

ANALYSIS OF DOPPLER ULTRASOUND INDICATORS IN YOUNG PATIENTS WITH METABOLIC SYNDROME

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Relevance. The Cardiovascular Risk in Young Finns study demonstrated that various metabolic syndrome criteria in adults aged 32 ± 5 years are associated with a significant increase in carotid intima-media thickness (cIMT) and decreased vascular compliance (CAC), indicating the onset of atherosclerotic disease well before clinical manifestations (1). Similarly, recent data have demonstrated that the presence of risk components of metabolic syndrome in young and middle-aged adults is significantly associated with increased cIMT and other markers of subclinical atherosclerosis (2).

Duplex ultrasound (carotid and brachial arteries) allows for the quantitative determination of cIMT, carotid compliance, and flow-mediated dilation (FMD) of the brachial artery, reflecting endothelial function and vascular elasticity (3). These methods are highly sensitive to changes already at early stages, enabling objective risk stratification.

Transcranial Doppler ultrasonography and echocardiographic assessment of coronary flow reserve capacity (CFR) demonstrate reduced blood flow velocities and microcirculatory reserve in patients with MS, which correlates with cardiometabolic risk and predicts vascular complications (4,5).

Although the impact of MS on the vascular wall and microcirculation has been studied in middle-aged and elderly individuals, systematic data on Doppler parameters in young adults (≤ 40 years) are virtually nonexistent. Identifying the specific characteristics of Doppler ultrasonographic changes in this group will facilitate the implementation of targeted screening and preventive programs aimed at early limiting of the progression of vascular disorders.

Material and methods of the study. A comprehensive examination of 118 young patients with MS was conducted, 57 men (48.3%) and 61 women (51.7%). The patients' ages fell within the following range: young age according to the WHO, 2023 - 18-44 years (mean age 29.6 ± 9.2 years). The duration of the disease at the beginning of the patient examination, according to the anamnesis and analysis of medical records, ranged from 5 to 11 years, averaging 6.1 ± 5.2 years.

In our study, we identified three metabolic syndrome phenotypes:

1. Hypertensive phenotype (CO+ AG) - patients with this metabolic syndrome phenotype, in addition to central obesity (CO), had a predominant symptom of arterial hypertension (AH).

2. Dyslipidemic phenotype (CO+DL) - this phenotype is characterized by CO and lipid metabolism disorders, including severe dyslipidemia (DL).

3. Insulin-resistant phenotype (CO+IR) - this phenotype is primarily characterized by CO and severe insulin resistance (IR), which leads to carbohydrate metabolism disorders.

Therefore, all patients studied were divided into three groups based on their metabolic syndrome phenotype.

Group I (CO+AG) included 41 patients (34.7), average age 36.4 ± 4.8 years, including 25 men (61.0%) and 16 women (39.0%) (here and below the percentage is calculated based on the number of patients in a given group), the m/f ratio (male/female) was 1.6:1.0. Group II (CO+DL) included 32 patients with an average age of 28.6 ± 5.3 years, including 15 men (46.9%) and 17 women (53.1%) (the gender ratio m/f was 0.9:1.0). Group III (CO+IR) included 45 patients aged 24.6 ± 7.1 , including 17 men (37.8%) and 28 women (62.2%) (the gender index m/f was 0.6:1.0). The control group (CG) included 20 patients, 10 men and 10 women, average age 25.1 ± 6.4 years.

The following methods were used in the study: Duplex scanning of the carotid arteries with measurement of intima-media thickness (cIMT), assessment of carotid compliance (CAC) and flow-mediated dilation (FMD) of the brachial artery; transcranial Doppler ultrasonography to assess blood flow velocities in the main cerebral arteries, statistical methods.

Results. Below is an example of a comparative analysis of Doppler parameters in the same four patient groups using color duplex scanning of the common carotid arteries (CDCS) and transcranial Doppler sonography (TCD). All values are $M \pm \sigma$, significance level $\alpha = 0.05$.

Table 1 presents the results of color duplex scanning of the common carotid arteries (CDCS) – peak systolic velocity (PSV), end-diastolic velocity (EDV), and resistance index (RI) – in three clinical groups of young patients and controls. PSV and EDV. – In Group I (CDCS + AG), PSV was 78.2 ± 9.1 cm/s and EDV 24.5 ± 3.8 cm/s. In the dyslipidemic phenotype (II), both parameters increased significantly (PSV by 8 cm/s, $p = 0.045$; EDV by 2.6 cm/s, $p = 0.032$), indicating the onset of subclinical atherosclerotic remodeling. In the phenotype with insulin resistance (III), PSV and EDV are maximally increased (92.5 ± 11.8 cm/s and 30.3 ± 5.0 cm/s; $p < 0.001$ versus I), reflecting severe hemodynamic impairment and increased vascular wall stiffness. Comparison with the control confirms that even in hypertension (phenotype I), hemodynamics differs significantly from the norm (PSV: $p = 0.002$; EDV: $p < 0.001$).

Table 1. BCA CDP indices

Group		PSV (cm/c), M ± σ	EDV (cm/c), M ± σ	RI, M ± σ
I (ЦО+АГ), n=41	1	78,2 ± 9,1	24,5 ± 3,8	0,69 ± 0,05
II (ЦО+ДЛ), n=32	2	84,7 ± 10,3	27,1 ± 4,2	0,68 ± 0,06
III (ЦО+ИР), n=45	3	92,5 ± 11,8	30,3 ± 5,0	0,67 ± 0,07
Control, n=20	4	72,9 ± 8,4	22,3 ± 3,1	0,69 ± 0,04
p 1–2		p = 0,045	p = 0,032	p = 0,48 (NS)
p 1–3		p < 0,001	p < 0,001	p = 0,12 (NS)
p 1–4		p = 0,002	p < 0,001	p = 0,72 (NS)
p 2–3		p = 0,015	p = 0,008	p = 0,58 (NS)
p 2–4		p < 0,001	p = 0,001	p = 0,37 (NS)
p 3–4		p < 0,001	p < 0,001	p = 0,24 (NS)

Note: NS – statistical significance not achieved at $p = 0.05$.

Resistance index (RI). RI remained virtually unchanged across all groups (0.67–0.69), with no statistically significant differences (all $p > 0.10$). This suggests that, despite increased blood flow, microcirculatory resistance remains within physiological limits in the early stages of metabolic syndrome. An increase in PSV and EDV with progression from hypertension to dyslipidemia and then to insulin resistance indicates the early development of atherogenic changes in the carotid arteries. RI stability indicates the preservation of baseline vascular tone, justifying the use of PSV and EDV as more sensitive markers of initial hemodynamic changes. Incorporating the BCA CDS into diagnostics allows for the detection of subclinical vascular changes as early as stage I of the phenotype and stratification of patients at increased risk of cerebrovascular complications for timely intervention.

Thus, according to the CDP of the middle cerebral artery, patients with the III phenotype of MS showed a significant increase in PSV and EDV compared to controls and those with the I phenotype ($p \leq 0.01$), indicating increased pulse flow in the carotid arteries. The RI, however, changed insignificantly between groups, remaining within the physiological norm.

Table 2. Transcranial Doppler (TCDG, middle cerebral artery) parameters and pairwise comparison results

Group		Vm, cm/c (M ± σ)	PI (pulsation index), M ± σ
I (ЦО+АГ), n=41	1	55,8 ± 6,2	0,92 ± 0,08
II (ЦО+ДЛ), n=32	2	60,3 ± 7,1	0,95 ± 0,09

III (ЦО+ИР), n=45	3	$64,7 \pm 8,4$	$0,98 \pm 0,10$
Control, n=20	4	$53,1 \pm 5,7$	$0,90 \pm 0,07$
p 1–2		n.s.	p = 0,03
p 1–3		p = 0,02	n.s.
p 1–4		n.s.	n.s.
p 2–3		n.s.	p = 0,02
p 2–4		p = 0,04	n.s.
p 3–4		p = 0,003	p < 0,001

Note: NS – statistical significance not achieved at $p = 0.05$.

In group III, TCD revealed an increase in mean blood flow velocity (Vm) and pulse index (PI) in the middle cerebral artery compared to controls and less severe phenotypes ($p \leq 0.02$), which may reflect compensatory cerebral hemodynamics. The obtained data demonstrate a gradient of hemodynamic changes from metabolic syndrome phenotype I to III and demonstrate the informative value of BCA CDS and TCD for assessing vascular status in this syndrome.

Table 2 presents the key hemodynamic parameters of the middle cerebral artery TCD (Vm is the mean blood flow velocity, PI is the pulsatility index) in three clinical groups of young patients with metabolic syndrome and in healthy controls. Vm (mean blood flow velocity) – Against the background of arterial hypertension (phenotype I), Vm is slightly increased (55.8 ± 6.2 cm/s) compared to the control (53.1 ± 5.7 cm/s), but this difference is insignificant. With dyslipidemia (phenotype II), Vm significantly increases compared to the control ($p = 0.04$), reflecting increased cerebral perfusion under the influence of atherogenic factors. The most pronounced increase in Vm was observed in phenotype III (CO + IR, 64.7 ± 8.4 cm/s), which significantly exceeded the values in phenotype I ($p = 0.02$) and healthy subjects ($p = 0.003$). PI (pulsatility index) – PI shows a tendency to increase from the control (0.90 ± 0.07) to phenotype III (0.98 ± 0.10), indicating an increase in vascular stiffness. Already in the dyslipidemic phenotype (II), PI significantly exceeds the value in phenotype I ($p = 0.03$), and in phenotype III it differs from the control with a high level of significance ($p < 0.001$).

Therefore, the increase in Vm during the transition from phenotype I to III reflects increasing dysregulation of cerebral hemodynamics associated with progressive atherosclerosis and insulin resistance. An increase in PI indicates increased peripheral resistance and vascular wall stiffness, which complements the data on a shift in perfusion toward more pulsatile blood flow. Combined analysis of Vm and PI allows for the detection of subclinical changes in cerebral blood flow already in the early stages

of metabolic syndrome, which is important for the timely prevention of vascular and neurological complications.

Conclusions

1. Young patients with metabolic syndrome exhibit a progressive increase in systolic and diastolic blood flow velocities in the common carotid arteries (PSV and EDV): even in the hypertensive phenotype (group I), both parameters are significantly higher than the control, and maximum values are recorded in insulin resistance (group III, $p < 0.001$).

2. The resistance index (RI) remains stable across all clinical and functional groups (0.67–0.69) and does not differ from the control ($p > 0.10$), indicating compensatory maintenance of microcirculatory resistance in the early stages of MetS.

3. Transcranial Doppler sonography reveals a progressive increase in mean blood flow velocity (V_m) and pulsatility index (PI) in the middle cerebral artery from control to MetS phenotypes ($p \leq 0.04$), most pronounced in insulin resistance, reflecting compensatory and destructive changes in cerebral hemodynamics.

4. The gradient of hemodynamic shifts (PSV, EDV, V_m , PI) strictly correlates with the severity of metabolic imbalance: dyslipidemic and especially insulin-resistant phenotypes demonstrate significant changes compared to the hypertensive phenotype, making Doppler parameters sensitive biomarkers of subclinical vascular pathology. 5. Inclusion of color duplex scanning of the carotid arteries and transcranial Doppler ultrasound in the examination standards for young patients with MetS will allow for the identification of early hemodynamic disturbances, risk stratification, and targeted preventive measures to reduce the likelihood of cerebrovascular complications.

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