УДК 616. 132-073. 4 -5-091.8

CAROTID ULTRASOUND COMPARISON WITH ANGIOGRAPHY. WHY DO WE MAKE MISTAKES AND HOW TO AVOID THEM?

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***Conflict of Interest Statement (We declare that we have no conflict of interest).**
*Заява про конфлікт інтересів (Ми заявляємо, що у нас немає ніякого конфлікту інтересів).
*Заявление о конфликте интересов (Мы заявляем, что у нас нет никакого конфликта интересов).

***No human/animal subjects policy requirements or funding disclosures.**
*Жодний із об'єктів дослідження (людина/тварина) не підпадає під вимоги політики щодо розкриття інформації фінансування.
*Ни один из объектов исследования не подпадает под политику раскрытия информации финансирования.

***Date of submission — 05.04.17**
*Дата подачі рукопису — 05.04.17
*Дата подачи рукописи — 05.04.17

***Date of acceptance — 03.05.17**
*Дата ухвалення — 03.05.17
*Дата одобрения к печати — 03.05.17

Atherosclerosis is the most common cause of stroke. Non-invasive diagnostic technique can detect and evaluate the severity of the stenosis of the arteries: carotid duplex scanning, magnetic resonance and computed tomography angiography. Selective digital subtraction angiography is minimally invasive method. Selective angiography is the «gold» standard in the diagnosis of atherosclerosis of carotid arteries. The method allows to evaluate the blood vessels that supply blood to the brain and at the same time to perform endovascular surgery.

Duplex scanning of the Carotid Arteries, magnetic resonance and computed tomography angiography showed high sensitivity and specificity for the diagnosis of Carotid Artery stenosis, compared with the selective digital subtraction angiography. Ultrasonography — fast, relatively inexpensive diagnostic study of vessels disease. Although the results of carotid duplex scanning may be different in other laboratories and researchers, but the sensitivity and specificity of this study is defined as the highest.

The article analyzes the results own researches and to introduce the review features of digital subtraction angiography and ultrasound. Possible reasons that cause different results from different methods have been analyzed.

Key words: atherosclerosis, carotid artery stenosis, carotid ultrasound, selective digital subtraction angiography.

Atherosclerotic lesion of extracranial arteries is a significant risk factor of ischemic stroke appearance [3, 15]. The most spread complication of the carotid artery atherosclerosis is stroke. Even significant stenosis of carotid arteries can be asymptomatic [3, 12, 15] and therefore do not diagnosed timely. Taking into account the high frequency of patients' disablement as the result of the brain circulation impairment, it is necessary to assess the risk degree of the stroke appearance to define the therapeutic approach [3, 12, 15, 21]. Modern diagnostic techniques, endovascular interference, vascular surgery and pharmacological therapy allow to define the individual approach in the treatment of atherosclerotic lesion of arteries and to improve its prognosis [3, 15, 18].

Development and improvement of non-invasive diagnostic techniques including the carotid arteries duplex scanning, magnetic resonance and computed tomography angiography, allow non-invasive detect the location and kind of artery atherosclerosis [3, 15, 19]. Selective digital subtraction angiography (DSA) is minimally invasive method.

Carotid ultrasound is fast non-invasive technique of atherosclerotic lesion diagnostic that is procedure of choice for screening and primary assessment of the stenosis degree [3, 11, 12, 23]. Duplex scanning of the magistral cervical arteries allows performing the selection of patients with the indications for the surgical treatment. In comparison with the «gold» standard (DSA) technique demonstrated high sensitivity and specificity [10, 11, 13, 21]. Data about the results accuracy of carotid ultrasound depends on the «limitation» of comparison performing. It can be explained by the improving of material base and development of the ultrasound techniques. According to the data of the meta-analysis of 47 researches that were published until 2003 where DSA was used as standard, sensitivity and specificity of carotid ultrasound for diagnostic of vessel stenosis 50 % and more was 98 % and 88 % correspondingly; for detecting stenosis 70 % and more — 90 % [25]. On the base of this meta-analysis in the last report of Preventive Services Task Force of USA detected the sensitivity and specificity of the carotidultrasound for the detecting of artery stenosis 60 % and more than 94 and 92 % correspondingly [27]. Results of other meta-analysis generally correspond with these data but in the latest publications noticed indicants for the ultrasonography are worse.

According to the data of «Screening for Asymptomatic Carotid Artery Stenosis: A Systematic Review and Meta-analysis for the U.S. Preventive Services», the reliability of the ultrasonography is doubtful because the accuracy can change depending on the laboratory [25]. Asymptomatic stenosis of carotid arteries is low spread in the general population among the grown population. Non-invasive screening with the usage of the ultrasound technique gives a lot of false-positive results. It is recommended to perform the confirming test to avoid the unnecessary interferences by the ultrasound diagnostic of hemodynamically significant stenosis [25].

The reason of the results difference of carotid ultrasound and DSA is the usage of the different measurement technique. In this case patients who have indications for the surgical treatment (carotid endarterectomy, stenting) can be missed and conversely patients with the moderate carotid stenosis can be directed to the surgery [18]. According to the results of the researches of J. Walker and A.R. Naylor [27], in some cases practicing physicians don't sure which criteria is necessary to use and don't know how to calculate it. The problem of method of performing ultrasound diagnostic of cervical vessels is presented in the researches and publications of different years of many international organizations — American Institute of Ultrasound in Medicine (AIUM), American College of Radiology (ACR), Society of Radiologists in Ultrasound (SRU), American Society of Echocardiography (ASE), Society of Vascular Medicine and Biology, European Association of Cardiovascular Imaging (EACVI) and other [1, 5].

Planimetric (by the diameter and area of thevessel) and hemodynamical methods are used to define the stage (percent) of artery stenosis by the duplex scanning [3, 13, 14, 23, 24]. Calculating of the stenosis by the area of the vessel transverse section [3, 11, 21]:

$$\mathbf{S = (A_1 - A_2) \cdot 100\ \% / A_1},$$

where A_1 — true area of the vessel transverse

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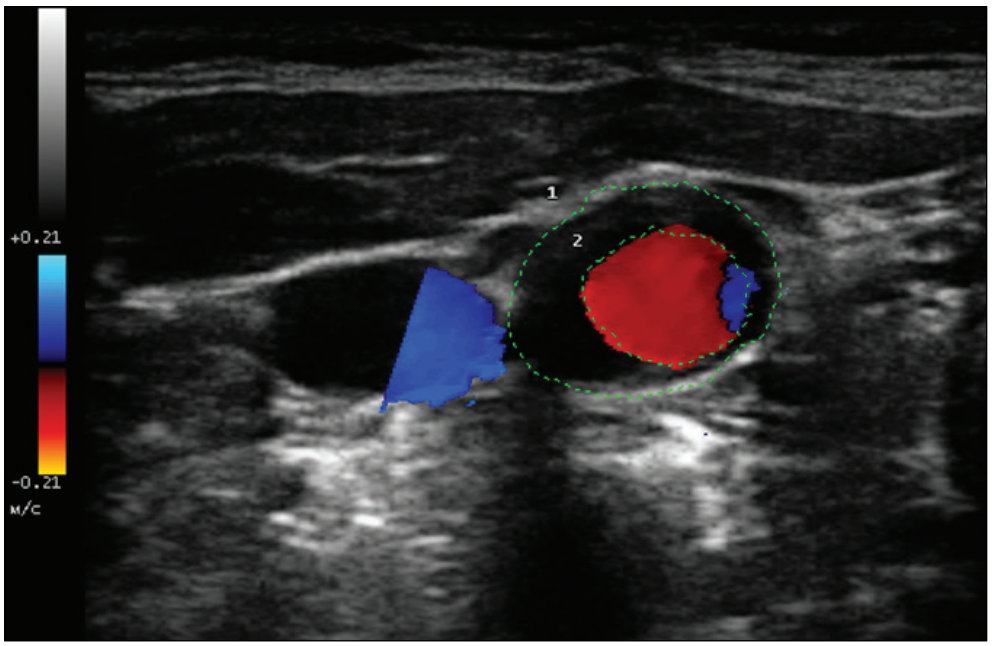

Fig. 1. *The transverse section of bifurcation of common carotid artery. Measuring of the stenosis by the area*

section; A_2 — residual area of the transverse section of the stenotic vessel.

Calculation of the stenosis by the diameter of the vessel (Sd) [3, 5]:

$$\mathbf{Sd = (D_1 - D_2) \cdot 100\ \% / D_1},$$

where D_1 — true vessel diameter; D_2 — residual diameter of the stenotic vessel.

Percent of the stenosis that is detected by the area of the vessel transverse section considers the plaque form and exceed the percent of the stenosis that is calculated by the diameter of the vessel, on 10–20 % [3]. This method is recommended for necessary usage of for the concentric and semi-concentric plaques but as addition to the percent of the stenosis by the diameter [3, 5]. The example of stenosis measuring by the area is presented on Fig. 1.

In case of measuring stenosis by the diameter the results depends on the measuring D_1 — true

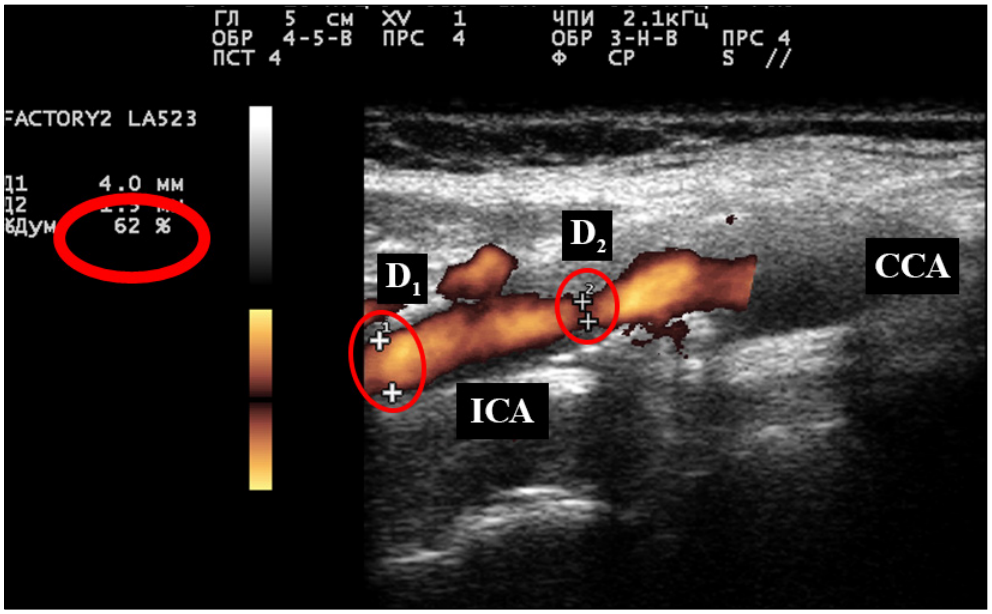

Fig. 2. *Longitudinal view: elongate plaque in the bifurcation of common carotid and of the internal carotid artery. Sketch of the stenosis calculating by the method NASCET: D_1 — true diameter of the internal carotid artery (distal places of the stenosis); D_2 — diameter of the residual lumen in the stenosis; ICA — internal carotid artery; CCA — common carotid artery*

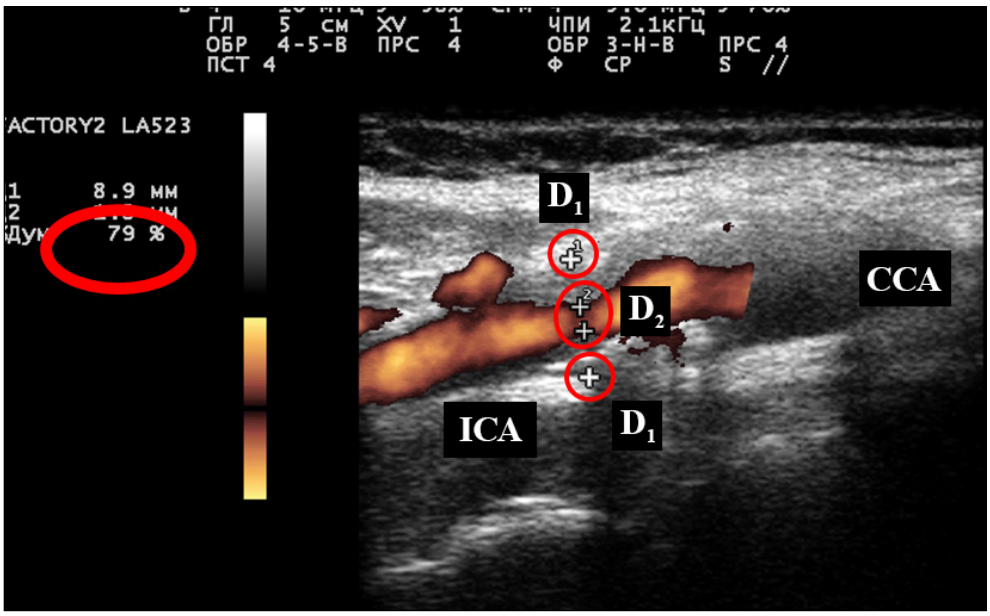

Fig. 3. *Measuring of the same plaque stenosis that in the Fig. 1. Sketch of the calculating of stenosis by the method ECST: D_1 — true diameter of the internal carotid artery (in the place of the maximal stenosis); D_2 — diameter of the residual lumen in the stenosis; ICA — Internal Carotid Artery; CCA — Common Carotid Artery*

diameter of the vessel: in the place of the stenosis or after the narrowing or before (diameter common carotid artery). NASCET (North American Symptomatic Carotid Endarterectomy Trial) [18, 21] (Fig. 2) is the acknowledged method for the measuring of the carotid stenosis by the diameter of the vessel that calculates the amount of the vessel narrowing — diameter of the residual lumen in the stenosis (D_2) in comparison with the diameter of internal carotid artery (D_1), so D_1 lumen more distal than bifurcation [18, 21]. Also ECST (European Carotid Surgery Trial) is often used, this method compares residual lumen in the stenosis (D_2) with the diameter of the artery in the point of stenosis (D_1) [3, 18] (Fig. 3).

The examples of measuring the same plaque on Fig. 1 and Fig. 2 presents the stenosis of the internal carotid artery 62 % by the diameter — method NASCET and 79 % — method ECST. Difference is very significant. Which method should be used? Method NASCET is more direct indicator of the narrowing amount of the internal carotid artery because compares stenotic part with the distal lumen of the artery [18] and more accurate defines the stenosis degree in comparison to the data of the angiography than method ECST [3]. The last gives better conception about changing the diameter in the place of the stenosis, not in distal segments. Method ECTS more convenient for the measuring in the place of the physiological widening (in bifurcation). Stenosis in the bifurcation of the carotid artery 40–50 % calculated by the method ECTS can be 0 % or 10 % by the calculation by the method NASCET if the residual lumen not as narrow as lumen of the distal internal carotid artery. In case of the non-essential narrowing in the wider area of bifurcation method ECST allows to assess changes in the point of the stenosis and in case of the usage method NASCET can be got negative indicant [18]. «Gold» standard in the diagnostic of the carotid arteries atherosclerotic lesion is the selective angiography [11, 13, 20, 21]. Comparison of stenosis size that is got by the means of the carotid ultrasound and data DSA was carried out in many researches. It was detected that data accuracy depends on the method of measuring [9–11, 13, 21, 27]. Methods of stricture formation measuring were examined in the North American research NASCET and European research ECST [11, 21]. In these researches DSA was used as method of visualisation for the diagnostic of the carotid stenosis. Received results were compared to the data of the carotid ultrasound. Comparison of two researches and methods of stenosis measuring demonstrated that stenosis of the vessel 50 % detected by the NASCET was equivalent to the 70 % stenosis in the ECST and stenosis 70 % in the ECST — to the stenosis 85 % [13, 21]. So usage of different methods leads to the receiving different results (different stenosis degree).

Table. *The assessment of hemodynamic criteria*

Stenosis % method ECST	< 50	60	70	80	90
Stenosis % method NASCET	-	-	50	67	83
Vps ICA in the area of stenosis, cm/s	< 120	120	200	300	> 400
Vd ICA in the area of stenosis, cm/s	< 40	40	80	130	> 130
Vps in the distal segment, cm/s	> 60	> 60	> 60	> 60	< 60
Collateralization activation	-	-	-	+	+

Note: ICA — internal carotid artery; Vps — peak systolic velocity; Vd — end-diastolic velocity.

Math formula, for the conversion of the stenosis size that was received by one method into the stenosis size by another method, was developed. Approximate equivalents of the internal carotid artery stenosis 50 % and 60 % calculated by the method NASCET are 75 and 80 % by the usage method ECST [13], correspondingly by the stenosis internal carotid artery 50 % calculated by the diameter by the method NASCET (absent indications to the surgical treatment), measuring stenosis by the another method demonstrated 70 % (indicated surgical treatment) [2, 3]. According to the recommendations by the defining the volume of evaluations for detecting indications for the performing surgical treatment by more correct method of detecting stenosis degree is NASCET (level of evidence is B) [3, 15, 18].

Literature data analysis gives the base for the next conclusions: measuring method NASCET has to be the standard [1, 3]; the place of the narrowing can be measured by the method ECST as the additional measuring but in the protocol has to be noticed which method was used to calculate the percent of the stenosis [2]. It will allow to avoid the confusion between themedical specialists, neurologist, neurosurgeon and also avoid unnecessary angiographies.

For avoiding the mistaken diagnostic of the severe stenosis by the data of the carotid ultrasound can help the usage of hemodynamic criteria. Measuring of the speed in the area of the stenosis (Vps) is enough to differ moderate stenosis from severe (≥ 70 % by the method NASCET) with the enough clinical accuracy [16]. Hemody-

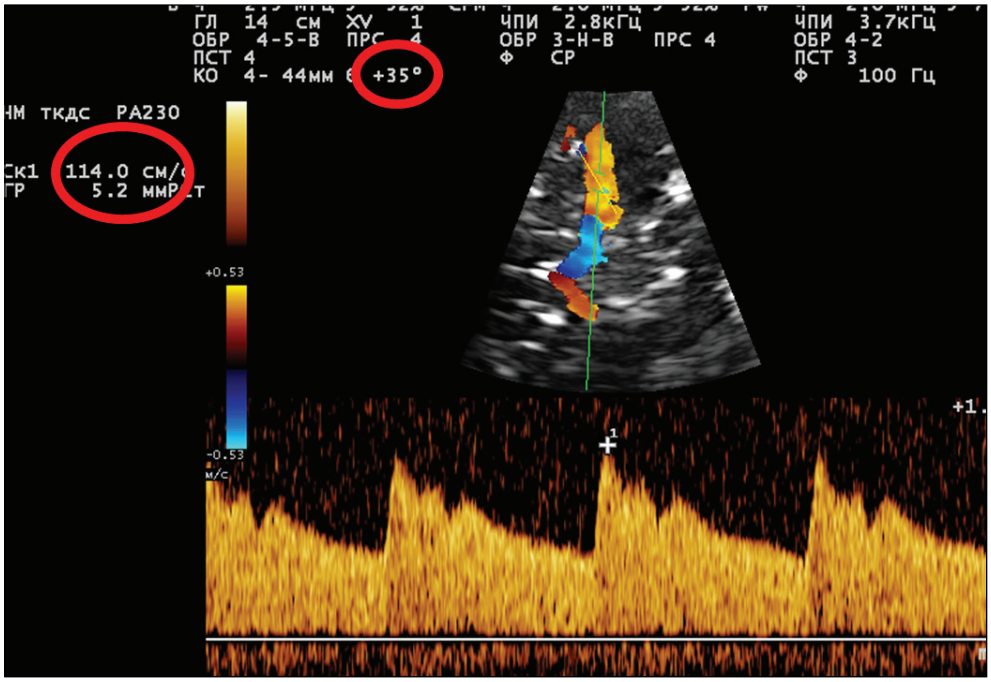

Fig. 4. *Middle cerebral artery. Zoom Mode. Velocity blood flow measurement. In the settings angle α is 35°*

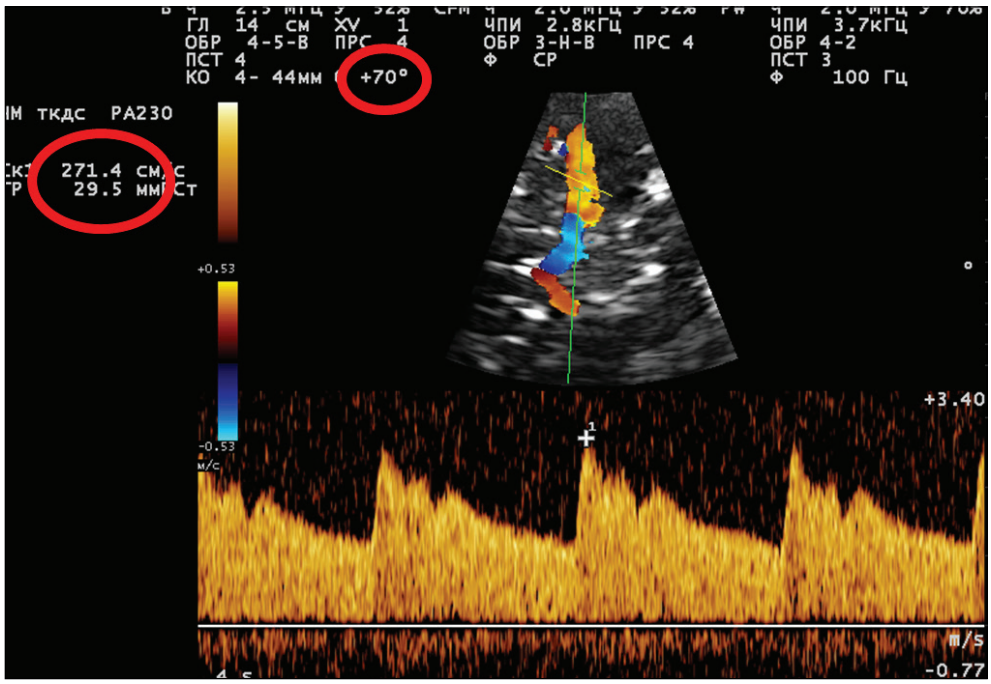

Fig. 5. *Middle cerebral artery. Zoom Mode. Velocity blood flow measurement. In the settings angle α is 70°*

namic criteria are recommended for the differentiation of moderate and severe stenosis [1, 4, 15]. Also it is recommended the search of collateral redistribution — assessment of the blood flow by examining of the ophthalmic artery, indicants presence of anterior and posterior communicating arteries functioning (transcranial Doppler sonography) [15]. Indicants of the activation of the collateral redistribution are specific for the hemodynamically significant stenosis. Therewith it is recommended to assess poststenotic speed of the blood flow in the distal segment, decreasing of which in comparison to the intact side allows additionally diagnose the severe stenosis [3, 6, 18, 22]. Approximate hemodynamic changes depending on the size of the stenosis are presented in the Table [4]. Disadvantage of the hemodynamic criteria is that it cannot be used for the patients with the general defect of perfusion, apparent hyperaemia, patients of the young age, and the fact that arterial hypertension influences on the speed of the blood flow, left ventricular ejection fraction, vasodilators reception, incorrect correction of Doppler angle.

Also it is necessary to remember that combined lesion influences on the size of the increasing of blood flow velocity in the place of the stenosis. Hemodynamic difference will be less in case of presence apparent stenosis more proximal. Also increasing of the blood flow velocity in the place of the stenosis will less apparent in case of the prolonged damage.

From the ultrasound hemodynamic criteria of stenosis prestenotic and poststenotic blood flow velocity and also peak velocity in the place of the maximal narrowing are assessed. It is necessary to adhere the rules of investigation in the Doppler mode for detecting real blood flow velocity in blood vessels. Special attention is recommended to pay to the size of the angle α [8, 16]. «Correct» blood flow velocity in the artery will depend on the angle size that is set by the doctor in the settings of the ultrasonic equipment. On the Fig. 4 and Fig. 5 measuring of the velocity in the middle cerebral artery at the different sizes of angle α is presented. The same patient, the same artery. At the angle 35° velocity was 114 cm/s, at the angle 70° — 271 cm/s. In this example indicated size of the angle α is wrong on the both pictures. Correct size of the angle α that is set by the doctor in the setting of the ultrasonic equipment has to be maximal parallel to coincide with the direction blood flow in the blood vessel. In the indicated examples on the Fig. 4 and Fig. 5 blood flow nearly parallel to the ultrasonic rays path. Corresponding correct angle α for receiving «correct velocity» has to be indicated as 5°. Adhering the Doppler principles of measuring of the blood flow quantitative indices is the base for receiving correct Doppler information. Also it is necessary

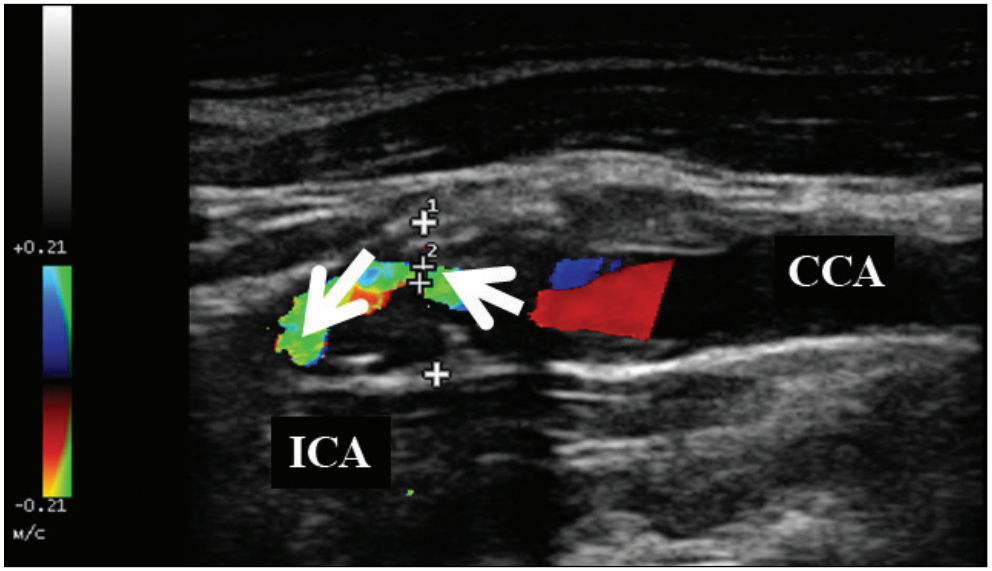

Fig. 6. *Color-flow duplex scanning: elongate plaque in the bifurcation of the common (CCA) and internal (ICA) carotid artery. Blood flow direction in the stenotic segment doesn't concur to the direction of the vessel course (indicated by the arrow)*

to remember that any Doppler measurements have to be performed at the angle α less 60° and the smaller the angle, the smaller the error.

In case of the atherosclerotic disease directly in the place of the stenosis blood flow direction can be discordant to the direction of the blood vessel course (Fig. 6). For receiving «correct» velocity by the measurement in the Pulsed Wave Doppler it is necessary to perform measuring by the usage of minimal possible angle as related to the direction of the stream flow by the atherosclerotic disease and not by the blood vessel location [17]. On the Fig. 6 approximate settings of the Doppler angle situation in dependence of the flow direction are indicated by the arrow.

Besides errors in the measurements the reason of the mistakes in the ultrasound investigations can be the phenomenon of the apparent acoustic shadowing [16, 19]. Usually proximal segment of the internal carotid artery is easily visualized and stenosis on this segment is easily available for the ultrasonic assessment. However apparent vessel wall calcification determines the appearing of the acoustic shadowing that leads to the difficulties with the visualization of this segment. Big calcific plaque by the data of the Color-flow duplex scanning can create the visibility of the blood flow absence by the length of couple centimetres that is connected with the big degree of the ultrasound reflection on the border of two mediums with the different acoustic density. Absence of the plaque «edges» in the B-mode are presented on the Fig. 7. In the B-mode by the longitudinal scanning in the internal carotid artery echo-shadow is visualized. It is impossible to perform the planimetric measurement of the the blood flow size. In this case is registered absence of the blood flow of this segment in the Doppler ultrasound. Phenomenon of the acoustic shadowing remains after the angioplasty and stenting and can be the reason of diagnostic of the stent pseudostenosis and pseudo-occlusion. In these cases the data of computer tomography and/or angiography are the most correct. Severe stenosis can be «suspected» in presence of the acoustic shadowing according to the ultrasonic data concerning decreasing the blood flow more distal than location of the damage in comparison with contralateral side, collateralization activation.

One more reason of the incorrect conclusions of the carotid ultrasound is the «anatomically difficult» patient. Visual and hemodynamic assessment of the stenosis is complicated in case of the high anatomical location of the bifurcation of the common carotid artery (on the level of the mandibular angle). In case of the big length of the cervical segment of the internal carotid artery and presence of the damage in the distal segment appears difficulties with the assessment of the hemodynamic parameters behind the area of the stenosis [8, 16, 17].

Presence of the concentric elongated damage and sufficient residual lumen can lead to the wrong results in case of the comparison of the DSA and data received as the result of the ultra-

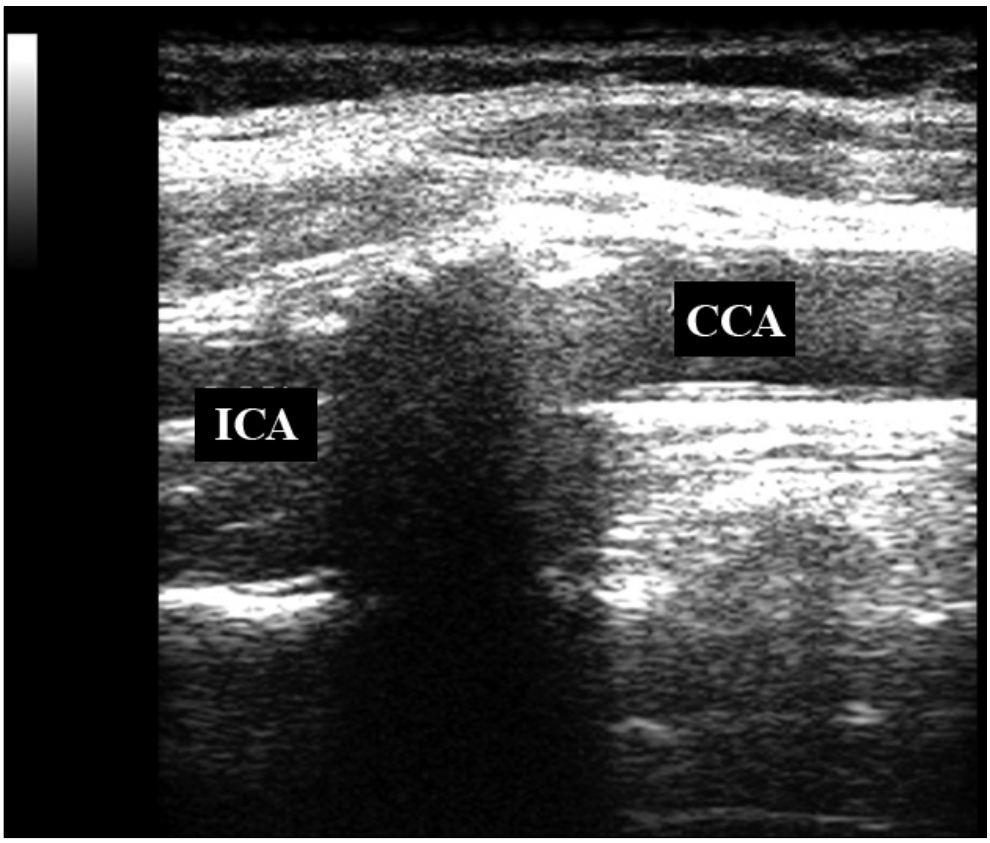

Fig. 7. *B-mode, longitudinal view. Atherosclerotic plaque with the phenomenon of the acoustic shadowing in the internal carotid artery: ICA — Internal Carotid Artery; CCA — Common Carotid Artery*

sound investigation. So on the Fig. 8 by the data of the carotid ultrasound, atherosclerotic plaque narrows the vessel from 25 to 60 % by the diameter and by the performing of the digital substraction angiography the same segment doesn't seemed so pathologically changed (Fig. 9).

Measuring of the stenosis «by eye» by sonologists or neurosurgeons can lead to the overvaluation or undervaluation of the stenosis size. On the Fig. 10 Angiogram data of the patient with the internal carotid artery stenosis nearly 50 % by the NASCET method by the program calculation

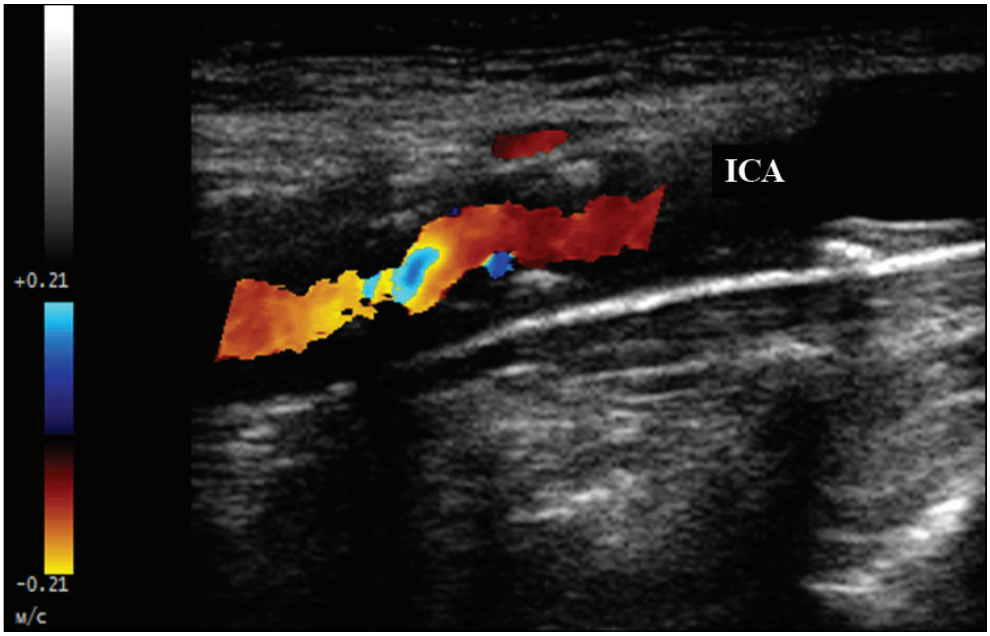

Fig. 8. *Elongated concentric plaque in the Internal Carotid Artery*

Fig. 9. *Common carotid artery. Indicated the segment of the internal carotid artery where by the data of the carotid ultrasound diagnostic elongated concentric narrowing to 60 % is present*

data. In case of the assessment «by eye» most doctors diagnosed stenosis nearly 70 %.

Conclusions

Carotid ultrasound investigation allows to assess the atherosclerosis of the cervical vessels with the high accuracy. By the literature data and own supervisions ultrasound assessment of the carotid stenosis can lead to the wrong results in comparison with data received as the result of the digital substraction angiography performing. Such cases are supervised notwithstanding that ultrasound method of the stenosis severity assessment accurate described and clinically proven but technologies of the carotid ultrasound are continuously developing.

Group of «difficult» patients for the ultrasonic investigation consist of patients with the anatomic features (short neck, high anatomical location of the bifurcation of the common carotid artery (on the level of the mandibular angle), big length of the cervical segment of the internal carotid artery and presence of the damage in the distal segment). Phenomenon of the acoustic shadowing complicates ultrasonic assessment. Presence of the concentric elongated damage and sufficient residual lumen of the vessel can lead to disparities with the data of the digital subtraction angiography. Incorrect indices can appear because of the method errors: measuring «by eye», wrong correction of the angle α in the Doppler ultrasound. It is recommended to assess the percent of the artery diameter narrowing by the NASCET method. Each method of the visualisation has advantages and disadvantages so results correlation that received by the couple of methods has to be the part of the program of quality guaranty in each laboratory and facility.

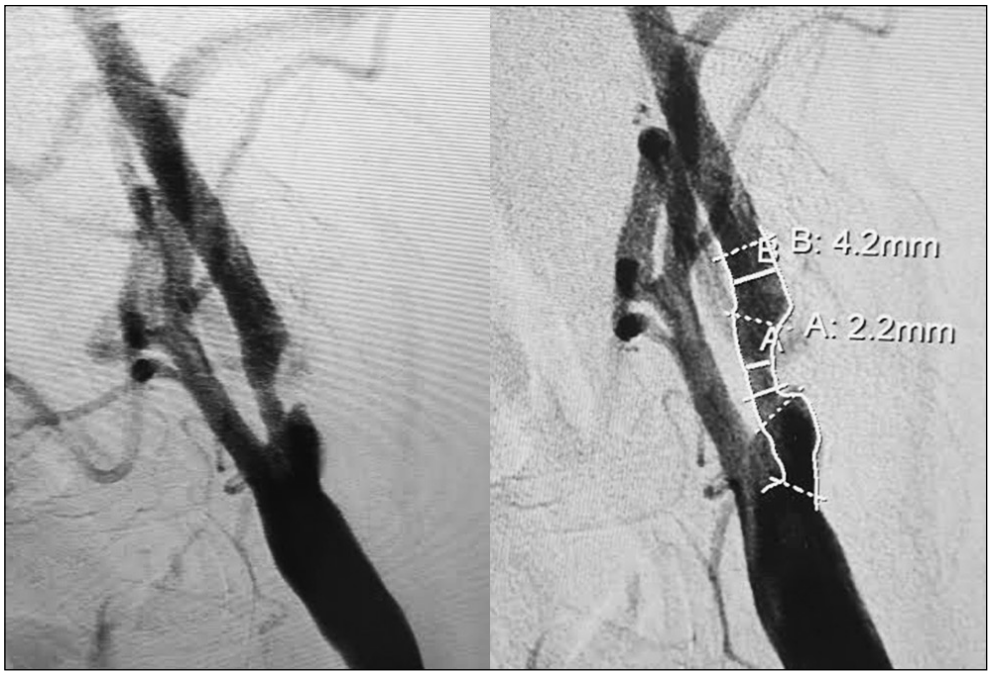

Fig. 10. *Measuring of the stenosis «by eye». Digital subtraction angiography: Internal carotid artery stenosis nearly 50 % by the NASCET*

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УЛЬТРАЗВУКОВАЯ ОЦЕНКА СТЕНОЗОВ СОННЫХ АРТЕРИЙ ПО СРАВНЕНИЮ С АНГИОГРАФИЕЙ. ПОЧЕМУ МЫ ДЕЛАЕМ ОШИБКИ И КАК ИХ ИЗБЕЖАТЬ?

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Атеросклеротическое поражение сонных артерий — частая причина возникновения нарушения мозгового кровообращения. Выявить и оценить тяжесть стеноза артерий позволяют неинвазивные диагностические методики: дуплексное сканирование сонных артерий, магнитно-резонансная и компьютерно-томографическая ангиография. К малоинвазивным методам относится селективная рентгеноконтрастная цифровая субтракционная ангиография. Селективная ангиография является золотым стандартом в диагностике атеросклеротического поражения сонных артерий. Методика позволяет всесторонне оценить сосуды, которые кровоснабжают головной мозг и одновременно провести эндоваскулярную операцию.

Дуплексное сканирование сонных артерий, магнитно-резонансная и компьютерно-томографическая ангиография показали высокую чувствительность и специфичность для диагностики стеноза сонных артерий по сравнению с рентгеноконтрастной цифровой субтракционной ангиографией. Ультразвуковое исследование — быстрое, относительно недорогое диагностическое исследование. Хотя результаты дуплексного сканирования сонных артерий могут сильно отличатся в разных лабораториях и у разных исследователей, чувствительность и специфичность этого исследования высокие.

Проанализированы результаты собственных исследований и данные литературы относительно возможностей ультразвукового исследования при стенозах экстракраниальных артерий по сравнению с рентгеноконтрастной цифровой субтракционной ангиографией. Приведены возможные причины отличия результатов, полученных разными методами.

Ключевые слова: атеросклероз, сонные артерии, стеноз, ультразвуковая диагностика, селективная рентгеноконтрастная цифровая субтракционная ангиография.

УЛЬТРАЗВУКОВА ОЦІНКА СТЕНОЗІВ СОННИХ АРТЕРІЙ ПОРІВНЯНО З АНГІОГРАФІЄЮ. ЧОМУ МИ РОБИМО ПОМИЛКИ І ЯК ЇХ УНИКНУТИ?

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Атеросклеротичне ураження сонних артерій — часта причина виникнення порушення мозкового кровообігу. Виявити та оцінити тяжкість стенозу артерій дають змогу неінвазивні діагностичні методики: дуплексне сканування сонних артерій, магнітно-резонансна та комп'ютерно-томографічна ангіографія. До малоінвазивних методів належать селективна рентгеноконтрастна цифрова субтракційна ангіографія. Селективна ангіографія є золотим стандартом у діагностиці атеросклеротичного ураження сонних артерій. Методика дає змогу оцінити судини, які кровопостачають головний мозок і одночасно провести ендоваскулярну операцію.

Дуплексне сканування сонних артерій, магнітно-резонансна та комп'ютерно-томографічна ангіографія показали високу чутливість і специфічність для діагностики стенозу сонних артерій порівняно з рентгеноконтрастною цифровою субтракційною ангіографією. Ультразвукове дослідження — швидке, відносно недороге діагностичне дослідження. Хоча результати дуплексного сканування сонних артерій можуть дуже відрізнятися у різних лабораторіях та у різних дослідників, чутливість і специфічність цього дослідження є високими.

Проаналізовано результати власних досліджень та дані літератури щодо можливостей ультразвукового дослідження при стенозах екстракраніальних артерій порівняно з рентгеноконтрастною цифровою субтракційною ангіографією. Наведено можливі причини відмінностей результатів, отриманих різними методами.

Ключові слова: атеросклероз, сонні артерії, стеноз, ультразвукова діагностика, селективна рентгеноконтрастна цифрова субтракційна ангіографія.