Modern approach to complex ultrasonic investigations of patients with pathologic deformation of the internal carotid artery

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Purpose

To determine ultrasonic characteristics of the blood flow in an internal carotid artery at different forms of pathological deformation; to estimate structure-functional properties of the arterial wall and condition of the reserve of a cerebral circulation in patients with various clinical implications of vascular-cerebral insufficiency.
Methods and Materials

58 patients with pathologic deformation (PD) of the internal carotid artery (ICA) aged from 15 to 82 years (mean - 52±17.9 years). Female patients (N=34) prevailed (58.6%). Patients with only isolated PD I## were studied. Patients with combined hemodynamic significant atherosclerotic lesion of arteries were not included in the study. Patients (N=52) with bilateral lesion of carotid arteries prevailed (89.7%). Arterial hypertension - (40 patients, 68.9 %), diabetes (4 patients, 6.9 %) and lack of glucose tolerance (1 patient, 1.7 %) accompanied the main disease.

Control group consisted of 20 patients aged from 25 to 63 years (mean - 33.2±10.6 years) without cardiovascular disorders.

40 patients (69%) with PD ICA had clinical implications of vertebral-basilar insufficiency and common cerebral semiotics: headache, dizziness and sonitus. The patients complained rarer to "a flicker in eyes", episodes of a loss of consciousness.

According to Pokrovsky' A.'s classification patients were parted (Table 1).

Table 1. Distribution of patients on degree of vascular-cerebral insufficiency

<table>
<thead>
<tr>
<th>Degree of vascular-cerebral insufficiency</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>8 (13,8%)</td>
</tr>
<tr>
<td>II</td>
<td>8 (13,8%)</td>
</tr>
<tr>
<td>III</td>
<td>34 (58,6%)</td>
</tr>
<tr>
<td>IV</td>
<td>8 (13,8%)</td>
</tr>
<tr>
<td></td>
<td><strong>58 (100%)</strong></td>
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</table>

Patients with asymptomatic stage of disease, with transitory ischemic attacks and with ischemic stroke in history and in equal parities - 8 (13.8 %). Most of the patients (N=34; 58.6 %) had clinical implications of circulatory encephalopathy.

The complex ultrasonic scanning (including CDS of ICA) performed for all patients using a routine approach. Investigation was supplemented with studying of structure-functional properties of the arterial wall of the common carotid artery (CCA), probing a reactive hyperemia in brachial artery. The second step comprised transcranial duplex scanning of Willis circle and hypercapnic probe. All ultrasonic investigations were performed using of device LOGIQ-9 (General Electric, Germany). According to recommendations of the International Working Group patients abstained from food, smoking and vascular active drugs during 8-12 hours before procedure. Any physical stresses for 4-6 hours prior to
the investigation were also excluded. An estimation of dysfunction of the endothelium in a brachial artery was performed by modified technique by D. Cellermajer et al. [1].

Probing of reactive hyperemia cuff of a sphygmomanometer imposed on the upper third of shoulder. A brachial artery was visualized in the sagital plane with a gauge locating at level of an ulnar fold. When a segment of artery with distinct visualization of forward and back walls measured of diameter of the vessel lumen on border the adventitia-media of forward wall and on border a media-adventitia of back wall were carried out. Diameter was averaged in three cardiac cycles. Then systolic pressure was applied in the cuff exceeding in a brachial artery by 50 mm Hg. A compression kept during 5 minutes, after that fast decompression was performed with simultaneous registration of a spectrum of Doppler frequencies shift (SDFS) in brachial artery and measurement of linear velocity of a blood flow (LVBF) and the resistance index (RI). Additionally diameter of a brachial artery was measured after a reactive hyperemia on 30, 60 and 90 seconds. The flow dependent (endothelium dependent) dilatation was calculated as a ratio of the diameter changes to initial diameter (in percentage). Estimations of elastic properties of a wall of the common carotid artery were performed by the conventional techniques:

**Distensibility Coefficient, DC**

\[
DC = \frac{2^*D^*#D + #D^2}{(#P^*D^2)}, \ (10^{-3} \text{ kPa}) \ [2]
\]

**Compliance Coefficient (CC)**

\[
## = \left( \frac{(2^*D^*#D + #D^2)}{4^*P^*D} \right), \ (\text{mm}^2/\text{kPa}) \ [2].
\]

**Regidity index (ß)**

\[
ß = \log \left( \frac{Ps}{Pd}/(#D/D) \right) \ [3],
\]

where D - diastolic diameter of the artery, #D - change of diameter under the influence of a pressure pulse, Ps - systolic, Pd - diastolic blood pressure.

Functional condition of the cerebral circulation was studied using of hypercapnic probe. Initial systolic velocity of the blood flow in the middle cerebral artery (MCA) and velocity of the blood flow in MCA at concentration ##_2 of 7% in expiration were measured. We calculated percentage of change of a blood flow respectively to initial systolic velocity (100 %).

Data processing was carried out by means of a package «Statistica 7.0». Significance of differences was estimated using unpaired Student test. Dependences were estimated by means of regression analyses.
Results

Distribution of patients depending on the form of pathological deformation of an internal carotid artery is presented in table 2. Patients were classified according to Weibel and Fields [4].

Table 2. Distribution of patients depending on the form of pathological deformation basing on CDS data

<table>
<thead>
<tr>
<th>Form of deformation of ICA</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C- # S-shaped (tortuosity)</td>
<td>23 (22.1%)</td>
</tr>
<tr>
<td>Kinking</td>
<td>51 (49%)</td>
</tr>
<tr>
<td>Coiling</td>
<td>30 (28.9%)</td>
</tr>
<tr>
<td></td>
<td><strong>104 (100%)</strong></td>
</tr>
</tbody>
</table>

Analyzing the data of CDS in ICA we estimated the deformation form, distance from the I## mouth to the winding, blood flow type and velocity on all extent of the artery. As measurement of linear velocity of blood flow depends on the exposed angle, we have introduced concept of a gradient of velocity which was calculated, as the ratio of maximal velocity at winding height to velocity before deformation. We compared the gradients of velocity of the blood flow at various forms of deformation. In group of patients with kinking of ICA (Fig. 1A) mean linear velocity prior to deformation was 49.8 ± 12.9 cm/s, on a site of the maximal winding was 125.6 ± 43.8 cm/s, thus gradient of velocity was 2.7 ± 0.77. In this group of patients at winding peak the turbulent blood flow was registered (33 cases #63.5 %).

We have found that the blood flow remains laminar at the maximal velocity on a winding 91.56±21.4 cm/s and a gradient 1.92±0.41 whereas turbulence appeared at the maximal velocity on winding 143.2±42.1 cm/s and a gradient 2.91±0.69 (Fig. 1B).

In patients with the coiling deformation of ICA (Fig. 2A) mean value of linear velocity (49.8 ± 10.3 cm/s) prior to the deformation did not differ from those under other forms of a tortuosity but at top of winding linear velocity and gradient of velocity were significantly lower 96.8±46.9 cm/s and 1.9±0.68 respectively. Turbulence of a blood flow was recorded only in 7 (22.6 %) cases and appeared at the maximal velocity 162.5±53.74 cm/s and the gradient 2.69±0.79 and were not detected at the maximum velocity in a deformation site of 77.15±19.1 cm/s and the gradient 1.68±0.44 (Fig. 2B).

Fraction of patients with coiling deformation of ICA was 43.7 % among all patients with PD ICA.
In patients with S-shaped deformation of ICA the mean values of linear velocities were: prior to the site of deformation - 40.1 ± 6.27 cm/s and at the top of winding - 116.8 ± 14.7 cm/s, gradient of velocity was 2.9 ± 0.4. Turbulence was detected in 9 (47.4%) cases at mean velocity at the top of winding 121.7 ± 16.9 and gradient of velocity 2.98 ± 0.44.

We did not analyze in details S-shaped deformation of ICA because we had not detected significant differences of linear velocity of blood and correspondingly turbulence. A comparison of a gradient of velocity with clinical implications of vascular-cerebral insufficiency (VCI) did not reveal any dependence between them. Thus values of the mean gradient at different degrees of insufficiency were: VCI(1) - 2.27, at VCI(2) - 3.21, VCI(3) - 2.44 and VCI(4) - 2.22. Also no correlation between difference of linear velocity before and after a site of deformation and clinical implications was found. Thus, the estimation of the hemodynamic importance of a tortuosity and conclusion about indication to surgical treatment cannot be based only on value of maximal linear velocity at top of winding, value of a gradient of velocity and turbulence of a blood flow the anatomic form of deformation be taken into account.

The mean values of the wall elasticity of CCA in patients with PD ICA (without atherosclerotic lesion) compared with practically healthy volunteers are given in table 3.

**Table 3 The mean values of the wall elasticity of CCA**

<table>
<thead>
<tr>
<th></th>
<th>Ps (mm Hg)</th>
<th>Pd (mm Hg)</th>
<th>Ds (mm)</th>
<th>Dd (mm)</th>
<th>DC (10^3/#P#)</th>
<th>CC (mm²/#P#)</th>
<th>ß</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volunteers</strong></td>
<td>95-135</td>
<td>60-90</td>
<td>3,9-7,0</td>
<td>4,3-7,7</td>
<td>3,2-9,9</td>
<td>0,1-0,31</td>
<td>0,96-1,3</td>
</tr>
<tr>
<td></td>
<td>113,5±15</td>
<td>74,6±9</td>
<td>5,3±0,8</td>
<td>5,9±0,9</td>
<td>6,4±1,96</td>
<td>0,17±0,06</td>
<td>1,14±0,11</td>
</tr>
<tr>
<td><strong>Patients with PD of ICA</strong></td>
<td>100-190</td>
<td>60-105</td>
<td>4,3-7,7</td>
<td>4,7-7,9</td>
<td>1,2-9,1</td>
<td>0,017-0,281,04-2,02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>131,51±20</td>
<td>81,1±11</td>
<td>5,4±0,6</td>
<td>5,9±0,6</td>
<td>3,47±1,78</td>
<td>0,094±0,051,37±0,21</td>
<td></td>
</tr>
</tbody>
</table>

As evident from table 3 statistically significant (p <0.05) rising of an index of rigidity of the arterial wall (from 1.14±0.11 in volunteers to 1.37 ± 0.21 in patients) was revealed. Additionally extensibility ((3.47 ± 1.78) 10^{-3}/kPa) and compliance (0.094 ± 0.05 mm²/kPa) were decreased compared to values in control group (6.4 ± 1.96) 10^{-3}/kPa and 0.17 ± 0.06 mm²/kPa. Flow dependent dilatation in majority of patients was suppressed in majority of patients from 10.5 ± 3.9% in control to 7.9 ± 3.8% (Fig. 4).
Elastic properties of an arterial wall and dysfunction of endothelium in the brachial artery in patients with PD ICA were analyzed for 2 groups (Table 4): till 40 years (13 patients # 22.4 %) and after 40 years (45 patients #77.6 %).

Table 4 Elastic properties of an arterial wall and dysfunction of endothelium in the brachial artery

<table>
<thead>
<tr>
<th>Group volunteers</th>
<th>Patients with PD of ICA</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>less 40 yo</td>
</tr>
<tr>
<td>DC- Distensibility Coefficient (10³/#P#)</td>
<td>6,4±1,96</td>
</tr>
<tr>
<td>CC- Compliance Coefficient (mm²/#P#)</td>
<td>0,17±0,06</td>
</tr>
<tr>
<td>β-Index og Rigidity</td>
<td>1,14±0,11</td>
</tr>
<tr>
<td>FDD (%)</td>
<td>10,5±3,9</td>
</tr>
</tbody>
</table>

In group 1 extensibility and compliance tended to decrease (rigidity tended to increase). In group 2 this tendency became the statistical significance (p <0.05). Thus flow dependent dilatation in patients till 40 years was in average 9.5±2.5 % and in patients after 40 years - 6.8±3.3 %.

The analysis of anatomic structure of Willis circle revealed that the closed structure (48 patients # 90.6 %) prevailed. Willis circle was opened due to absence of one out of 2 back connecting arteries (4 patients) or absence a frontal connecting artery - 1 patient. We failed to visualize Willis circle in 8 patients (15.1 %) due to dense scales of a temporal bone and in 5 patients (8.6%) due to lack of transtemporal ultrasonic window. Values of linear velocity of blood in cerebral arteries (Willis circle) in majority of patients (51 # 96.2 %) were in limits of age norm. Asymmetry of a blood flow in middle and frontal cerebral arteries has revealed only in 4 patients (7.5 %), in back cerebral arteries - in 6 (11.3 %). In 2 patients (3.8 %) we revealed significant stenosis of middle cerebral artery in segment #2.

In healthy volunteers the linear velocity of blood was increased during hypercapnic probe by at least 24%. To patients with PD ICA we performed hypercapnic probe on the side of planned operation. We have selected 4 types of responses of a cerebral circulation to hypercapnia:

- 1 type - decrease of systolic rate of the blood flow in middle cerebral artery (MCA) (test gave negative values). This response was found in 2 patients (3.8%).
• 2 type - absence of increase of systolic rate of a blood flow in MCA (reserve of cerebral circulation is equal to 0). No response was revealed in 1 patient (1.9%).
• 3 type - increase of systolic rate of a blood flow in MCA less than 20 % (the lowered value of reserve of cerebral circulation). This type was found in 9 patients (17%).
• 4 type - increase of systolic rate of a blood flow in MCA more than 20 % (normal reserve of cerebral circulation). Normal reaction displayed 41 patients (77.3%)

We have spent studying of a condition of size of reserve ## depending on a clinical current of disease: at ### 1 its average value have made 29,2 ± 9,3 %; at ### 2 - 21,98±15,98 %; at ### 3 - 36,88±19,2 %; at ### 4 - 14,95±18,8 % (Fig. 5). In each group the size of reserve ## fluctuated in a wide range of value. It is necessary to notice that at 3 (37 %) patients with an asymptomatic current of disease the size of a reserve of a cerebral circulation has been lowered.

Reserves of cerebral circulation at different extents of vascular-cerebral insufficiency (VCI) were: VCI(1) - 29.2 ± 9.3%, VCI(2) - 21.98±15.98%, VCI(3) - 36.88±19.2% and VCI(4) -14.95±18.8% (Fig. 6).
Fig. 0: (A) The ultrasonic image of kinking type of deformation of ICA. A regimen of energy reflected Doppler signal. (B) Occurrence of turbulence versus the velocity gradient in group of patients with kinking

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Fig. 0: (A) The ultrasonic image of the loop-like deformation of ICA. Regimen of energy reflected Doppler signal (B) Appearance of turbulence versus the gradient of velocity in patients with loop-like deformation of ICA

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**Fig. 0:** The image of hemodynamic significant S-shaped deformation of ICA. Regimens CDS and SDSF.

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**Fig. 0**: Flow dependent dilatation in healthy volunteers and in patients.

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**Fig. 0:** Reserve of cerebral circulation measured by means of hypercapnic probe versus degree of vascular cerebral insufficiency (VCI).

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**Fig. 0:** Reserve of cerebral circulation in symptomatic and asymptomatic patients.

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Conclusion

Ultrasonic criteria of the hemodynamic importance of deformation are still not accurately defined. Some authors [5] consider as significant a deformation when an angle of winding is less than 60° and thus formulate the indications to surgical treatment. Recently maximal linear velocity of blood in deformation focus is mostly used as criterion of hemodynamic importance of PD. However different authors define different critical values: from 150 cm/s [6, 7] to 200 cm/s [8]. Some authors [8] consider turbulence in the artery lumen as a leading criteria of hemodynamically significant deformation. Also an increase of the stenosis degree by 60% (and more) accompanied by reduction of linear velocity of blood by 50% under functional turns of head serves as indication to surgical treatment.

According to our data the gradient of velocity may serve as objective indicator of the hemodynamic significance of a tortuosity because it does not depend on an angle of measurement in contrast to the maximal velocity of blood. However, estimating of the hemodynamic significance of deformation making use of only gradient without taking into account the form of deformation seems to be not quite correct. In patients with the loop-like deformation of ICA the mean linear velocity at top of deformation did not exceed 100 cm/s and the gradient was less than 2.0, turbulence was detected more rarely than in other types of deformations. Nevertheless, 43.7% of patients suffering from transitory ischemic attacks or from stroke had the loop-like deformations of ICA. Thus, patients with loop-like deformation of ICA were included in group of risk of the stroke development (with recommendation to prophylactic operation) in spite of low values of gradient and absence of turbulence. S-shaped deformation and kinking type deformation of ICA were considered as hemodynamically significant at gradient equal to and bigger than 2.9 and detected turbulence at the pot of deformation.

We have found that patients with PD ICA have a tendency to decrease of elasticity and rising of dysfunction of an endothelium. At microscopic study of removed regions of ICA degeneration of elastic and muscular fibers with replacement by connective tissue [6, 10-16] was revealed. It causes weakening of the arterial wall and can initiate the deformation under adverse hemodynamic factors (high arterial pressure and/or turbulence of a blood flow). Thus, the revealed structure-functional changes of an arterial wall in patients with PD ICA may serve as one of the possible pathogenic mechanisms of development of the pathology.
References


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