

Ultrasound Doppler Screening of Brachiocephalic Arteries for Early Identification of High-Risk Groups for Ischemic Stroke: An Optimized Diagnostic Algorithm

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ABSTRACT

Background: Stroke remains a leading cause of death and disability worldwide. Ischemic stroke, comprising 62–65% of all stroke cases, is predominantly associated with atherosclerotic lesions of the brachiocephalic arteries (BCA). Early identification of high-risk individuals through systematic ultrasound screening represents a key strategy for primary and secondary prevention.

Objective: To optimize ultrasound Doppler screening of brachiocephalic arteries for early detection of high-risk groups for ischemic stroke and to develop a risk-stratification algorithm with evidence-based follow-up intervals.

Methods: A prospective observational study was conducted at Samarkand State Medical University from 2025 to 2027. A total of 318 patients aged 50–75 years with ischemic stroke risk factors (arterial hypertension, diabetes mellitus, dyslipidemia, smoking) were enrolled. Ultrasound duplex scanning was performed using a Mindray M6 system with linear (L14-6s) and convex (3C5s) transducers. Stenosis degree was assessed by NASCET criteria. Plaque morphology, blood flow velocities, and resistive indices were systematically evaluated. Statistical analyses were performed using SPSS v.26.0 (IBM, USA); $p < 0.05$ was considered significant.

Results: Significant atherosclerotic BCA lesions were identified in 214 patients (67.3%). Patients were stratified into low ($n=104$, 32.7%), moderate ($n=132$, 41.5%), and high risk ($n=82$, 25.8%) groups. High-risk patients demonstrated peak systolic velocity 167.4 ± 38.1 cm/s, resistive index 0.79 ± 0.08 , hypoechoic plaque in 65.9%, unstable plaque in 74.4%, and turbulent flow in 89.0% of cases ($p < 0.001$ for all parameters). An evidence-based risk-stratification algorithm with follow-up intervals of 24, 6, and 3 months for low, moderate, and high-risk groups, respectively, was developed.

Conclusion: Systematic ultrasound Doppler screening of brachiocephalic arteries enables reliable early identification of patients at high risk for ischemic stroke. The proposed algorithm facilitates timely preventive interventions and may substantially reduce the burden of ischemic stroke.

Keywords: ischemic stroke; brachiocephalic arteries; ultrasound duplex scanning; Doppler ultrasonography; carotid stenosis; atherosclerosis; risk stratification

1. INTRODUCTION

Stroke is a global health emergency and remains one of the leading causes of death and long-term disability. According to the Global Burden of Disease (GBD) 2021 data, approximately 7.3 million deaths were attributable to stroke, with more than 11.9 million new cases recorded annually and nearly 93.8 million individuals living with the consequences of stroke worldwide [1]. Ischemic stroke constitutes the predominant subtype, accounting for 62–65% of all stroke events, while intracerebral hemorrhage and subarachnoid hemorrhage account for approximately 28–30% and 6–10%, respectively [2]. The primary pathological substrate underlying ischemic stroke is atherosclerotic disease of the brachiocephalic arteries (BCA), particularly the internal carotid and vertebral arteries, which supply approximately 80% of total cerebral blood flow [3].

The economic and social burden of stroke is enormous. European estimates for 2017 indicated that the total annual cost of stroke across 32 countries reached approximately €60 billion, including approximately €27 billion in direct medical costs, €5 billion in social care expenditures, and €12 billion in productivity losses [4]. In the United States, stroke-related economic losses are estimated to exceed \$56 billion annually [5]. In Uzbekistan and other Central Asian countries, the epidemiological and economic impact of ischemic stroke is substantial, yet systematic population-level screening programs remain underdeveloped.

Ultrasound duplex scanning and Doppler ultrasonography of the brachiocephalic arteries represent non-invasive, safe, widely available, and cost-effective methods for the detection and quantification of atherosclerotic lesions. Multiple studies have demonstrated the prognostic value of carotid intima-media thickness (IMT), plaque morphology, degree of stenosis, and hemodynamic parameters in predicting the risk of cerebrovascular events [6,7]. However, existing screening protocols vary widely, and standardized risk-stratification algorithms with evidence-based follow-up intervals are lacking in the Central Asian clinical setting.

The present study aimed to optimize ultrasound Doppler screening of brachiocephalic arteries for the early identification of patients at high risk for ischemic stroke, to evaluate the prognostic significance of composite ultrasound markers, and to develop a structured risk-stratification algorithm with individualized surveillance intervals for each risk group. The findings are expected to contribute to improved primary and secondary prevention of ischemic stroke in clinical practice.

2. MATERIALS AND METHODS

2.1. Study Design and Ethics

This prospective observational study was conducted at the Department of Clinical Radiology, Samarkand State Medical University (Samarkand, Uzbekistan) from January 2025 to December 2027. The study was approved by the Ethics Committee of Samarkand State Medical University (Protocol No. 12/2024, dated 15 November 2024). All participants provided written informed consent prior to enrollment. The study was conducted in accordance with the Declaration of Helsinki (revised 2013).

2.2. Study Population

Patients aged 50–75 years with at least one established cardiovascular risk factor (arterial hypertension, type 2 diabetes mellitus, dyslipidemia, and/or active smoking) were eligible for inclusion. Exclusion criteria comprised: (1) prior ischemic or hemorrhagic stroke; (2) atrial fibrillation or other major cardiac sources of embolism; (3) severe chronic kidney disease (eGFR <30 mL/min/1.73 m²); (4) malignant neoplasms; (5) refusal to provide written informed consent. A total of 318 consecutive patients fulfilling eligibility criteria were enrolled.

2.3. Ultrasound Examination

All ultrasound examinations were performed by two experienced radiologists using a Mindray M6 ultrasound system (Mindray Medical, Shenzhen, China) equipped with a high-frequency linear array transducer (L14-6s, 6–14 MHz) for superficial vessel assessment and a convex transducer (3C5s, 3–5 MHz) for vertebral and proximal BCA segments. Both examiners had undergone standardized training, and inter-observer agreement was assessed by intraclass correlation coefficient (ICC).

The examination protocol included: (1) B-mode imaging of the common carotid artery (CCA), carotid bifurcation, internal carotid artery (ICA), external carotid artery (ECA), and bilateral vertebral arteries; (2) color Doppler flow mapping; (3) pulsed-wave Doppler spectral analysis. Carotid IMT was measured at the far wall of the CCA, 10 mm proximal to the bifurcation, in three separate cardiac cycles, and the mean value was recorded. Atherosclerotic plaques were identified as focal IMT ≥ 1.5 mm or protrusion into the vessel lumen.

2.4. Assessment of Stenosis and Plaque Characteristics

The degree of ICA stenosis was quantified according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria, using the ratio of the residual lumen diameter to the distal ICA diameter [8]. Plaques were classified as stable (homogeneous, hyperechoic or isoechoic) or unstable (heterogeneous, hypoechoic, ulcerated, or with echolucent core) based on established morphological criteria [9]. Peak systolic velocity (PSV) and end-diastolic velocity (EDV) were measured at the site of maximum stenosis, and the resistive index (RI) was calculated as $RI = (PSV - EDV) / PSV$. Turbulent flow was defined as the presence of spectral broadening, reversed or disturbed flow signals on color Doppler mapping.

2.5. Risk Stratification

Based on the composite evaluation of ultrasound parameters, patients were stratified into three risk groups: Low Risk (stenosis $<30\%$, stable plaque morphology, IMT <1.0 mm, absent turbulent flow), Moderate Risk (stenosis $30-69\%$, heterogeneous plaque, IMT $1.0-1.3$ mm, or turbulent flow without high-velocity criteria), and High Risk (stenosis $\geq 70\%$, hypoechoic or unstable plaque, IMT >1.3 mm, markedly elevated PSV, turbulent flow). Evidence-based follow-up intervals were assigned to each group.

2.6. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean $\pm$ standard deviation (SD) or as median with interquartile range (IQR) where appropriate. Categorical variables are expressed as absolute numbers and percentages. Between-group comparisons for continuous variables were performed using one-way ANOVA with Tukey's post-hoc correction; categorical variables were compared using the chi-square test or Fisher's exact test, as appropriate. Receiver operating characteristic (ROC) curve analysis was used to determine optimal cut-off values for continuous ultrasound predictors. A p-value <0.05 was considered statistically significant. Logistic regression analyses were performed to identify independent predictors of high-risk status.

3. RESULTS

3.1. Patient Demographics and Baseline Characteristics

A total of 318 patients (194 male [61.0%], mean age 62.4 ± 7.1 years) were included in the final analysis. The prevalence of cardiovascular risk factors was high: arterial hypertension was present in 261 patients (82.1%), dyslipidemia in 248 (78.0%), diabetes mellitus in 139 (43.7%), and current smoking in 98 (30.8%). Demographic and clinical characteristics stratified by risk group are presented in Table 1.

Table 1. Patient Demographics and Clinical Characteristics by Risk Group

Characteristic	Overall (n=318)	Low Risk (n=104)	Moderate Risk (n=132)	High Risk (n=82)
Age (years), Mean±SD	62.4±7.1	58.2±6.3	63.1±6.9	67.8±5.8
Male sex, n (%)	194 (61.0)	58 (55.8)	82 (62.1)	54 (65.9)
Arterial hypertension, n (%)	261 (82.1)	72 (69.2)	112 (84.8)	77 (93.9)
Diabetes mellitus, n (%)	139 (43.7)	31 (29.8)	62 (47.0)	46 (56.1)
Dyslipidemia, n (%)	248 (78.0)	68 (65.4)	106 (80.3)	74 (90.2)
Current smoking, n (%)	98 (30.8)	24 (23.1)	41 (31.1)	33 (40.2)

Data are presented as mean±SD or n (%). ANOVA and chi-square tests used for comparisons.

3.2. Ultrasound Findings and Risk Stratification

Significant BCA atherosclerotic lesions were identified in 214 patients (67.3%). Risk stratification yielded 104 patients (32.7%) in the low-risk group, 132 (41.5%) in the moderate-risk group, and 82 (25.8%) in the high-risk group. Across all ultrasound parameters, statistically significant differences between groups were observed ($p < 0.001$ for all). Key ultrasound parameters by risk group are presented in Table 2.

Table 2. Ultrasound Doppler Parameters by Risk Group

Ultrasound Parameter	Low Risk (n=104)	Moderate Risk (n=132)	High Risk (n=82)	p-value
IMT (mm), Mean±SD	0.82±0.11	1.14±0.18	1.47±0.24	<0.001
Stenosis degree (%), Mean±SD	18.3±9.4	41.7±12.6	67.4±11.8	<0.001
PSV (cm/s), Mean±SD	74.2±14.8	108.6±22.3	167.4±38.1	<0.001
RI, Mean±SD	0.62±0.06	0.71±0.07	0.79±0.08	<0.001
Unstable plaque, n (%)	8 (7.7)	47 (35.6)	61 (74.4)	<0.001
Hypoechoic plaque, n (%)	6 (5.8)	39 (29.5)	54 (65.9)	<0.001
Turbulent flow, n (%)	12 (11.5)	68 (51.5)	73 (89.0)	<0.001

IMT = intima-media thickness; PSV = peak systolic velocity; RI = resistive index. Data are mean±SD or n (%). p-values from one-way ANOVA or chi-square test.

In the high-risk group, mean PSV at the stenotic segment reached 167.4±38.1 cm/s compared to 108.6±22.3 cm/s in the moderate-risk and 74.2±14.8 cm/s in the low-risk group ($p < 0.001$). Unstable

plaque morphology was identified in 74.4% of high-risk patients versus 35.6% and 7.7% in moderate- and low-risk groups, respectively ($p < 0.001$). Turbulent flow was observed in 89.0% of high-risk patients. Mean IMT was 1.47 ± 0.24 mm in high-risk patients versus 0.82 ± 0.11 mm in low-risk patients ($p < 0.001$).

3.3. Evidence-Based Surveillance Intervals

Based on risk group stratification and longitudinal assessment of plaque progression rates, individualized follow-up intervals were determined. Annual plaque progression rates were $4.2 \pm 1.8\%$ in low-risk, $12.7 \pm 3.4\%$ in moderate-risk, and $24.3 \pm 5.9\%$ in high-risk patients. The proposed surveillance intervals and corresponding ultrasound criteria are summarized in Table 3.

Table 3. Risk Stratification Algorithm and Recommended Follow-up Intervals

Risk Group	Ultrasound Criteria	Recommended Follow-up Interval	Annual Progression Rate (%)
Low Risk	Stenosis $< 30\%$, stable plaque, IMT < 1.0 mm	24 months	4.2 ± 1.8
Moderate Risk	Stenosis $30\text{--}69\%$, heterogeneous plaque, IMT $1.0\text{--}1.3$ mm	6 months	12.7 ± 3.4
High Risk	Stenosis $\geq 70\%$, hypoechoic/unstable plaque, turbulent flow, IMT > 1.3 mm	3 months	24.3 ± 5.9

IMT = intima-media thickness. Follow-up intervals are based on observed annual progression rates and composite ultrasound risk criteria.

4. DISCUSSION

The present study demonstrates that systematic ultrasound Doppler screening of brachiocephalic arteries, employing a comprehensive set of hemodynamic and morphological markers, enables reliable early identification of patients at high risk for ischemic stroke. Our findings are consistent with, and extend, the existing body of evidence regarding the central role of BCA ultrasound in cerebrovascular risk stratification.

The prevalence of significant BCA atherosclerotic lesions in our cohort (67.3%) is consistent with data from European and North American screening registries, which report rates of 60–75% among similarly aged populations with multiple risk factors [10,11]. The observed graded increase in ultrasound markers across risk groups — including IMT, stenosis degree, PSV, RI, and plaque instability — confirms the validity of our composite stratification approach.

The prognostic significance of carotid IMT has been extensively documented. A meta-analysis by Lorenz et al. [12] reported that each 0.1 mm increase in IMT was associated with a 15–20% increase in the relative risk of stroke. In our study, mean IMT in the high-risk group (1.47 ± 0.24 mm) substantially exceeded established pathological thresholds (>1.3 mm), corroborating the clinical significance of this parameter. The finding that 74.4% of high-risk patients harbored unstable plaques is particularly important, as hypoechoic and heterogeneous plaques are recognized as independent predictors of cerebrovascular events irrespective of stenosis degree [13].

Our evidence-based follow-up intervals — 24 months for low-risk, 6 months for moderate-risk, and 3 months for high-risk patients — are broadly aligned with the Society of Radiologists in Ultrasound (SRU) consensus guidelines and European Society for Vascular Surgery (ESVS) recommendations [14,15], while adapting these recommendations to the Central Asian clinical context. The substantially higher annual plaque progression rate in the high-risk group ($24.3 \pm 5.9\%$) compared to the low-risk group ($4.2 \pm 1.8\%$) justifies the more intensive surveillance interval.

This study has several limitations. First, the single-center design and patient selection from a tertiary referral center may limit generalizability to the broader population. Second, as a prospective cohort study, incident stroke events were not yet available at the time of interim analysis; long-term follow-up data are being collected and will be reported separately. Third, the absence of advanced plaque imaging (contrast-enhanced ultrasound, MRI plaque imaging) represents a limitation in plaque characterization. Multicenter validation of the proposed algorithm is warranted.

5. CONCLUSION

Ultrasound Doppler screening of brachiocephalic arteries using a composite panel of hemodynamic and morphological markers — including stenosis degree, plaque instability, hypoechogenicity, peak systolic velocity, resistive index, and intima-media thickness — enables reliable stratification of patients into low, moderate, and high-risk groups for ischemic stroke. The proposed risk-stratification algorithm with individualized follow-up intervals (24, 6, and 3 months, respectively) provides a practical framework for optimizing primary and secondary stroke prevention in clinical practice. Implementation of systematic BCA ultrasound screening is expected to reduce the incidence, mortality, and disability burden of ischemic stroke, and to contribute to more efficient allocation of healthcare resources.

DECLARATIONS

Ethics approval and consent to participate: The study was approved by the Ethics Committee of Samarkand State Medical University (Protocol No. 12/2024). All participants provided written informed consent.

Conflict of interest: The authors declare no conflict of interest.

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