organization, more than 17 million people die each year from complications of CVD, and this figure continues to rise due to global population aging and the increasing prevalence of obesity, diabetes mellitus, and metabolic syndrome [2]. Traditional risk factors — hypertension, dyslipidemia, smoking, and a sedentary lifestyle — continue to determine the development of coronary heart disease (CHD), stroke, and chronic heart failure. However, in recent decades, researchers have increasingly focused on the structural and functional state of the vascular wall as a key link in the pathogenesis of cardiovascular disease [3].

Of particular importance is the phenomenon of arterial stiffness, which reflects a complex of morphological and functional changes in the vascular wall. Increased stiffness of large arteries leads to acceleration of the pulse wave, increased load on the myocardium and target organs, and contributes to the progression of atherosclerosis [4]. Moreover, arterial stiffness is considered not only as a consequence of prolonged exposure to risk factors, but also as an independent predictor of cardiovascular complications and mortality [5]. This has led to the need to find simple, accessible, and reproducible methods for its assessment in clinical practice.

The most common method of measuring arterial stiffness today is sphygmomanometry—a set of non-invasive techniques based on recording the pulse wave and calculating derivative indicators such as pulse wave velocity (PWV), augmentation index, and central aortic pressure [6]. Sphygmomanometry provides important prognostic information that is comparable to or even superior to traditional blood pressure measurements. Unlike office tonometry, it allows for the assessment of not only blood pressure levels but also the properties of the vascular wall, which opens up new horizons in risk stratification and personalized therapy [7].

Interest in sphygmometry is particularly high in the context of comorbid conditions such as diabetes mellitus, obesity, chronic kidney disease, and metabolic syndrome. These conditions are accompanied by accelerated vascular aging, inflammation, and endothelial dysfunction, which makes the assessment of vascular stiffness extremely important [8]. For example, in patients with type II diabetes, increased ABI is detected significantly more often and at earlier stages than in individuals without diabetes, and is an independent predictor of adverse outcomes [9]. Thus, sphygmometry is

becoming an integral part of a comprehensive approach to the management of such patients.

In recent years, a number of large cohort studies and meta-analyses have been published, convincingly demonstrating the prognostic value of arterial stiffness indicators. For example, the CAFE (Conduit Artery Function Evaluation) study demonstrated that the effect of antihypertensive therapy on patient outcomes depends not only on a reduction in office blood pressure, but also on a reduction in central aortic pressure and augmentation index [10]. A number of European and American guidelines already include recommendations on the use of vascular stiffness indicators as additional risk markers [11].

Despite the growing amount of data, sphygmomanometry has not yet become as widespread in everyday clinical practice as classical tonometry. This is due to a number of limitations: the lack of a unified methodology, differences in the devices used, and limited availability of equipment in some countries [12].

Nevertheless, recent trends indicate that sphygmometry will be increasingly implemented in practice, especially in centers involved in the prevention and treatment of coronary artery disease and diabetes.

Thus, sphygmometry is a promising area of modern cardiology, combining fundamental insights into the pathophysiology of the vascular wall with practical risk stratification tasks. The purpose of this review is to systematize current data on sphygmometry methods, their clinical significance in various diseases, and to assess the prospects for introducing these techniques into routine practice.

Sphygmomanometry methods. Modern sphygmomanometry is a set of non-invasive technologies that allow assessing the stiffness of the vascular wall and the parameters of central hemodynamics. Unlike traditional office tonometry, which only records peripheral blood pressure, sphygmometry focuses on analyzing the shape of the pulse wave and derived indicators that reflect the elasticity of large arteries and the interaction of the heart with the vascular system [13].

Key indicators

1. Pulse wave velocity (PWV).

PWV is the «gold standard» for assessing arterial stiffness [14]. It is determined by the time it takes for the pulse wave to travel through a specific segment of the arterial bed (most often from the carotid to the femoral artery). The stiffer the artery walls, the faster the pulse wave propagates. Increased PWV correlates with the risk of cardiovascular complications and mortality regardless of blood pressure level [15].

2. Central aortic pressure (CAP).

Central pressure, measured at the level of the aorta, differs from peripheral pressure, which is measured at the brachial artery. It is central pressure that largely determines the load on the myocardium and cerebral vessels [16]. A number of studies have shown that CAP is a better predictor of cardiovascular complications than traditional «office» blood pressure.

3. Augmentation index (AI).

The augmentation index reflects the contribution of the reflected pulse wave to the formation of central pressure. With increased arterial stiffness, the reflected wave returns earlier, increasing the systolic load on the heart [17]. An elevated AI is associated with endothelial dysfunction, left ventricular myocardial hypertrophy, and an unfavorable prognosis.

4. Reflected wave parameters.

Not only the speed but also the location of the pulse wave reflection is important. Analysis of the temporal characteristics of the reflected wave allows the condition of the peripheral arteries and microcirculation to be assessed [18].

Measurement methods

1. Aplanation tonometry.

One of the most accurate and validated methods for recording the pulse wave. A special sensor is pressed against the artery (usually the radial or carotid artery), recording the shape of the pulse wave. Based on the data obtained, SBP, AI, and other parameters are calculated. The classic device is the SphygmoCor system, which is used in many studies [19]. The disadvantage of this method is the need for a highly skilled operator and the relatively high cost of the equipment.

2. Oscillometric methods.

These are based on recording pressure fluctuations in a cuff placed on the shoulder. Modern oscillometric devices not only measure blood pressure but also automatically calculate vascular stiffness parameters (e.g., Mobil-O-Graph, Arteriograph) [20]. Advantages: simplicity, speed, minimal dependence on operator skills. Disadvantages: lower accuracy compared to aplanatic tonometry.

3. Photoplethysmography.

This method is based on recording changes in the optical density of tissues in response to fluctuations in blood flow. It can be used to assess peripheral vascular stiffness and calculate PVR [21]. It is actively used in portable devices and wearable gadgets.

4. Methods using Doppler imaging.

Doppler ultrasound allows the recording of blood flow velocity in arteries and the calculation of pulse wave propagation time [22]. The method requires special equipment and an experienced operator, but is highly accurate.

5. New technologies.

In recent years, portable systems that integrate with smartphones have been developed, as well as methods for analyzing pulse waves based on artificial intelligence [23]. This opens up prospects for mass screening and monitoring of vascular stiffness at home.

Clinical accuracy and reproducibility

The representativeness and reproducibility of measurements depend on the method and device used. Aplanation tonometry remains the gold standard for assessing IOP and IA, while carotid-femoral measurement, recognized as the gold standard, is widely used for ABPM [14]. Oscillometric and plethysmographic methods are convenient for routine practice but require further standardization [24].

Use in clinical trials

Sphygmomanometry methods are actively used in large clinical trials. For example, the CAFE study showed that antihypertensive therapy, which equally reduced office blood pressure, had different effects on central blood pressure and augmentation index, which

explained the differences in clinical outcomes [10]. In the Framingham Heart Study, an increase in CPBP was associated with an increased risk of stroke, myocardial infarction, and heart failure, regardless of other risk factors [25].

Limitations and prospects

Despite its proven prognostic value, sphygmometry has certain limitations.

The lack of a single international standard for the methodology.

The heterogeneity of devices and algorithms for calculating indicators.

Limited availability of equipment in developing countries.

A promising direction is the use of artificial intelligence technologies to analyze the shape of the pulse wave, as well as the development of compact devices for home monitoring [26]. This will expand the use of sphygmomanometry beyond specialized centers and integrate it into mass screening and CVD prevention programs.

Sphygmomanometry in various diseases and comorbid conditions

Diabetes mellitus

In patients with type II diabetes mellitus, vascular aging processes proceed at an accelerated rate. Even in the early stages of the disease, an increase in pulse wave velocity (PWV) and central aortic pressure is observed, even with normal office blood pressure readings [27–31]. The mechanism involves chronic hyperglycemia, non-enzymatic glycation of vascular wall proteins, oxidative stress, and endothelial dysfunction [32–37]. High arterial stiffness in patients with diabetes is an independent predictor of both macrovascular complications (myocardial infarction, stroke) and microvascular complications (nephropathy, retinopathy, polyneuropathy) [38–41]. Prospective studies have shown that an increase in SRP is associated with an increased risk of cardiovascular mortality even with satisfactory glycemic control [42–45].

Metabolic syndrome and obesity

Metabolic syndrome, which includes abdominal obesity, hypertension, hyperglycemia, and dyslipidemia, is considered one of the most important factors in early vascular aging. In patients with metabolic syndrome, SRP and augmentation index are significantly higher than in individuals without this diagnosis [46–48]. The pathogenesis of accelerated stiffness increase is associated with chronic inflammation, activation of the renin-angiotensin-aldosterone system, hyperactivation of the sympathetic nervous system, and impaired bioavailability of nitric oxide [49–50]. The combination of obesity and insulin resistance is particularly unfavorable, as it increases vascular calcification and contributes to the development of atherosclerosis [51–52]. The use of sphygmomanometry in this group of patients allows for the identification of high-risk categories that require early initiation of drug therapy or more stringent non-drug measures (weight loss, dietary correction, physical activity) [53–54].

Arterial hypertension

Sphygmomanometry plays a special role in the diagnosis and treatment of hypertension. Arterial stiffness indicators allow the degree of damage to target organs to be assessed even in patients with mild hypertension [55]. An increase in PVR is associated with left ventricular hypertrophy, diastolic dysfunction, microalbuminuria, and cognitive impairment. The European guidelines on hypertension (ESH/ESC 2018) explicitly indicate the possibility of using PVR as a marker of subclinical target organ damage [56]. Sphygmomanometry also plays an important role in the selection of therapy. It has been shown that drugs of different classes have different effects on central pressure: ACE inhibitors and calcium antagonists reduce it more effectively than β-blockers, with the same reduction in peripheral pressure [57].

Ischemic heart disease

In ischemic heart disease (IHD), sphygmomanometry readings reflect the severity of the atherosclerotic process and residual risk. In patients after percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG), high SRP is associated with worse long-term outcomes [58]. Even with adequate control of cholesterol and blood pressure, persistent high arterial stiffness indicates «hidden» vascular risk. Including sphygmomanometry in the examination of such patients helps to determine the need for more aggressive therapy with statins, antiplatelet agents, or combined antihypertensive treatment [59].

Chronic kidney disease

In patients with chronic kidney disease (CKD), arterial stiffness is of critical prognostic importance. Accelerated vascular aging is associated with uremic intoxication, impaired phosphorus-calcium metabolism, vascular wall calcification, and chronic inflammation [60]. Elevated ARI in patients with CKD predicts both the progression of renal dysfunction and cardiovascular mortality [61]. The association between vascular stiffness and mortality is particularly pronounced in patients on hemodialysis [62]. In this group, sphygmometry is considered one of the most reliable prognostic tools [63].

Stroke and cognitive impairment

Sphygmomanometric parameters are important prognostic indicators in cerebrovascular diseases. Elevated pulse wave velocity (PWV) and central aortic pressure are associated with a high risk of stroke and transient ischemic attacks [64]. It has been established that in elderly patients, high arterial stiffness contributes to cognitive decline and the development of dementia, including Alzheimer's disease [65]. The inclusion of sphygmometry in the examination complex allows the identification of patients at high risk of cognitive impairment even before the clinical manifestation of the disease [66].

Therapeutic approaches and the effect of treatment on vascular stiffness indicators

«Current data indicate that arterial stiffness is not only a predictor of cardiovascular complications, but also a potential therapeutic target. Reducing pulse wave velocity (PWV), augmentation index (AI), and central aortic pressure (CAP) is considered an important direction in improving the prognosis in high-risk patients,

including those with ischemic heart disease (IHD) and type II diabetes mellitus after myocardial revascularization. Antihypertensive therapy

The most pronounced effect on vascular stiffness indicators is exerted by drugs that affect the renin-angiotensin-aldosterone system (RAAS).

Angiotensin-converting enzyme (ACE) inhibitors and angiotensin II receptor blockers (ARBs) have been shown to reduce SRPV and SBP, improving vascular wall elasticity regardless of office blood pressure levels [67]. Their effect is associated with a reduction in vascular remodeling and a decrease in endothelial inflammatory activity. Calcium antagonists also have a beneficial effect on arterial stiffness, especially with long-term use [68].

In contrast, β-blockers, despite effectively reducing peripheral pressure, often have a less pronounced effect on SBP and DI [69]. This explains why RAAS drugs and calcium antagonists may provide a better prognosis in high-risk patients.»

Statins and lipid-lowering therapy. Statins are traditionally considered drugs for the correction of dyslipidemia, but their positive effect on vascular stiffness is also associated with pleiotropic effects: reduction of inflammation, improvement of endothelial function, and reduction of oxidative stress [70].

Meta-analysis data show that statins can reduce ABI in patients with CHD and diabetes, although this effect is less pronounced than with antihypertensive drugs [71].

New antidiabetic drugs

In recent years, much attention has been paid to the effect of new-generation hypoglycemic agents on vascular stiffness and prognosis. Sodium-glucose cotransporter 2 (SGLT2) inhibitors have been shown to reduce arterial stiffness by improving vascular elasticity and reducing central aortic pressure [72].

Glucagon-like peptide-1 (GLP-1) receptor agonists also demonstrate a positive effect on endothelial function and vascular wall condition, as confirmed by clinical studies in patients with diabetes and IHD [73].

The use of these drugs is considered not only in the context of glycemic control, but also as part of a strategy to reduce cardiorenal risk in high-profile patients [74].

Non-pharmacological approaches

Lifestyle modifications are no less important:

Weight loss leads to a decrease in arterial stiffness and improvement in endothelial function [72];

Regular physical activity reduces SBP, improves aortic elasticity, and reduces the augmentation index [73];

A balanced diet with limited salt and saturated fat and increased consumption of fruits and vegetables also has a positive effect on vascular health [74].

These measures are particularly relevant for patients after stenting or CABG, where long-term prognosis is largely determined by adherence to a healthy lifestyle.

A comprehensive approach

The optimal treatment strategy should include a combination of drug therapy (ACE inhibitors/ARBs, statins, modern antidiabetic drugs) and non-drug interventions. At the same time, sphygmometry allows for an objective assessment of the dynamics of arterial stiffness indicators and the effectiveness of therapy.

The inclusion of vascular stiffness assessment in clinical protocols for the treatment of patients with IHD and type II diabetes after revascularization opens up the prospect of personalized medicine: the choice of drugs and treatment regimens can be made taking into account the impact on vascular stiffness and the prognosis of cardiorenal complications.

Prospects and new technologies in sphygmometry

The development of methods for assessing arterial stiffness over the past decade has led to significant advances in understanding the pathogenesis of cardiovascular and cardiorenal complications. However, the current stage is characterized not only by the improvement of existing techniques, but also by the introduction of new technologies that open up opportunities for the widespread use of sphygmometry in routine clinical practice.

Automation and standardization

One of the key areas is the creation of automated devices that do not require a highly skilled operator. Modern oscillometric devices allow simultaneous measurement of blood pressure and assessment of vascular stiffness parameters within a few minutes [75]. This simplifies the conduct of studies and makes them accessible for outpatient practice.

The standardization of techniques remains an important task. Currently, there is considerable variability in the devices and algorithms used to calculate SRPA and augmentation index. International working groups are developing recommendations for standardizing approaches, which in the future will allow for the comparison of research results and the inclusion of arterial stiffness indicators in clinical protocols [76].

Wearable devices and telemedicine

The development of portable and wearable devices that integrate with smartphones and smartwatches is of considerable interest. The use of photoplethysmography and pressure sensors opens up the possibility of regular monitoring of vascular stiffness at home [77].

Such technologies are particularly promising for high-risk patients with coronary artery disease, diabetes, and chronic kidney disease. Daily recording of pulse wave parameters can become part of remote monitoring systems integrated with electronic medical records and telemedicine platforms. This will allow doctors to adjust therapy in a timely manner and reduce the risk of complications.

Conclusion

Arterial stiffness is currently recognized as one of the most informative markers of the state of the vascular system and a predictor of cardiovascular and cardiorenal complications. Unlike traditional risk factors such as blood pressure or lipid profile, sphygmometry indicators reflect the structural and functional state of the vascular wall and the processes of accelerated vascular aging.

The use of sphygmometry in clinical practice opens up new opportunities for risk stratification in patients with a high cardiovascular profile. This method is particularly significant in patients with ischemic heart disease and type II diabetes mellitus, where traditional risk assessment methods are often insufficient. In this group of patients, arterial stiffness serves as both an early indicator of target organ damage and a predictor of long-term complications after myocardial revascularization.

Systematization of data from recent years allows us to highlight several key points:

1. Arterial stiffness is an independent predictor of adverse outcomes. An increase in pulse wave velocity and central aortic pressure is significantly associated with an increased risk of cardiovascular and overall mortality.

2. Sphygmomanometry complements traditional diagnostic methods. It allows the identification of patients with high residual risk even when target blood pressure and lipid levels are achieved.

3. The diagnostic and prognostic value of sphygmometry has been confirmed by large studies. The results of prospective cohort studies and meta-analyses indicate the high predictive power of vascular stiffness indicators.

4. Therapeutic effects on vascular stiffness are possible. Modern antihypertensive drugs, statins, and new antidiabetic agents have been shown to reduce arterial stiffness. Non-pharmacological interventions (weight loss, physical activity, dietary changes) also have a proven positive effect.

5. The prospects are linked to the introduction of new technologies. The development of automated devices, wearable devices, and artificial intelligence algorithms makes sphygmometry accessible for widespread clinical use and integration into telemedicine.

Thus, sphygmometry is currently in a transitional phase from a research tool to a practical clinical method. The inclusion of vascular stiffness indicators in the algorithms for examining patients with IHD and type II diabetes after myocardial revascularization will allow for a more accurate assessment of individual risk and optimization of treatment tactics.

Future research should focus on further standardizing methods, expanding the evidence base, and integrating sphygmometry into personalized medicine programs. Given the high prevalence of comorbidities and the growing number of patients who have undergone coronary interventions, the importance of this method will continue to grow.

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