

ISSN 1607-0771(Print); ISSN 2408-9494 (Online)

<https://doi.org/10.24835/1607-0771-386>

Quantitative ultrasound assessment of carotid atherosclerosis in ischemic stroke risk stratification

I.N. Umnov^{1, 2*}, D.A. Chugaev¹¹ LLC “European Institute of Family Health”; 35, bld. 1, Trudyashchikhysya Boulevard, Kolpino, St. Petersburg 196657, Russian Federation² City Hospital No. 33; 16A, Pavlovskaya str., Kolpino, St. Petersburg 196653, Russian Federation

Objective. To evaluate the role of quantitative ultrasound parameters of atherosclerotic plaque (ASP) as predictors of the development of the primary composite endpoint in patients with carotid atherosclerosis.

Materials and methods. A total of 675 patients with carotid atherosclerosis with no history of transient ischemic attack or ischemic stroke at the time of inclusion in the study were examined; 48.4% were men, with an average age of 66 [61; 72] years. All patients underwent electrocardiography, echocardiography, carotid arteries duplex ultrasound with assessment of the degree of stenosis according to NASCET and maximum wall thickness (MWT) of plaque with subsequent analysis of ASP images in DICOM format. A computer software (own development) was used to calculate the total area of the ASP and segment the image by grayscale ranges (“blood”, “lipids”, “muscle and fibrous components”, and “calcium”). The observation period was 5 years. The primary composite endpoint was the development of an ischemic event in the carotid territory on the affected side or surgical treatment of carotid stenosis. Differences were considered statistically significant at $p < 0.05$.

Results. During the follow-up period, 85 patients (12%) achieved primary composite endpoint. This event occurred 3 and 10 times more frequently in patients with Gray-Weale ASP types I and II than in those with types III and IV, respectively. Independent predictors in the five-year risk stratification model for event development included the NASCET stenosis grade, MWT, and the plaque image segmentation parameters excluding the “fibrous component”. Patients were divided into three groups: a “high-risk” group for developing primary composite endpoint (the predicted overall five-year risk (OR) was 30% or more) – 136 patients (21%), a “low-risk” group (less than 15% OR) – 405 patients (64%), and a “medium (intermediate) risk” group (from 15% to 30% OR) – 99 patients (15%). The median values of the degree of stenosis according to NASCET and the MWT were 15 [4; 25]% and 2.5 [2.1; 3.1] mm for the low-risk group, 24 [14; 27]% and 3.0 [2.5; 3.6] mm for the average risk group, and 50 [38; 69]% and 4.3 [3.8; 5.5] mm, respectively ($p < 0.0001$).

Conclusions. The degree of stenosis according to NASCET, MWT and the results of segmentation of the gray-scale image of the ASP by gray-scale ranges are significant independent predictors of the development of primary composite endpoint in asymptomatic patients with carotid atherosclerosis.

Keywords: atherosclerotic plaque; carotid stenosis; quantitative analysis; ultrasound; ischemic stroke; transient ischemic attack; risk stratification

Ivan N. Umnov – MD, Head of the Department of Functional Diagnostics, LLC “European Institute of Family Health”; physician of ultrasound and functional diagnostics, City Hospital No. 33, St. Petersburg.
<https://orcid.org/0000-0002-4247-3522>

Dmitry A. Chugaev – IT specialist, LLC “European Institute of Family Health”, St. Petersburg.
<https://orcid.org/0009-0002-7159-0821>

Correspondence* to Ivan N. Umnov – e-mail: uin.eizs@yandex.ru

Conflict of interests. The authors have no conflicts of interest to declare.

Financing. This study had no sponsorship.

Citation: Umnov I.N., Chugaev D.A. Quantitative ultrasound assessment of carotid atherosclerosis in ischemic stroke risk stratification. *Ultrasound and Functional Diagnostics*. 2026; 32 (2): ##-##. <https://doi.org/10.24835/1607-0771-386>

Received: 20.03.2026.

Accepted for publication: 14.05.2026.

Published online: 18.05.2026.

INTRODUCTION

Ischemic stroke (IS) remains one of the leading causes of mortality and disability worldwide and ranks among the most prevalent non-communicable diseases. The high prevalence of traditional risk factors (arterial hypertension, diabetes mellitus, dyslipidaemia, smoking, and others), together with the long asymptomatic course of atherosclerosis, contributes to a substantial burden of stroke, particularly in countries with very high cardiovascular risk, including the Russian Federation. Contemporary primary prevention of cardiovascular events is based on global risk estimation using clinical and demographic scores (SCORE2, SCORE2-OP) followed by correction of modifiable risk factors. However, the predictive accuracy of these tools for atherothrombotic IS in asymptomatic patients with carotid atherosclerosis is limited, which underscores the need for additional imaging-based risk modifiers.

Ultrasound examination of the carotid arteries is of particular importance, as it enables assessment not only of stenosis severity but also of plaque morphology. Ultrasound features associated with an increased risk of stroke in asymptomatic patients include stenosis progression, spontaneous embolic signals on transcranial Doppler, reduced cerebrovascular reactivity, large hypoechoic and heterogeneous plaques, and a pronounced juxtaluminal hypoechoic zone [3]. However, stratification based solely on the degree of stenosis is now regarded as insufficient, since several morphological characteristics of carotid plaque have been shown to be independent predictors of IS irrespective of luminal narrowing [4]. In 2024, the Carotid Plaque-RADS system for IS risk stratification was proposed [5]. It was founded on the concept that carotid plaque histopathology is constant, whereas imaging

modalities (ultrasound, magnetic resonance imaging, computed tomography, and others) may evolve, and their diagnostic statements should rely on the available evidence base.

One approach to refining ultrasound assessment of carotid atherosclerosis is the development and implementation of quantitative criteria, such as greyscale-based methods for plaque characterization [6]. Studies in this area, however, have generally been conducted in relatively small cohorts, and harmonized criteria for image acquisition and analysis are lacking, which precludes firm conclusions about the incremental value of quantitative ultrasound over other imaging techniques in evaluating vulnerable carotid plaques [7].

The objective of the present study was therefore to assess the role of quantitative ultrasound parameters of carotid atherosclerotic plaque (ASP) as predictors of the primary composite endpoint in patients with carotid atherosclerosis.

MATERIALS AND METHODS

We examined 675 individuals (48.4% men; median age 66 [61; 72] years) who underwent outpatient evaluation and treatment at two clinics of the European Institute of Family Health LLC between 2018 and 2023. Patients were eligible for inclusion if they met all of the following criteria:

- 1) presence of an ASP in the carotid sinus with thickness ≥ 1.5 mm;
- 2) no documented history of transient ischemic attack (TIA) or IS in the ipsilateral carotid territory at the time of enrolment;
- 3) no atrial fibrillation on electrocardiogram or in the medical history;
- 4) no occlusion of the internal carotid artery (ICA);

5) on echocardiography at baseline: no aortic arch atherosclerotic plaque, mechanical or bioprosthetic valve prostheses, conduits, signs of infective endocarditis, left ventricular thrombus, cardiomyopathy, or patent foramen ovale, and no Fontan circulation after repair of congenital heart disease;

6) no documented systemic vasculitis or fibromuscular dysplasia;

7) no malignant neoplasm;

8) adequate carotid imaging quality, with exclusion of patients with severe calcification causing acoustic shadowing, suboptimal acoustic windows (high carotid bifurcation, marked angulation of the ICA), or unfavourable anthropometric features ("short, thick neck").

Patients were followed for up to 5 years or until occurrence of the primary composite endpoint, defined as IS or TIA in the territory of the stenotic carotid artery, carotid artery stenting, or carotid endarterectomy. Individuals who reached the primary composite endpoint formed the event group, whereas the remaining patients constituted the comparison group. Exclusion (drop-out) criteria during follow-up were:

1) death from any cause other than IS in the ipsilateral carotid territory;

2) occurrence of IS adjudicated as cardioembolic;

3) change of residence precluding further follow-up.

Initially, 695 patients were enrolled. During follow-up, 20 patients were excluded: 8 died, 10 experienced cardioembolic stroke, and 2 moved to a different place of residence.

The median prospective follow-up duration was 4 [2; 6] years. The final event group therefore comprised 85 patients (12%) who reached the primary composite endpoint, and the comparison group consisted of 590 patients (88%) who remained asymptomatic. In the event group, age ranged from 40 to 78 years, with a median of 64 [58; 68] years; the median age of men and women was 63 [52; 66] and 67 [64; 71] years, respectively. In the comparison group, age ranged from 30 to 90 years, with a median of 67 [61; 73] years. Eighteen patients (21%) in the event group underwent carotid revascularisation.

The study was conducted in accordance with the principles of the Declaration of Helsinki. The study protocol (No. 12) was

approved by the local ethics committee on 18 March 2023. Written informed consent was obtained from all participants prior to inclusion.

Standard 12-lead electrocardiography and transthoracic echocardiography were performed in all participants. Cardiac structure and function, valve apparatus, and the aorta were assessed using ultrasound systems Logiq E9 and Logiq F8 (General Electric, USA). The Logiq E9 system was equipped with an M5S-D matrix phased-array transducer (1.7–4.6 MHz), whereas the Logiq F8 system used a 3Sc-RS phased-array transducer (1–4 MHz). Echocardiographic examinations were performed by experienced specialists (more than 10 years of practice) in accordance with current recommendations [8].

Duplex ultrasound of the brachiocephalic arteries was carried out on the same scanners by ultrasonographers with more than 10 years of experience, using 9L-D (3–9 MHz) and 11L-D (4–10 MHz) linear transducers on the Logiq E9 and an L2-12-RS (4–13 MHz) linear transducer on the Logiq F8. During carotid ultrasound, maximum wall thickness (MWT) of plaque in the carotid sinus [9] was measured in mm, and NASCET stenosis grade was quantified planimetrically in per cent [4]. In cases with NASCET stenosis $\geq 40\%$, additional Doppler assessment of haemodynamic stenosis severity was performed according to the multiparametric ultrasound criteria of DEGUM [10]. All B-mode images of ASP were saved and exported in DICOM format for subsequent off-line greyscale analysis.

Custom software was developed in Python for quantitative analysis of plaque images. The algorithm converted B-mode images into an 8-bit greyscale (0–255) and normalised them analogously to Adobe Photoshop, with the vessel lumen set as the 0-intensity reference. ASP segmentation by predefined greyscale ranges was implemented following the approach of Image-Pro Plus (Media Cybernetics, USA). The following greyscale intervals were assigned to specific tissue components: 0–4 to "blood", 8–26 to "lipids", 41–76 to "muscle component", 112–196 to "fibrous tissue", and 211–255 to "calcium" [6, 11]. After manual tracing of plaque contours in the longitudinal plane, the software automatically calculated total plaque area (TPA) (mm²) based on DICOM metadata and

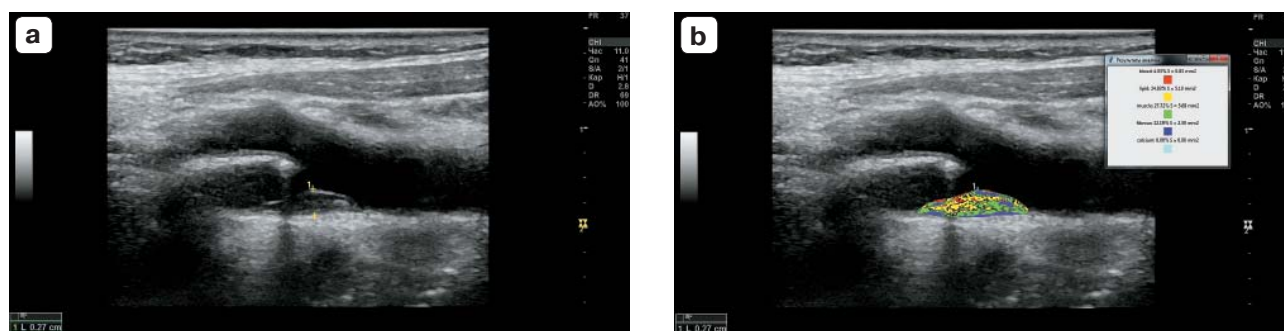


Fig. 1. B-mode ultrasound of the carotid arteries. Atherosclerotic plaque in the carotid sinus (a), results of segmentation by gray scale ranges of this carotid sinus plaque using an own developed computer software (b).

quantified the relative (per cent) and absolute (mm²) content of each component (Fig. 1).

ASP echostructure was additionally graded according to the Gray-Weale classification [12]. Given that the custom software allowed segmentation of anechoic (“blood”) and hypoechoic (“lipid”) components, we sought to render this qualitative scale more objective by re-defining ASP types according to the summed proportion of these components. Reference images of the four Gray-Weale plaque types from the original publication [12] were imported in JPG format, normalised as described above, and segmented over the 0–255 greyscale range. Threshold values for the combined percentage of “blood” and “lipid” were derived for each type: 63% for type I, 30% for type II, 17% for type III, and 2% for type IV. On this basis, ASP in the study cohort were classified as follows: type I – ≥60%; type II – 30–59%; type III – 17–29%; and type IV – ≤16% of the combined anechoic and hypoechoic components.

All recorded variables were prepared for statistical analysis and explored using standard descriptive and inferential methods. Normality of distribution was assessed with the chi-square test and the Kolmogorov–Smirnov test. Because most variables were non-normally distributed, non-parametric tests were used for group comparisons. Event-free survival, defined as the probability of not reaching the primary composite endpoint, was analysed using Kaplan–Meier survival curves stratified by Gray-Weale plaque type.

To develop a carotid ultrasound-based model for cerebrovascular risk stratification, Cox proportional hazards regression with

backward stepwise selection was applied, with follow-up time as the survival variable, the primary composite endpoint as the outcome, and quantitative ultrasound parameters as candidate predictors. Model significance was evaluated using chi-square statistics for the joint effect of time and covariates. Discriminative performance was assessed by Harrell’s concordance index (C-index). From the baseline cumulative hazard function, the mean cumulative risk (CR) at 5 years was estimated for the study cohort. Knowing the population risk (PR) of IS or TIA in this population (13%), the overall risk (OR) was calculated as:

$$OR = CR + PR,$$

where OR is the overall risk (%), CR is the cumulative risk (%), and PR is the population risk (%).

Receiver operating characteristic (ROC) analysis was then performed using the regression function values as the independent variable and group status (event vs non-event) as the dependent variable, yielding sensitivity, specificity, and the optimal cut-off. For the best-performing model, the cut-off of the regression function was mapped to a calculated OR value. Patients with $OR \geq 30\%$ were classified as high-risk (risk category 3). Those with $OR < 15\%$ (approximately a two-fold lower OR) were classified as low-risk (risk category 1), and patients with intermediate OR ($15\% < OR < 30\%$) were assigned to the intermediate-risk category (risk category 2).

All analyses were performed using MedCalc for Windows (version 22.023). A two-sided p-value < 0.05 was considered statistically significant.

RESULTS

The main quantitative ultrasound characteristics of the study population and their distribution between patients who did and did not reach the primary composite endpoint are summarized in Table 1.

Quantitative parameters such as MWT, TPA and NASCET stenosis grade differed significantly between the event and comparison groups, with systematically higher values in patients who reached the primary composite endpoint. In the event group, Gray-Weale type II plaques predominated, whereas type IV plaques were most frequent in the comparison group. The Spearman rank correlation coefficient between group status and Gray-Weale type was 0.385 ($p < 0.0001$), indicating a moderate association whereby higher ASP type was more common in the comparison group.

Because of the small number of type I plaques ($n = 8$), types I and II were combined for Kaplan–Meier analysis to ensure sufficient statistical power. Kaplan–Meier curves for event-free survival (Fig. 2) demonstrated significant differences between plaque types ($p < 0.0001$). The largest area under the survival curve was observed for type IV plaques (4.901), the smallest for types I–II (4.101), and an intermediate value for type III plaques (4.621).

As shown in Table 2, Gray-Weale types I–II were associated with a three-fold higher risk of reaching the primary composite endpoint compared with type III ASP and an al-

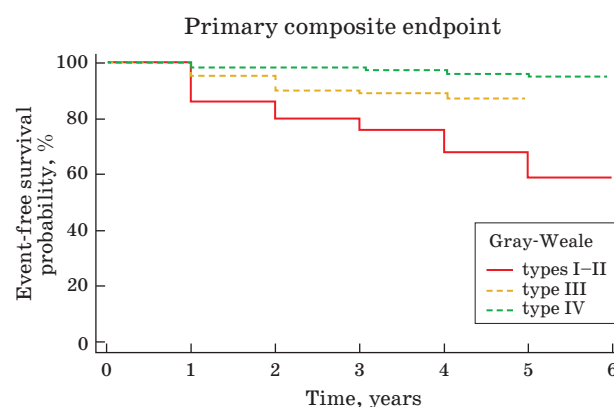


Fig. 2. Results of the Kaplan–Meier analysis depending on the atherosclerotic plaque type according to Gray-Weale.

most ten-fold higher risk compared with type IV ASP, which were virtually benign in this context.

To estimate cerebrovascular risk based on quantitative ultrasound parameters, three Cox regression models were constructed. The first model included TPA, MWT, and NASCET stenosis grade. The second model incorporated the areas of all segmented ASP components across predefined grayscale ranges. The third, composite model combined variables from both approaches. The composite model demonstrated the best predictive performance and retained the following independent predictors after backward elimina-

Table 1. Instrumental characteristics of patients

Indicator	All patients	PCEP (+) (n = 85)	PCEP (–) (n = 590)	p-values
MWT, mm	2.9 [2.3; 3.7]	4.7 [3.9; 5.9]	2.8 [2.2; 3.3]	0.0001
TPA, mm ²	21.3 [14.1; 33.6]	59 [41.9; 82.3]	19.4 [13.2; 29]	0.0001
NASCET stenosis, %	20 [10; 40]	54 [42; 70]	18 [8; 30]	0.0001
Gray-Weale type :				
I	8 (1)	4 (5)	4 (1)	–
II	112 (17)	45 (53)	67 (11)	–
III	140 (21)	21 (25)	119 (20)	–
IV	415 (61)	15 (17)	400 (68)	–

Note. Data are presented as absolute number (%), median [Q1; Q3]. PCEP – primary composite endpoint; MWT – maximum wall thickness; TPA – total plaque area.

Table 2. Odds ratios for achieving the primary composite endpoint by atherosclerotic plaque type according to Gray-Weale

Factor	PCEP (+)	PCEP (–)	HR (95% CI)	p-values
Types I–II	49 (41)	71 (59)	9.92 (6.13; 16.07)	0.0001
Type III	21 (15)	119 (85)	3.37 (2.09; 5.41)	0.0001
Type IV	15 (4)	400 (96)	0.29 (0.18; 0.49)	0.0001

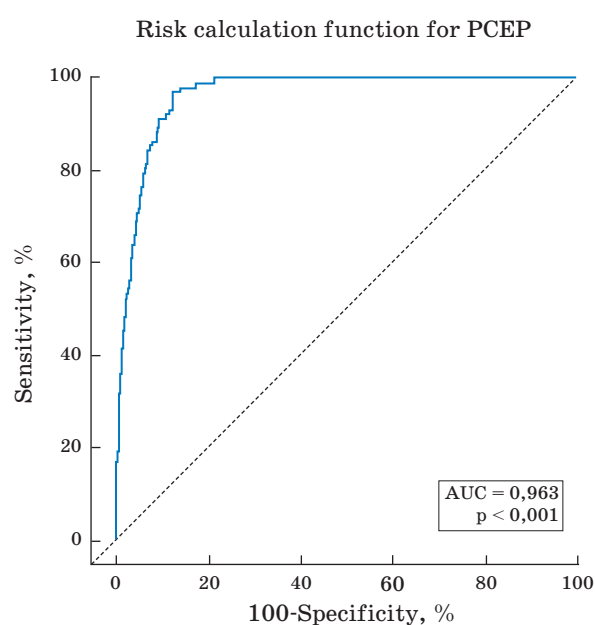
Note. Data are presented as absolute number (%). PCEP–primary composite endpoint; CI – confidence interval; HR – hazard ratio.

Table 3. Statistical parameters of the comprehensive prognostic model based on all quantitative parameters

χ^2		214	
df		6	
p		<0.0001	
Harrell's C-index		0.665	
Harrell's C-index (95% CI)		(0.633; 0.697)	
Indicator	Regression coefficient	Hazard ratio (95% CI)	p
Maximum wall thickness	0.386	1.46 (1.18; 1.81)	0.0005
NASCET stenosis	0.03086	1.03 (1.02; 1.04)	<0.0001
“Blood”	0.03255	1.03 (1.01; 1.06)	0.0037
“Lipids”	0.06633	1.07 (1.03; 1.1)	0.0006
“Muscle”	–0.05606	0.93 (0.89; 0.97)	0.0007
“Calcium”	0.03607	0.84 (0.78; 0.92)	0.0002

tion: MWT, NASCET stenosis grade, and grayscale segmentation parameters for “blood”, “lipids”, “muscle component”, and “calcium”, whereas TPA and the “fibrous tissue” component did not reach the predefined significance level and were excluded (Table 3).

The regression model showed moderate discriminative ability (Harrell's C-index 0.665, 95% CI 0.633–0.697), significant hazard ratios for all retained covariates (95% CI not including 1), and high overall model significance ($p < 0.0001$). The predicted mean overall five-year risk of the primary composite endpoint in asymptomatic patients was 31%, rounded to 30%. The optimal cut-off value of the regression function was 2.7739; patients with values at or above this threshold were classified as high-risk, with an overall accuracy of 93%, sensitivity of 95%, and specificity of 90% (Fig. 3). Patients with an approximately two-fold lower overall risk ($< 15\%$; regression function < 1.387) were classified as low-risk, and those with values between 1.387 and 2.7739 were assigned to the intermediate-risk category.

**Fig. 3.** Evaluation of the effectiveness of the comprehensive prognostic model for assessing the risk of developing the primary composite endpoint (PCPE).

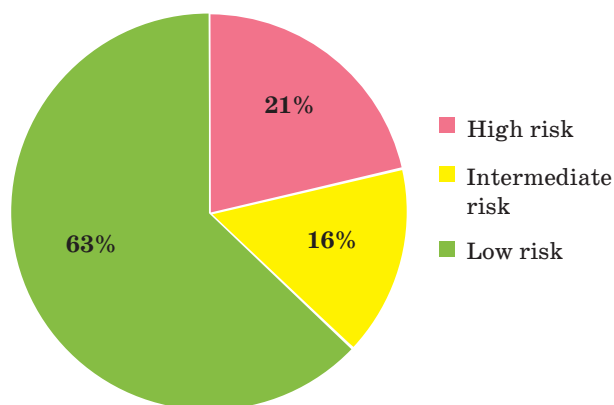


Fig. 4. Distribution of patients by risk group.

Fig. 4 shows the distribution of asymptomatic patients at baseline across the three risk categories. The largest group comprised low-risk patients ($n = 405$, 64%), followed by high-risk patients ($n = 136$, 21%) and intermediate-risk patients ($n = 99$, 15%).

Fig. 5 shows the median NASCET carotid stenosis grades in the three risk groups: low risk – 15% [4; 25], intermediate risk – 24% [14; 37], and high risk – 50% [38; 69]. Highly significant between-group differences were observed (Kruskal–Wallis test $H = 282$, $p < 0.0001$), which were confirmed by Dunn’s post hoc analysis.

Fig. 6 presents the distribution of MWT according to risk stratification for the primary composite endpoint. The analysis showed a consistent increase in median MWT with rising risk: low risk, 2.5 [2.1; 3.1] mm;

intermediate risk, 3.0 [2.5; 3.6] mm; and high risk, 4.3 [3.8; 5.5] mm. Application of the Kruskal–Wallis test revealed highly significant between-group differences ($H = 288$; $p < 0.0001$). Subsequent Dunn’s post hoc analysis confirmed statistically significant differences between all pairs of groups, indicating that increasing ASP geometry is associated with higher cerebrovascular risk.

DISCUSSION

In our study, the median follow-up time from enrolment to the occurrence of IS or TIA in the event group was 2 years. Similar follow-up durations have been reported in studies with a comparable design [7, 13].

Publications specifically addressing the qualitative Gray-Weale classification of carotid ASP types and their relationship with plaque instability are relatively scarce, and the available data are highly inconsistent. Some reports highlight the usefulness of this classification and its considerable value in predicting embolic risk associated with vulnerable ASP [12], whereas others fail to demonstrate a significant association between individual Gray-Weale plaque types and an increased risk of IS [14]. Recognizing that the main limitation of this scheme is its qualitative and therefore subjective nature, with low inter-operator reproducibility, we converted it into a quantitative assessment in our study and determined ASP type for each patient automatically, based on the percentage of the hypo to anechoic component within

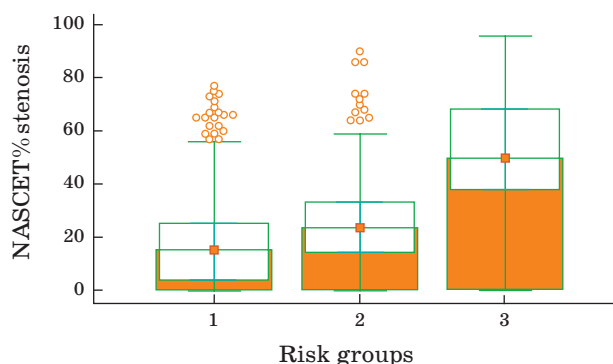


Fig. 5. Distribution of median carotid stenosis grades according to NASCET across risk groups for developing the primary composite endpoint.

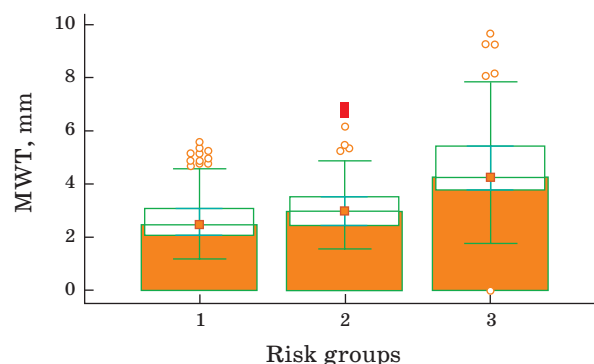


Fig. 6. Distribution of median maximum plaque height (MPH) across risk groups for developing the primary composite endpoint.

the ASP. A similar approach was identified in the work of Nicolaides A. et al. [13], in which image segmentation was also performed using dedicated software and ASP were classified into four types according to the proportion of low echogenic tissue (grey scale median (GSM) < 25). Although their thresholds produced somewhat different distributions across ASP types, they partially overlapped with our gradations: type I corresponded to “GSM < 25 ” in $> 85\%$ of the plaque, type II to 50–85%, type III to 15–50%, and type IV to $< 15\%$.

In our study, we found statistically significant differences in ASP types between the event group and the control group. The predominant ASP types in patients who reached the primary composite endpoint were Gray-Weale types I and II (more hypoechoic plaques), whereas type IV (hyperechoic plaque) predominated in the comparison group. A moderate but significant association was observed between ASP type and clinical group, confirming the trend that more hypoechoic plaques are more emboligenic, while more hyperechoic ASP are more stable. Similar findings were reported by Pogorelova O.A. et al. [15], who analyzed the grey-scale median of carotid plaques. According to our survival analysis, Gray-Weale type IV ASP were associated with a negligible risk of IS or TIA, whereas the presence of type I or II ASP increased the risk of ischemic events almost three-fold compared with type III and nearly ten-fold compared with type IV. Comparable results were obtained in the CREST-2 trial [16].

We developed a composite regression model for risk stratification of the primary composite endpoint that included MWT, NASCET stenosis grade and quantitative greyscale parameters of ASP, with the exception of the “fibrous tissue” component. The “muscle component” on the greyscale scale was associated with a lower probability of the endpoint and improved survival. This model can be used to predict the risk of IS or TIA in asymptomatic patients with carotid atherosclerosis. The cumulative five year risk estimated by the model was 18%, while the population risk was 13%. Accordingly, we defined high risk as an overall risk $\geq 30\%$, intermediate risk as 15– $< 30\%$, and low risk as $< 15\%$. According to the literature [13], similar five year cere-

brovascular risk estimates in comparable populations have been obtained using Kaplan–Meier analysis, in which continuous variables with a significant impact on outcome (ECST carotid stenosis grade, GSM < 25 , TPA) were converted into ordinal categories, and cumulative risk was calculated from hazard ratios between baseline and extreme values.

We evaluated the performance of our risk stratification against independent predictors such as NASCET carotid sinus stenosis grade and MWT. The differences in median NASCET stenosis between the risk groups were highly significant, with a median stenosis of 50% [38; 69] % in the high risk group, a range that would generally warrant consideration of surgical treatment in symptomatic patients. Similarly, MWT showed highly significant between group differences; in the intermediate risk group, the median value was 3.0 [2.5; 3.6] mm. According to published data, MWT ≥ 3 mm is a marker of asymptomatic patients who should be classified as having at least intermediate cerebrovascular risk [5, 13].

The limitations of this study include its single-centre design, the absence of external validation of the model, and the potential influence of ultrasound system settings on source images; inter observer reproducibility was not assessed. The proposed technique can be applied only to ASP in the carotid sinus and is not suitable for evaluating plaques in other vascular territories. Multicentre studies with external validation, inter-laboratory assessment of the method, and comparison with other imaging modalities are required.

CONCLUSIONS

Using quantitative ultrasound criteria, we developed a prognostic model for five year risk stratification of the primary composite endpoint in asymptomatic patients. Preference was given to a composite model based on MWT, NASCET stenosis grade and quantitative greyscale segmentation parameters of ASP (“blood”, “lipids”, “muscle component”, and “calcium”), which demonstrated superior performance metrics, including concordance index, accuracy, sensitivity, and specificity. On the basis of this model, asymptomatic patients in our cohort were assigned to three five year risk categories for IS or TIA

in the ipsilateral carotid artery territory: low risk (risk 1) – overall risk <15%; intermediate risk (risk 2) – overall risk 15–<30%; and high risk (risk 3) – overall risk ≥30%.

Authors' participation

Umnov I.N. – concept and design of the study, conducting research, collection and analysis of data, analysis and interpretation of the obtained data, text preparation and editing.

Chugaev D.A. – conducting research, collection and analysis of data, analysis and interpretation of the obtained data.

REFERENCES

1. GBD 2021 Diseases and Injuries Collaborators. Global incidence, prevalence, years lived with disability (YLDs), disability-adjusted life-years (DALYs), and healthy life expectancy (HALE) for 371 diseases and injuries in 204 countries and territories and 811 subnational locations, 1990–2021: a systematic analysis for the Global Burden of Disease Study 2021. *Lancet*. 2024; (published online April 17.) [https://doi.org/10.1016/S0140-6736\(24\)00757-8](https://doi.org/10.1016/S0140-6736(24)00757-8)
2. Visseren F., Mach F., Smulders Y. et al. 2021 Guidelines on cardiovascular disease prevention in clinical practice with representatives of the European Society of Cardiology and 12 medical societies. *Eur. Heart J.* 2021; 42 (34): 3227–3337. <https://doi.org/10.1093/eurheartj/ehab484>
3. Mazzolai L., Teixido-Tura G., Lanzi S. et al. 2024 ESC Guidelines for the management of peripheral arterial and aortic diseases: Developed by the task force on the management of peripheral arterial and aortic diseases of the European Society of Cardiology (ESC). *Eur. Heart J.* 2024; 45 (36): 3538–3700. <https://doi.org/10.1093/eurheartj/ehae179>
4. Naylor R., Rantner B., Ancetti S. et al. European society for vascular surgery (ESVS) 2023 Clinical practice Guidelines on the management of atherosclerotic carotid and vertebral artery disease. *Eur. J. Vasc. Endovasc. Surg.* 2023; 65 (1): 7–111. <https://doi.org/10.1016/j.ejvs.2022.04.011>
5. Saba L., Cau R., Murgia A. et al. Carotid plaque-RADS: a novel stroke risk classification system. *JACC: Cardiovasc. Imaging*. 2024; 17 (1): 62–75. <https://doi.org/10.1016/j.jcmg.2023.09.005>
6. Lai B., Hobson R., Hammed M. et al. Noninvasive identification of the unstable carotid plaque. *Ann. Vasc. Surg.* 2006; 20 (2): 167–174. <https://doi.org/10.1007/s10016-006-9000-8>
7. Kakkos S., Griffin M., Nicolaides A. et al. The size of juxtaluminal hypoechoic area ultrasound images of asymptomatic carotid plaques predicts the occurrence of stroke. *J. Vasc. Surg.* 2013; 57 (3): 609–618. <https://doi.org/10.1016/j.jvs.2012.09.045>
8. Lang R., Badano L., Mor-Avi V. et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J. Am. Soc. Echocardiogr.* 2015; 28 (1): 1–39. <https://doi.org/10.1016/j.echo.2014.10.003>
9. Touboul P., Hennerici M., S. Meairs S. et al. Mannheim carotid intima-media thickness and plaque consensus (2004-2006-2011). An update on behalf of the advisory board of the 3rd, 4th and 5th watching the risk symposia, at the 13th, 15th and 20th European Stroke Conferences, Mannheim, Germany, 2004, Brussels, Belgium, 2006, and Hamburg, Germany, 2011. *Cerebrovasc. Dis.* 2012; 34: 290–296. <https://doi.org/10.1159/000343145>
10. Arning C., Widder B., von Reutern G. et al. Revision of DEGUM ultrasound criteria for grading internal carotid artery stenoses and transfer to NASCET measurement. *Ultraschall Med.* 2010; 31 (3): 251–257. <https://doi.org/10.1055/s-0029-1245336>
11. Lai B., Hobson R., Pappas P. et al. Pixel distribution analysis of B-mode ultrasound scan images predicts histological features of atherosclerotic carotid plaques. *J. Vasc. Surg.* 2002; 35 (7): 1210–1217. <https://doi.org/10.1067/mva.2002.122888>
12. Gray-Weale A., Graham J., Burnett J. et al. Carotid artery atheroma: comparison of preoperative B-mode ultrasound appearance with carotid endarterectomy specimen pathology. *J. Cardiovasc. Surg.* 1988; 29 (11): 115–123.
13. Nicolaides A., Kakkos S., Kyriacou E. et al. Asymptomatic internal carotid artery stenosis and cerebrovascular risk stratification. *J. Vasc. Surg.* 2010; 52 (6): 1486–1496. <https://doi.org/10.1016/j.jvs.2010.07.021>
14. Reiter M., Bucek R., Effenberger I. et al. Plaque echolucency is not associated with the risk of stroke in carotid stenting. *Stroke*. 2006; 37 (9): 2378–2380. <https://doi.org/10.1161/01.STR.0000237087.86583.c8>
15. Pogorelova O.A., Tripoten M.A., Hamchieva L.Sh., Guchaeva D.A., Kozlov S.G., Shakhnovich R.M., Balakhonova T.V. Echogenicity of atherosclerotic plaque – a criterion for assessing the dynamics and prognosis of cardiovascular diseases. *Ultrasound & Functional Diagnostics*. 2023; 4: 35–48. <https://doi.org/10.24835/1607-0771-2023-4-35-48> (In Russian)
16. Kulcarni P., Lal B., Jreij G. et al. CRESTOMICS: Analyzing carotid plaques in the CREST-2 trial with a new additive classification model. *Preprint on arXiv*. 2026. <https://arxiv.org/abc/2603.04309>