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THE EVALUATION OF THE HEMODYNAMICALLY SIGNIFICANT STENOSIS OF THE CAROTID ARTERIES: ANALYZING THE RESULTS FROM THE DUPLEX SCANNING OF VESSELS, FROM THE COMPUTED TOMOGRAPHIC AND THE TRANSCATHETER X-RAY CONTRAST ANGIOGRAPHY

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ABSTRACT

BACKGROUND: *Atherosclerotic stenosis of the carotid arteries is one of the main reasons of stroke, of transient ischemic attacks, of developing cognitive disorders and of incapacitating the population. The key indication to invasive treatment for this disease is the degree of stenosis in the carotid artery, due to which the most important problem in the diagnostics is the maximally precise evaluation of the stenosis degree. The duplex scanning of the carotid arteries is a safe, non-invasive and relatively inexpensive visualization method, which is the first line of diagnostics. The precision of measuring the stenosis and the occlusion of the carotid artery, according to the ultrasound examination data, varies from 70% to 90%. At the same time, the degree of stenosis, measured using various methods, does not always match.* ***AIM:*** *to compare the data obtained by duplex scanning of the brachiocephalic arteries and by other instrumental diagnostics methods in terms of the precision of measuring the percentage of stenosis in the carotid arteries, as well as to analyze the reasons of discrepancies between the obtained data.* ***METHODS:*** *The research is based on the retrospective analysis of case history data from the patients hospitalized to the Vascular Surgery Department of the Federal State Budgetary Institution «Federal Scientific and Clinical Center» under the Russian Federal Medical-Biological Agency during the period from 01.05.2023 until 20.05.2024. The obligatory inclusion criteria for the analysis were the presence of the main disease of the I65 group according to the ICD-10 and undergoing at least one of the examination types within the settings of the FSBI «Federal Scientific and Clinical Center» under the Russian Federal Medical-Biological Agency (duplex scanning, computed tomographic angiography, transcatheter X-ray contrast angiography). The statistical processing was done using the Statistica software pack version 10.0 (StatSoft).* ***RESULTS:*** *The conducted research has shown that there is no complete matching between the data from the transcatheter X-ray contrast angiography, the computed tomographic angiography and the duplex scanning. The analysis of the reasons of discrepancies when measuring the degree of stenosis in the orifices of the internal carotid arteries from the results of duplex scanning and computed tomographic angiography has allowed for isolating three main groups: the human factor (operator-dependent, 30.4%), the anatomic factor (23.2%) and the differences in descriptions (46.4%).* ***CONCLUSION:*** *Upon examining the patients, it is necessary to strictly follow the algorithm of diagnosing the stenoses of the carotid arteries, beginning from the duplex scanning of the extracranial segments of brachiocephalic arteries as the most accessible and highly informative method. Computed tomographic angiography of this vascular segment is required for selecting the patients for surgical treatment, for it is necessary to keep in mind the potential risk of developing the contrasted nephropathy and the risks of radiation exposure. A properly done ultrasound examination allows for not only decreasing the number of discrepancies between these two diagnostic methods, but also to avoid the necessity of conducting such an invasive radio-contrasting method as angiography.*

Keywords: *duplex; carotid artery internal; carotid stenosis; reasons for discrepancies; data comparison.*

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ОЦЕНКА ГЕМОДИНАМИЧЕСКИ ЗНАЧИМОГО СТЕНОЗА СОННЫХ АРТЕРИЙ: АНАЛИЗ РЕЗУЛЬТАТОВ ДУПЛЕКСНОГО СКАНИРОВАНИЯ СОСУДОВ, КОМПЬЮТЕРНО-ТОМОГРАФИЧЕСКОЙ И ЧРЕСКАТЕТЕРНОЙ РЕНТГЕНОКОНТРАСТНОЙ АНГИОГРАФИИ

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АННОТАЦИЯ

Обоснование. *Атеросклеротический стеноз сонных артерий является одной из основных причин инсульта, транзиторной ишемической атаки, развития когнитивных нарушений, инвалидизации населения. Ключевым показанием к инвазивному лечению данного заболевания является степень стеноза сонной артерии, в связи с чем важнейшей проблемой диагностики является максимально точное определение выраженности стеноза. Дуплексное сканирование сонных артерий является безопасным, неинвазивным, относительно недорогим методом визуализации, являясь первой линией диагностики. Точность определения стеноза и окклюзии сонной артерии по данным ультразвукового исследования составляет от 70% до 90%. Вместе с тем степень стеноза, определённая разными методами, не всегда совпадает.* ***Цель исследования*** *— сопоставить данные дуплексного сканирования брахиоцефальных артерий и других инструментальных методов диагностики в точности определения процента стеноза сонных артерий, а также провести анализ причин расхождения полученных данных.* ***Методы.*** *Исследование основано на ретроспективном анализе данных историй болезни пациентов, госпитализированных в отделение сосудистой хирургии ФГБУ ФНКЦ ФМБА России в период с 01.05.2023 по 20.05.2024. Обязательными критериями включения в анализ являлись наличие основного заболевания группы I65 по МКБ-10 и выполнение любых двух исследований в условиях ФГБУ ФНКЦ ФМБА России (дуплексное сканирование, компьютерно-томографическая ангиография, чрескатетерная рентгеноконтрастная ангиография). Статистическая обработка проводилась с использованием пакета программ Statistica версии 10.0 (StatSoft).* ***Результаты.*** *Обнаружено отсутствие полного совпадения между данными чрескатетерной рентгеноконтрастной ангиографии, компьютерно-томографической ангиографии и дуплексного сканирования. Анализ расхождений в оценке степени стеноза устьев внутренних сонных артерий по результатам дуплексного сканирования и компьютерно-томографической ангиографии позволил выделить три основные группы причин: человеческий фактор (операторзависимость, 30,4%), анатомический фактор (23,2%), различия описаний (46,4%).* ***Заключение.*** *При обследовании пациентов необходимо строго придерживаться алгоритма диагностики стенозов сонных артерий, начиная с дуплексного сканирования экстракраниальных отделов брахиоцефальных артерий как наиболее доступного и высокоинформативного метода. Компьютерно-томографическая ангиография данного сосудистого бассейна необходима при отборе пациентов для хирургического лечения, так как необходимо помнить о потенциальном риске развития контрастной нефропатии и радиационного воздействия. Качественно выполненное ультразвуковое исследование позволяет не только снизить число противоречий между этими двумя методами диагностики, но и избежать необходимости проведения такого инвазивного рентгеноконтрастного метода исследования, как ангиография.*

Ключевые слова: *дуплексное сканирование; внутренняя сонная артерия; стеноз сонной артерии; причины расхождений; сопоставление данных.*

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BACKGROUND

Atherosclerotic stenosis of the carotid arteries is an important cause of stroke, of transient ischemic attack, of developing cognitive disorders and of incapacitating the population. It is not very often when it is considered a marker of systemic atherosclerotic vascular lesions, commonly being associated with the ischemic heart disease and with the lesions in the arteries of the lower limbs [1].

According to data from the World Health Organization, in 2021, within the territorial borders of the Russian Federation, the ischemic stroke was the cause of death of more than 200 000 persons, which makes it the third most frequent cause of death in the country at that year [2]. In the worldwide statistics, stroke is the second leading cause of incapacitation and mortality [3–5]. Every year worldwide approximately 6 million people die of this disease, approximately 5 million become disabled[1] [6]. The most widespread causes of cerebral infarction are the stenotic-occlusive lesions of the brachiocephalic arteries [7, 8].

Currently, when providing medical aid to the patients with the lesions in the carotid arteries, first of all, it is necessary to follow the two officially validated documents: "The national recommendations on managing the patients with the diseases of the brachiocephalic arteries" (2013) [5] and the guidelines from the Ministry of Health of the Russian Federation "Occlusion and stenosis of the carotid artery" (2016) [9]. In 2022, a Russian Consensus on the diagnostics and treatment of patients with the stenosis of the carotid arteries was also published, which, however, was not approved by the Ministry of Health of the Russian Federation and which has a recommendatory value.

One of the main indications to the invasive treatment is the degree of stenosis in the carotid artery [5]. Hence, the most important diagnostic problem is the maximally precise determination of the severity of stenosis. It is also important to note that the main diagnostic criteria were compiled based on the two large trials conducted in 1980–1990 and based only on the angiography findings [10, 11].

As of today, the examination of the patients with suspected atherosclerotic lesions in the carotid arteries includes several instrumental diagnostics methods: the duplex scanning (DS) of the brachiocephalic arteries, the computed tomographic angiography (CTA) and the transcatheter X-ray contrast angiography (AG).

With every passing year, the number of surgical interventions in the brachiocephalic arteries irreversibly grows. The surgeons show the tendency of preferring the usage of data from the computed tomographic angiography without taking into account the results of vascular duplex scanning (due to the dependence of visualization by means of DS on a specific operator).

Research aim — to compare the data obtained during the duplex scanning of brachiocephalic arteries, conducted at the Federal State Budgetary Institution "Federal Scientific and Clinical Center for Specialized Types of Medical Aid and Medical Technologies" under the Federal Medical-Biological Agency" (FSBI "Federal Scientific and Clinical Center" under the Russian Federal Medical-Biological Agency) with other instrumental diagnostics methods in terms of the precision of measuring the percentage of stenoses in the carotid arteries, as well as to analyze the reasons of discrepancies in the obtained data.

METHODS

Research design

A retrospective analysis was conducted with including the data from the case histories of the patients hospitalized the Vascular Surgery Department of the FSBI "Federal Scientific and Clinical Center" under the Russian Federal Medical-Biological Agency during the period from 01.05.2023 until 20.05.2024. The analysis included the anonymized case history data (gender, age, conducted surgical interventions in the carotid system vessels) along with the examination protocols for brachiocephalic arteries (DS, CTA, AG).

Conformity Criteria

Inclusion criteria: the presence of the main disease from the I65 group (occlusion and stenosis of the pre-cerebral arteries, not resulting in a cerebral infarction) according to the International Classification of Diseases (10th revision) and undergoing at least one of the examinations within the premises of the FSBI "Federal Scientific and Clinical Center" under the Russian Federal Medical-Biological Agency (duplex scanning, computed tomographic angiography, transcatheter X-ray contrast angiography).

Research findings

The comparative analysis also included the data on the differences observed when assessing the percentage of stenosis in the orifices of the internal carotid arteries when using two of the three methods (if any). The main analysis of discrepancies was carried

[1] World Health Organization [Internet]. Health affairs. Available from: https://www.who.int/ru Accessed: March 3, 2025.

out in groups: the percentage of stenosis according to CTA data minus the percentage of stenosis according to DS data (CTA-DS) and the percentage of stenosis according to DS data minus the percentage of stenosis according to AG data (DS-AG).

Statistical analysis

The statistical processing was done using the ''Statistica'' software package Version 10.0 (StatSoft). Due to the impossibility of following the normal distribution criteria, the statistical analysis was undertaken with using the non-parametric statistics criteria. The statistical significance was stated as the value of p <0.05. As for the quantitative indicators, the continuous variables were presented as the median and the lower/upper quartiles (Me [25%; 75%]). The differences of the quantitative indicators were assessed using the Mann-Whitney U test.

RESULTS

Research sample (participants)

Data from the case histories of 207 patients were analyzed, of which 140 (68%) were males and 67 (32%) were females, the mean age at the moment of hospitalization of which was 68.9 years (median — 69 years with a range from 42 to 89 years), with the mean age of males significantly differing from the mean age of females — 67.7 vs. 71.4, respectively (Z=2.9; p=0.003).

All the 207 patients were undergoing diagnostic examinations: CTA — 189, DS — 164, AG — 21, with 16 patients having all the mentioned types of examinations (all of them being operated). Before the conduction of AG, CTA was always carried out. The combined diagnostics by means of CTA and DS was reported for 146 patients.

All the patients were divided into groups by the number of imaging methods involved in the examination. The distribution of methods among the patients operated during the present hospitalization (n=171), is shown in Fig. 1.

Primary findings

We have arranged a detailed analysis of data in two groups of patients: 16 individuals in which all the three types of examinations were carried out (Group 1); 130 individuals undergoing CTA and DS (without the inclusion of the patients from Group 1; Group 2).

In 16 patients of the Group 1, the described findings included lesions in 27 internal carotid arteries (ICA) with the stenoses of various degree of intensity: upon the paired comparison of the data from three methods (CTA-DS, CTA-AG, DS-AG), no significant differences were found (Fig. 2). Predominantly, the scattering

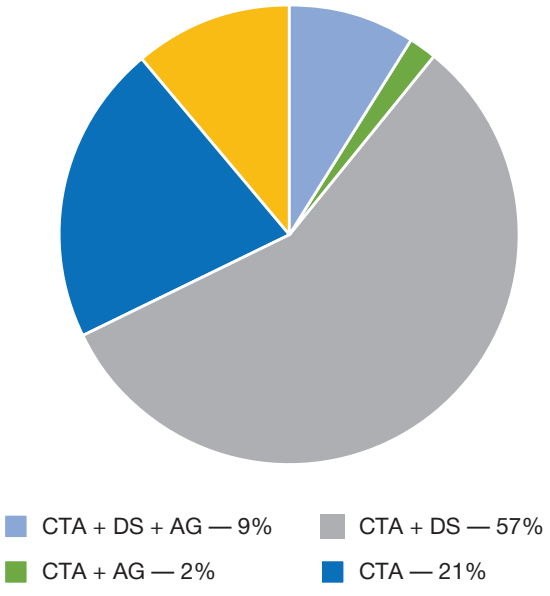

Fig. 1. The structure of pre-operational examination in patients with hemodynamically significant stenosis of the carotid arteries. CTA — computed tomographic angiography; DS — duplex scanning of the brachiocephalic arteries; AG — transcatheter X-ray contrast angiography. [From the archive of the Federal State Budgetary Institution «Federal Scientific and Clinical Center» under the Russian Federal Medical-Biological Agency, 2025. Published for the first time].

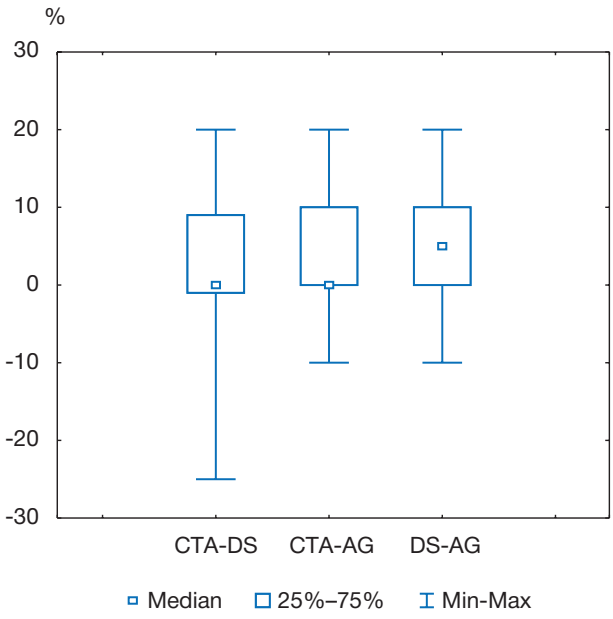

Fig. 2. Paired comparison of the results from three diagnostic methods. CTA — computed tomographic angiography; DS — duplex scanning of the brachiocephalic arteries; AG — transcatheter X-ray contrast angiography. [From the archive of the Federal State Budgetary Institution «Federal Scientific and Clinical Center» under the Russian Federal Medical-Biological Agency, 2025. Published for the first time].

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of data was 10%. Higher scattering of data was found for DS.

The detailed analysis of the detected 5 (18.5%) cases of discrepancies >10% has demonstrated the following:

Patient No. 68: the percentage of stenosis acc. to DS data was higher comparing to the CTA by 15%, but the stenosis was hemodynamically insignificant, due to which further AG was done only on the contralateral side, where there was a hemodynamically significant atherosclerotic plaque.

Patient No. 206: underestimation of stenosis comparing to CTA by 10%, comparing to AG — by 15%.

Patient No. 141: according to data from DS, the stenosis is 20% less than comparing to data from CTA and AG, probable cause — underestimation of hemodynamic criteria.

Patient No. 189: the patient from the ICU with the diagnosis of acute cerebrovascular event on the left side; underestimation of stenosis according to data from DS by 20%.

Patient No. 185: according to data from DS, the stenosis is 25% higher comparing to data from CTA, but the DS result was completely matching with the AG findings.

A total of 130 patients from the group 2 — 202/260 (77.7%) ICA — had atherosclerotic plaques. The distribution of differences in evaluating the stenoses between CTA and DS is shown in Fig. 3. In 149/202 (73.8%) ICA, there were no deviations or they were within the range of 10%, in 23/202 (11.4%) — from 15 to 20%, in 15/202 (7.4%) — ≥20%, with the predominance of higher stenosis degree in the results of the DS — 26 (12.9%) cases, while lower percentage of stenosis was found in 12 (5.9%) cases.

For the purpose of comparison, data were analyzed on the severity of stenoses in the ICA orifices using the methods of CTA and DS comparing to the AG data, for particularly this method is the gold standard in assessing the stenoses. The groups of AG-CTA and AG-DS (Fig. 4) did not show any differences, though it is necessary to note that the transcatheter X-ray contrast angiography was done only in 21 patients and only with an evaluation of stenosis degree in the zone of interest.

When analyzing the discrepancies in evaluating the degree of stenosis in the orifices of the ICA on the results of DS and CTA >10% (56 ICA in both control groups with the exclusion of two cases, where the DS findings differed from only one of the control methods — AG or CTA), several causative factors can be pointed out.

- The human factor, or the operator dependence (17 patients, 30.4%): in this group, we have summarized the discrepancies of >10%, revealed when analyzing the medical documentation, but without the presence of other evident cause.

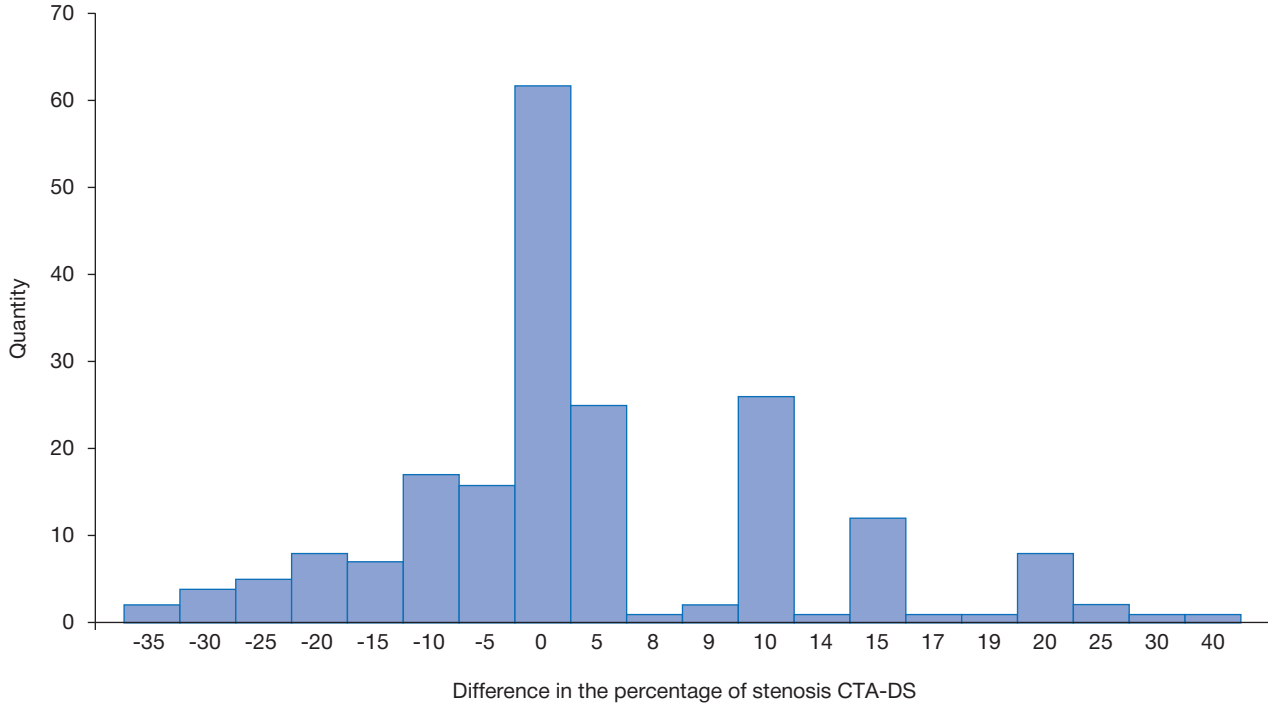

Fig. 3. The histogram of the distribution of differences in evaluating the stenoses in the orifices of the internal carotid arteries (CTA data minus DS data). CTA — computed tomographic angiography; DS — duplex scanning of the brachiocephalic arteries; АГ — transcatheter X-ray contrast angiography. [From the archive of the Federal State Budgetary Institution "Federal Scientific and Clinical Center" under the Russian Federal Medical-Biological Agency, 2025. Published for the first time].

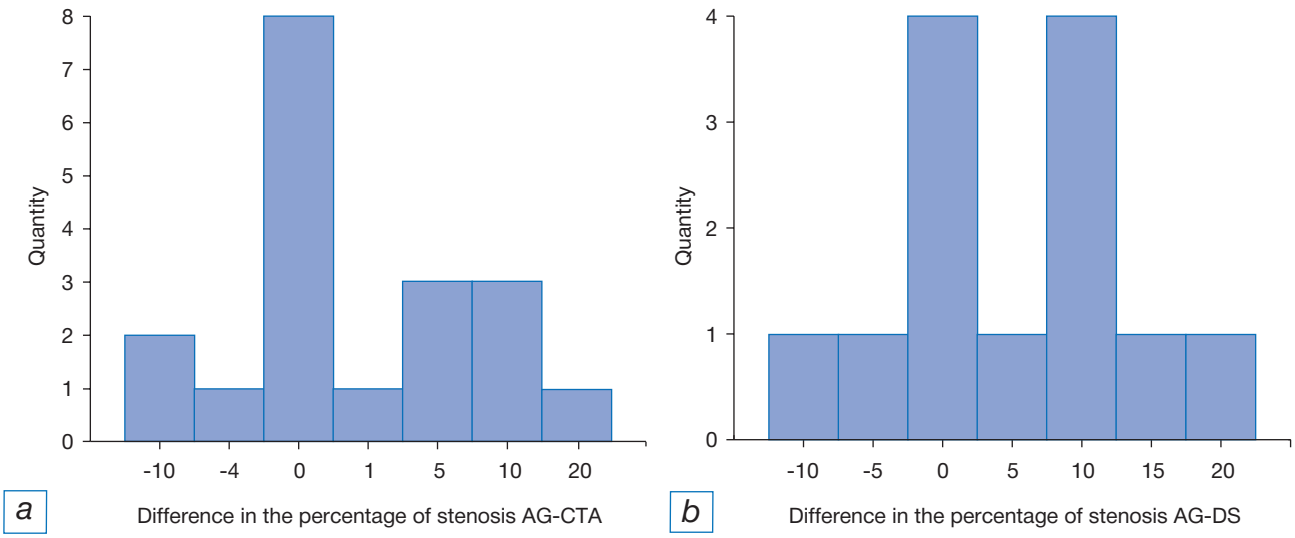

Fig. 4. The histogram of the distribution of differences in evaluating the stenoses in the orifices of the internal carotid arteries: *a* — AG data minus CTA data; *b* — AG data minus DS data. CTA — computed tomographic angiography; DS — duplex scanning of the brachiocephalic arteries; AG — transcatheter X-ray contrast angiography. [From the archive of the Federal State Budgetary Institution «Federal Scientific and Clinical Center» under the Russian Federal Medical-Biological Agency, 2025. Published for the first time].

- The anatomic factor (13 patients, 23.2%): this group summarized all the discrepancies, which were based on the difference in the interpretation of the degree of stenosis by the anatomical landmarks (visualization of the carotid bifurcation, of the orifice and of the proximal segment of ICA).
- Description differences (26 patients, 46.4%): in this group, we have summarized the cases in which there was a clearly trackable difference in the interpretation of data from different examinations. This group included the discrepancies related to the visualization of plaques (10%, 15% by the CTA data) and the discrepancies in evaluating the stenoses (less than 50%). The separation of the group of plaques "without significant stenosing" according to the CTA data was not taken into account. This group also contained the cases when the difficulties were occurring when interpreting the hemodynamical data for the stenoses.

Thus, the conducted research has shown that there is no complete matching between the data from AG, CTA and DS. When evaluating the degree of stenoses in the ICA orifices, the DS data were equivalent to the CTA data. The widely known drawback of ultrasound diagnostics is the dependence of the examination results on the operator, which may lead to differences in interpreting the obtained data not only between several specialists, but even upon the repeated examinations done by the same specialist. The operator dependence of ultrasonic methods leads to the necessity of using confirmatory methods (CTA, AG) when selecting the candidates for surgical treatment. We have found that the highest percentage of discrepancies between CTA and DS was related to the cases of stenoses reaching up to 50%, not least because of the difference in the criteria for evaluating such stenoses. The less frequent, but more significant reason of discrepancies was the difference in the interpretation of some anatomic structures and in the circulation criteria.

DISCUSSION

X-ray contrast angiography is the gold standard in the diagnostics of the lesions in the arteries, however, as of today, the higher significance in the diagnostics of the carotid artery stenosis, as well as in making the clinical decisions on determining the indications to surgical interventions is gained by the duplex scanning of the brachiocephalic arteries[1].

The duplex scanning of the carotid arteries is a safe, non-invasive and relatively inexpensive visualization method. This method allows for evaluating the circulation in the bulb and in the proximal part of the ICA. The distal ICA segments are not always accessible for scanning [2]. Generally, when evaluating the stenosis using the DS method, it is recommended to pay attention not only to the planimetric changes, but also to the specific features of circulation [12].

As the confirmatory examination for the setting the definitive diagnosis and for evaluating the necessity and the type of surgical treatment,

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contrast-enhanced methods are required, such as the X-ray contrast transcatheter angiography, the magnetic resonance angiography or the computed tomographic angiography [2].

The clinical significance of computed tomographic angiography is due to the anatomical correctness of the method, as well as to the possibility of obtaining information on the very corrugated vessels, the small diameter vessels and on the distal areas of vascular system[1].

The transcatheter X-ray contrast angiography remains a diagnostic standard in patients with the lesions in the extracranial arteries, however, the risks for the patient and the financial cost are the limitations for angiography as a screening method. Direct angiography is also indicated for cases of obtaining controversial findings on the results of other non-invasive methods[1]. The literature data confirm that the combined use of two non-invasive methods (DS with magnetic resonance angiography or CTA) allows for avoiding the use of radiocontrast angiography. However, even when using two methods, an insufficiently precise determination of the degree and spreading of stenosis was found in almost 20% of the patients [5].

In the research work by R.M. Daolio et al. [13], presenting an analysis of the systematic review based on the Cochrane data base and compiled in 2022, the authors have provided the evidence of high diagnostic precision of color DS, especially in terms of differentiating the stenoses of the carotid arteries with a degree of up to 50% and in the range of 50–99%. The review has included 22 articles with an analysis of 4957 instrumental examinations of this vascular system, on the results of which, a conclusion was made that the precision of evaluating the stenosis and the occlusion of the carotid artery when using the ultrasound examination varies from 70% to 90%.

In accordance with clinical recommendations from the Ministry of Health of the Russian Federation [14] and the recommendations from the World Health Organization[1], the examination of the carotid arteries should start from color DS of the brachiocephalic arteries. Later on, either the magnetic resonance tomography or the CTA can be conducted. In case of proper execution of these examinations and in case when the results are matching, the decision on surgical treatment can be drawn up without the need for radiocontrast angiography. In case when the examination findings are controversial or in case of insufficient visualization of the arteries, using the X-ray contrast angiography remains obligatory.

Research limitations

The absence of unified standards of describing (anatomic landmarks, criteria that are obligatory for describing, terms in the protocols) due to the absence of the recommendations for such methods as the DS of the brachiocephalic arteries and the CTA of the brachiocephalic arteries, as well as the absence of general standards for these two methods, complicates the interpretation of the conclusions even within a single medical institution. Particular difficulties may develop when comparing the data on stenoses with a degree of less than 50%.

CONCLUSION

When arranging the examination of the patients, it is necessary to strictly follow the diagnostics algorithm for stenoses of the carotid arteries, beginning from the duplex scanning of the extracranial segments of brachiocephalic arteries as the most accessible and highly informative method. The computed tomographic angiography of this vascular system is necessary when selecting the patients for surgical treatment, for it is necessary to keep in mind the potential risk of developing contrasted nephropathy and of the radiation exposure. The proper execution of the ultrasound examination allows for decreasing the number of discrepancies between these two diagnostic methods, which means decreasing the necessity for performing the angiography.

ADDITIONAL INFORMATION

Author contribution. *N.S. Nosenko* — concept and design of the study, literature review, collection and analysis of literary sources, writing the text and editing the article; *E.M. Nosenko* — scientific revision of the manuscript, concept and design of the study, editing of the article; *D.S. Alemasova* — literature review, collection and analysis of literary sources, writing the text and editing the article; *T.V. Dedy* — scientific revision of the manuscript. The authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

Ethics approval. The protocol of the retrospective study was agreed upon by the Local Ethics Committee of the Federal State Budgetary Institution FNCC of the FMBA of Russia (minutes of the meeting of the LEK No. 12-2024 dated 11.11.2024).

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Competing interests. The authors declare that they have no competing interests.

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