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Ultrasonographic Characteristics of Carotid and Middle Cerebral Arteries in Patients with Ischemic Stroke

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Abstract

Introduction: Atherosclerotic lesions of carotid and large cerebral vessels are an important cause of stroke, which leads to a higher risk of early recurrent ischemia than any other stroke subtype. Extra cranial ultrasound and Transcranial Dopplerography (TCD) in triplex mode is a non-invasive approach to obtaining qualitative changes in the carotid and middle cerebral arteries, and the quantitative parameters of the blood flow in them.

Objective: Ultrasonographic assessment of carotid and middle cerebral arteries in patients with hemispheric stroke, caused by atherosclerosis of this vessels.

Materials and Methods: A retrospective analysis of the results of carotid ultrasound and Transcranial Dopplerography (TCD) of the Middle Cerebral Artery (MCA) was performed in 134 patients with hemispheric Ischemic Strokes (IS) of large vessel subtype. The age of the subjects was 41-80 years, among them 65 (48,5%) men and 69 (51,5%) women. The maximum intima-media thickness, atherosclerotic plaque sizes and types, carotid stenosis degree, middle cerebral artery diameter and stenosis were determined. The comparative group consisted of 78 patients without previous transient ischemic attack or ischemic stroke.

Results: 112 (83.6%) patients with stroke had a local thickening of the Internal Carotid Artery (ICA) wall more than 1,1 mm, wall calcification and atherosclerotic plaques of various types. Stenosis of the ICA in the range of 31-50% was noted in 43 (32.1%) patients, 51-70% in 35 (26.15%) patients, more than 70 % - in 12 (9.0%) patients, respectively.

A soft plaque on the wall of the ICA was recorded in 13 (9.7%) patients. Carotid artery wall calcification was noted in 32 (23.9%) cases - in 21 of them it caused stenosis of the artery lumen in the range of 31-50%. Isolated calcified plaques were recorded in 27 (20.1%) cases. In 19 cases they contributed to the stenosis of the ICA in the range of 31-50%. Stenosis of the lumen of the ICA more than 50% was caused by a local thickening of the oppositely located walls of the ICA in combination with calcification. Ulcerated plaques were diagnosed in 14 (10.4%) patients with stroke - significantly more often than in the comparative group. Atherosclerotic changes in the walls of the Common Carotid Artery (CCA) were noted in 109 (81.3%) patients with stroke. Stenosis of the CCA in range of 31-50% was noted in 57 (42.5%) patients, 51-70% in 23 (17.2%) patients. Large plaques causing stenosis of the CCA lumen more than 50% were recorded in 36 (26.9%) cases. In 25 cases, these plaques were soft, homogeneous, in 11 cases - non-uniform with the presence of calcification sites. With TCD a good visualization of the MCA was performed in 98 (73.1%) patients, and satisfactory in 27 (20.1%) patients. In 9 (6.7%) patients, the MCA was not visualized at all, but the Doppler spectrum without visualization of the artery was obtained in 7 of them. In TCD stenosis of the middle cerebral artery (> 50%) was diagnosed in 28 (20.9) patients.

Conclusion: The relationship between the nature of atherosclerotic plaque, the degree of stenosis of the internal carotid artery and the frequency of occurrence of ischemic stroke are established. Ulcerated and embologenic plaques in the carotid arteries, stenosis of the internal carotid artery more than 70% increase the risk of ischemic stroke. Hemodynamically significant stenosis of the middle cerebral artery can be diagnosed by color Doppler in more than 70% of patients with ischemic stroke.

Keywords: Carotid Atherosclerosis; Carotid Stenosis; Extracranial Ultrasonography; Ishemic Stroke; Transcranial Dopplerography

Introduction

Calcification of the wall of the general and internal carotid arteries or thickening of the wall up to 3 cm in length to 2 cm and after 2 cm from bifurcation significantly increases the risk of ischemic stroke [1,2]. Compared to un-contrast CT, perfusion CT has a four-fold accuracy in the diagnosis of ischemic stroke, permits differentiation of irreversibly damaged brain tissue from reversibly impaired "tissue at risk" and is used to select patients for reperfusion therapy [3,4]. CT and MR angiography allows to determine the causes and mechanisms of the onset of a stroke, the degree of expansion of the cerebral infarction and the localization of the occlusion of the arteries. These methods can be used to identify the expansion of potential viable brain tissue (semitraum) and irreversible brain damage (core) using CT perfusion and / or diffusion weighting and perfusion weighted MR imaging [5]. Coutinho J.M. et al. (2017) conducted a case-control study to determine whether there is an association between carotid artery web and ischemic stroke [6]. A carotid web was considered when a thin, smooth, membrane-like intraluminal filling defect was found on the posterior walls of the carotid bulb on oblique sagittal images and the corresponding thin septum on axial images [7.].

In the diagnosis of ischemic stroke, along with CT and MRI, transcranial dopplerography is used to determine the site of stenosis of the main arteries of the brain [8,9]. Ultrasonography makes it possible to evaluate the type of atherosclerotic plaques in the carotid arteries. Freilinger T.M. et al. (2012) assessed the prevalence of complicated American Heart Association (AHA) lesion type VI plaques in the carotid arteries of patients with cryptogenic stroke. This study suggests that arterio-arterial embolism from complicated, nonstenosing carotid atherosclerotic plaques may play a role in a subgroup of patients previously diagnosed with cryptogenic stroke [10]. Extracranial carotid atherosclerosis is not only a major cause of ischemic cardiovascular disease but is also known to be a reliable marker of systemic atherosclerosis. Approximately 15% of ischemic strokes are caused by atherosclerosis of large vessels [11]. Flaherty M.L. et al. (2013) determined the types of large vessel atherosclerosis responsible for ischemic strokes in a large, population-based stroke study. They focused especially upon Extracranial ICA stenosis because of the pronounced benefit of appropriate treatment for this stroke mechanism [12]. The presented literature data demonstrate the relevance of determining the relationship between the type of atherosclerotic changes and the degree of stenosis of carotid arteries and ischemic stroke.

Objective

Ultrasonographic assessment the relationship between the ischemic stroke event rate and the severity and appearance of the carotid atherosclerosis.

1. Materials and Methods

A retrospective analysis of the results of carotid ultrasound and Transcranial Dopplerography (TCD) of the Middle Cerebral Artery (MCA) was performed in 134 patients with hemispheric ischemic strokes (IS) of large vessel subtype. The age of the subjects was 41-80 years, among them 65 (48,5%) men and 69 (51,5%) women. Among the patients aged 40-60 years, men were 29 (21,6%), women 26 (19,4%), and at the age of 61-80 years, 36 (26,9%) and 43 (32,1%) respectively (Table 1). As can be seen from the table, IS among women aged 61-80 years was significantly ($P < 0.05$) more often than at the age of 40-60 years (Table 1).

Age	**40 - 60 лет**		**61 - 80 лет**		**Total, n=134**	
Sex	Абс.	%	Абс.	%	Абс.	%
Men	29	21,6±3,6	36	26,9±3,8	65	48,5±4,3
Women	26	19,4±3,4	43	32,1±4,0 P<0,05	69	51,5±4,3
Total	55	41,0±4,2	79	54,8±4,9	134	100,0

Table 1: Distribution of patients with ishemic stroke, taking into account gender and age.

The atherosclerotic risk factors of ischemic stroke is presented in Table 2. The main risk factors for ischemic stroke are Hypertension, Diabetes mellitus, Dislipidemia, Coronary artery disease. When comparing these factors in patients with and without ischemic stroke, a significant difference (P <0.05) was noted only for diabetes mellitus.

Atherosclerotic risk factors	Ishemic Stroke (n=134)	Comparative group (n=78)	P, value
Hypertension	72 (53,7±4,3)	36 (46,2±5,6)	-
Diabetes mellitus	21 (15,7±3,1)	9 (11,5±3,6)	**P<0,05**
Dislipidemia	28 (20,9±3,5)	12 (15,4±4,1)	
Coronary artery disease	11 (8,2±2,4)	5 (6,4±2,8)	

Table 2: Atherosclerotic risk factors in patients with Ishemic Stroke and comparative group.

The comparative group consisted of 78 patients without previous transient ischemic attack or ischemic stroke. In addition, patients were excluded from the study if they had a cardiac valvular or rhythm disorder likely to be associated with cardiogenic embolism; if they had organ failure of the kidney, liver, heart, or lung, or had cancer; or if they did not have Ultrasonographic carotid images of good quality. We examined the total and internal carotid arteries from a distance of 3 cm from the total bifurcation of the carotid artery to 3 cm from the distal to the bifurcation and recorded whether carotid artery calcification or carotid artery wall thickness ≥3 mm. We used the last criterion for wall thickness, as previous studies of CTA suggested that there is a connection between carotid plaque and ipsilateral ischemic stroke when the wall thickness is (approximately) above this threshold [2].

The Intimal-Medial Thickness (IMT) was evaluated as the distance between the luminal-intimal interface and the medial-adventitial interface, and it was measured using two calipers on the frozen frame of a suitable longitudinal image. On the basis the upper limit of normal for the IMT was defined as 1.0 mm, and lesions with an IMT ≥1.1 mm were defined as atheromatous plaques.

To assess the atherosclerosis of the carotid artery, the maximum thickness and extent of the altered wall section of the vessel were measured in longitudinal and transverse sections. Stenosis (% ST) was calculated as the ratio between the residual lumen and the initial lumen. The type of plaques was determined - soft, non-uniform with calcification, the presence of ulcerative lesions as the presence of large open excavations (U) and / or plaques with multiple cavities or cavernous appearance. We took into account the stenosis of carotid arteries in the range of 31-50%, 51-70% and more than 70%. The study of Middle Cerebral Artery (MCA) was conducted without preliminary preparation of the patient in a supine position from the trans temporal access. The MCA diameter, maximum Systolic Velocity (Vs), the end Diastolic Velocity (Vd), Average Systolic Velocity (TAMX), the resistance and Pulsativity Indexes (RI, PI) in MCA were determined [13].

Results

Ultrasonographic evidence of carotid artery atherosclerosis in patients with Ishemic Stroke and comparative group (Table 3)

USG evidence of carotid artery atherosclerosis	Ishemic Stroke (n=134)		Comparative group (n=78)	
	ICA	CCA	ICA	CCA
	1	2	1	2
Carotid artery wall local thickness ≥1,1 mm	112 (83.6±3,2) P 1-1 <0,05	109 (81,3±3,4)	53 (67,9±5,3)	54 (69,2±5,2)
Carotid artery wall thickness ≥3,0 mm	12 (9,0±2,5)	15 (11,2±2,7)	5 (6,4±2,8)	5 (6,4±2,8)
Carotid artery wall calcification	32 (23,9±3,7)	27 (20,1±3,5)	16 (20,5±4,6)	15 (19,2±4,5)
Soft atherosclerotic plaque	13 (9,7±2,6)	14 (10,4±2,6)	7 (9,0±3,2)	9 (11,5±3,6)
Isolated calcified plaques	27 (20,1±3,5	26 (19,4±3,4)	15 (19,2±4,5)	16 (20,5±4,6)

Ulcerated plaques	14 (10,4±2,6) P 1-1 <0,05	11 (8,2±2,4) P 1-1 <0,05	2 (2,6±1,8)	1 (1,3±1,3)
Carotid artery stenosis 31-50%	43 (32,1±4,0	57 (42,5±4,3)	29 (37,2±5,5)	28 (35,9±5,4)
Carotid artery stenosis 51-70%	35 (26,1±3,8) P 1-1 <0,05	23 (17,2±3,3)	11 (14,1±3,9)	12 (15,4±4,1)
Carotid artery stenosis > 70%	12 (9,0±2,5) P 1-1 <0,05	-	2 (2,6±1,8)	-

Table 3: Ultrasonographic evidence of carotid artery atherosclerosis in patients with Ishemic Stroke and comparative group.

112 (83.6%) patients with stroke had a local thickening of the internal carotid artery wall more than 1,1 mm (Figure 1), wall calcification and atherosclerotic plaques of various types. Stenosis of the internal carotid artery in the range of 31-50% was noted in 43 (32.1%) patients, 51-70% in 35 (26.15%) patients, more than 70 % - in 12 (9.0%) patients, respectively.

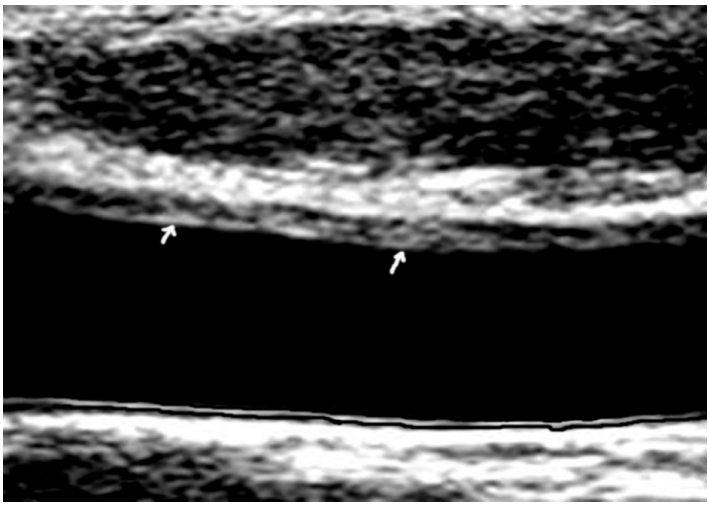

Figure 1: Thickening of the anterior wall of the common carotid artery (arrows). The layers of the artery wall do not differentiate.

A soft plaque on the wall of the internal carotid artery was recorded in 13 (9.7%) patients. It was visualized in the form of a local thickening of the vessel wall no more than 2.3 mm, a length of 3-5 mm (Figure 2). Carotid artery wall calcification was noted in 32 (23.9%) cases - in 21 of them it caused stenosis of the artery lumen in the range of 31-50%.

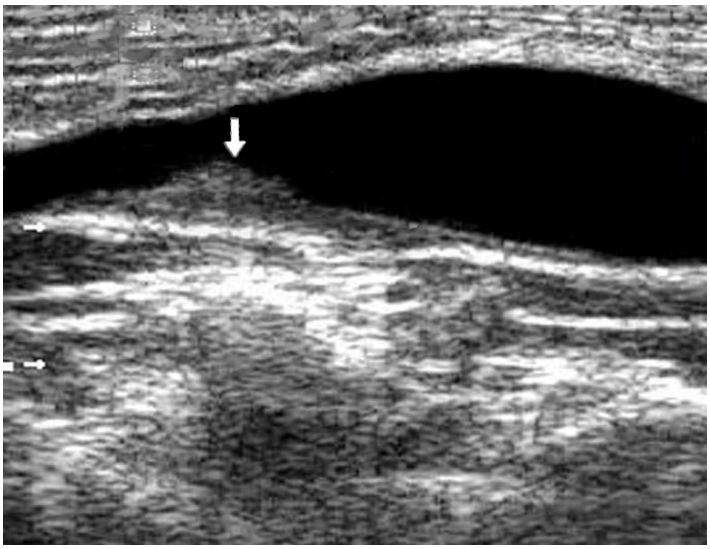

Figure 2: Soft plaque on posterior wall of bifurcation of OCA (arrow). Local thickening of the proximal part of the posterior wall of the internal carotid artery.

Isolated calcified plaques were recorded in 27 (20.1%) cases. In 19 cases they contributed to the stenosis of the ICA in the range of 31-50%. Stenosis of the lumen of the internal carotid artery more than 50% was caused by a local thickening of the oppositely located walls of the ICA in combination with calcification (Figure 3). In 2 (1.5%) patients, the stenosis of the ICA lumen more than 70% was due to the presence of an isolated large plaque. In one case, an atherosclerotic plaque had a high risk of embolization, since it was located on a loose base (Figure 4). In the second case, the plaque had a homogeneous structure, fine-focal calcification

of the surface (Figure5). Ulcerated plaques were diagnosed in 14 (10.4%) patients with stroke - significantly more often than in the comparative group (Figure 6).

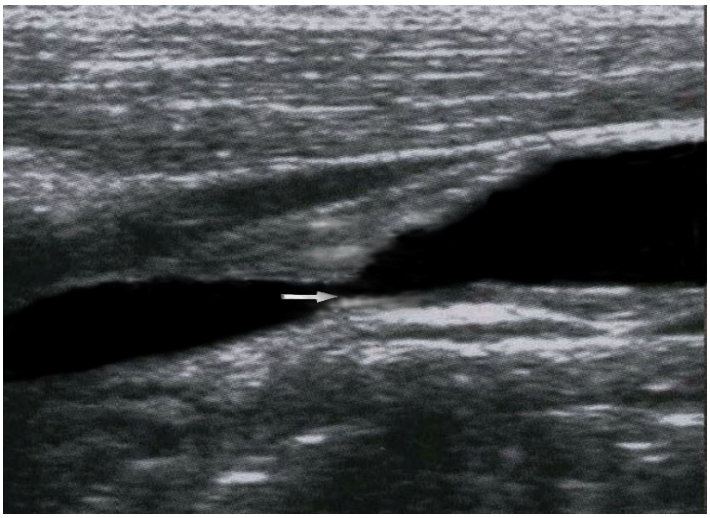

Figure 3: Stenosis of the internal carotid artery about 75% due to local thickening of the walls (arrow).

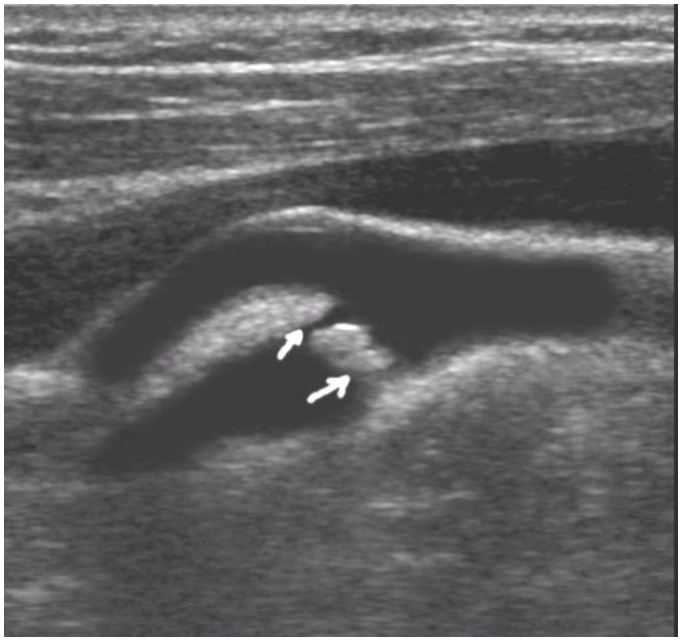

Figure 4: Embologenic plaque on the posterior wall of the proximal segment of the ICA. Stenosis of the artery lumen exceeds 75% (upper arrow). Calcined plaque is located on a loose base (lower arrow).

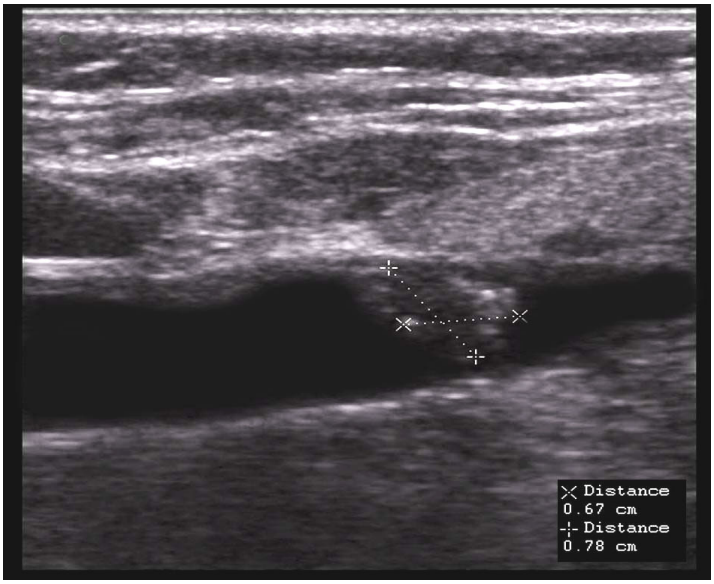

Figure 5: Large plaque on the anterior wall of the internal carotid artery, a homogeneous structure, on a wide base. Stenosis of the ICA is more than 75%.

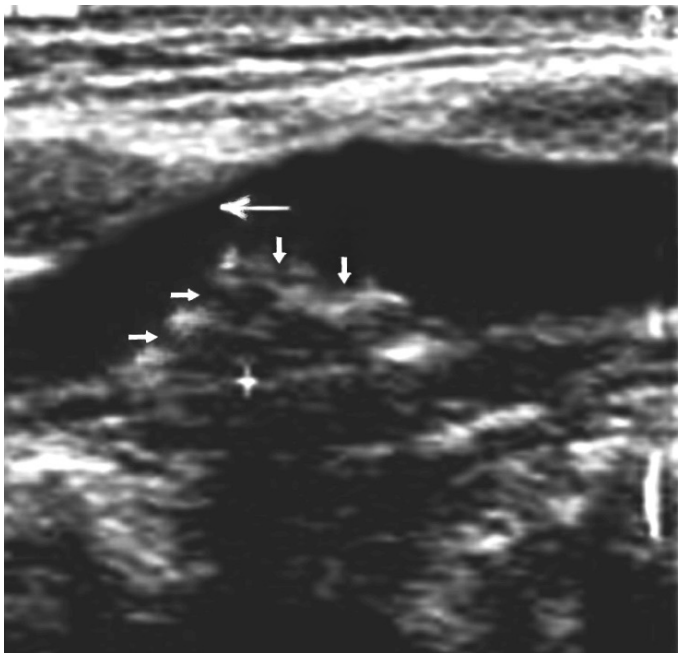

Figure 6: Large ulcerated atherosclerotic plaque on posterior wall of bifurcation of common carotid artery (small arrows). A large horizontal arrow shows an ICA stenosis of more than 50%.

Atherosclerotic changes in the walls of the common carotid artery (CCA) in the form of local or diffuse wall thickening, as well as with the appearance of atherosclerotic plaques were noted in 109 (81.3%) patients with stroke. Stenosis of the common carotid artery in range of 31-50% was noted in 57 (42.5%) patients, 51-70% in 23 (17.2%) patients, respectively (Figure 6). Large plaques causing stenosis of the CCA lumen more than 50% were recorded in 36 (26.9%) cases. In 25 cases, these plaques were soft, homogeneous, in 11 cases - non-uniform with the presence of calcification sites (Figures 7-9a).

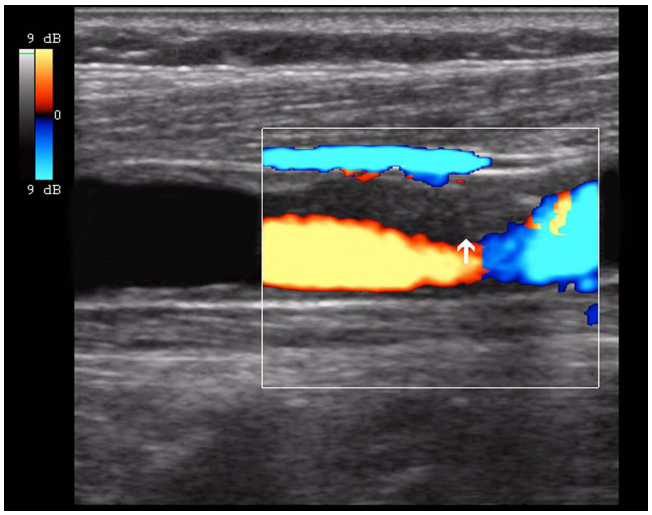

Figure 7: Large soft plaque on posterior wall of CCA is causes of stenosis in the range of 55-60%. Color Doppler mapping of blood flow in the CCA in the stenosis region shows a turbulent flow.

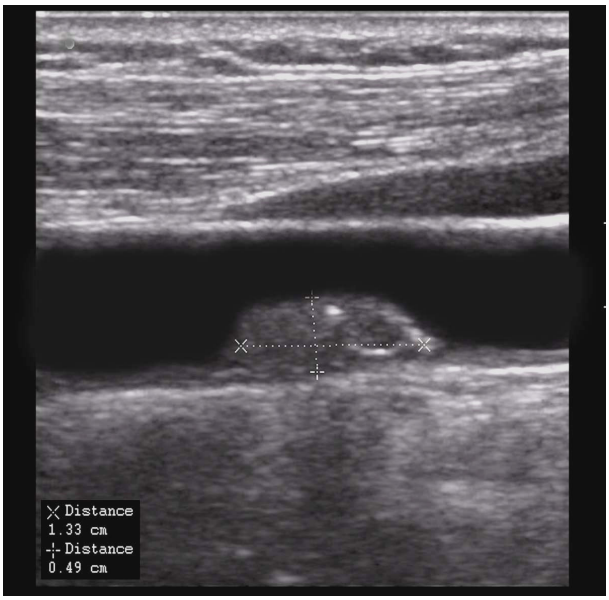

Figure 8: Large soft plaque on posterior wall of CCA is causes of stenosis in the range of 50-55%.

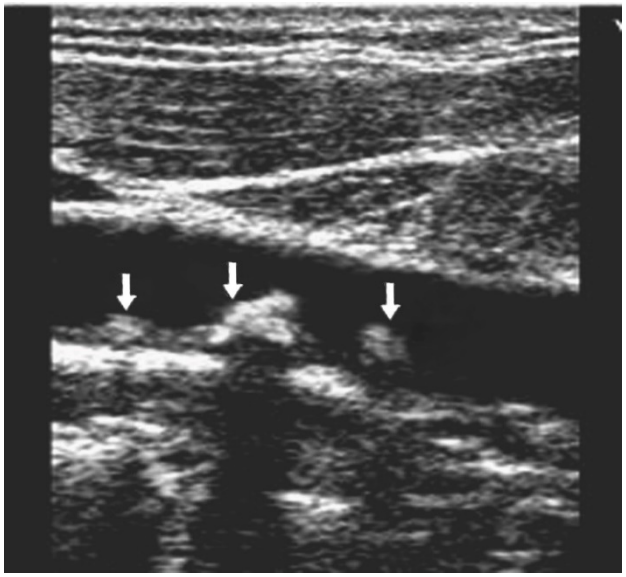

Figure 9a: Multiple atherosclerotic plaques on the posterior wall of the common carotid artery of various types. Stenosis of the CCA exceeds 50%.

In 4 cases the plaques were embolic, between the calcified sites localized loose areas with reduced echogenicity. There was a high probability of detachment of the plaque fragment (Figure 9b). In one case, dynamic observation recorded the detachment of the plaque fragment on the posterior wall of the OSA bifurcation (Figure 10).

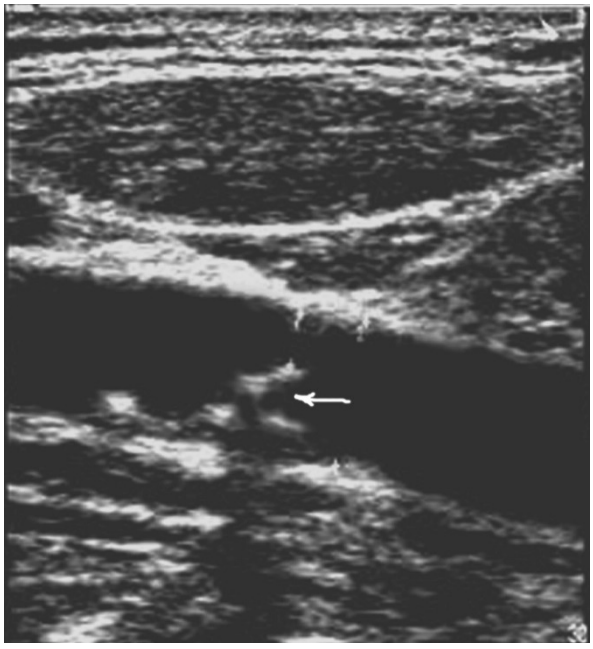

Figure 9b: Atherosclerotic plaque on the posterior wall of the OCA of a non-uniform structure, presence of a loose area between the calcified parts (arrow).

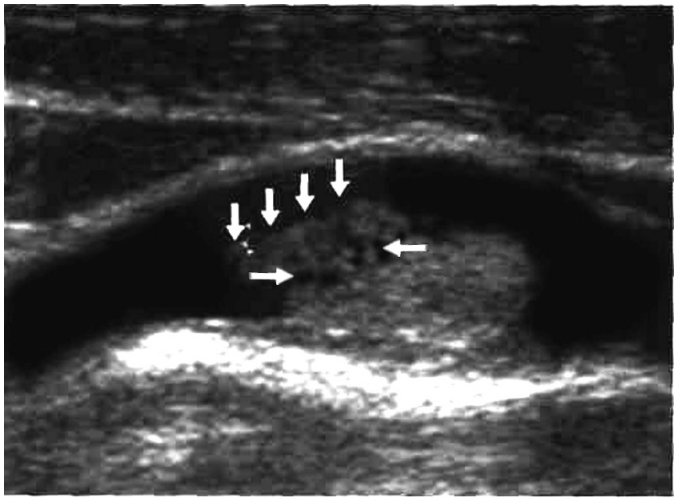

Figure 10: Embolic atherosclerotic plaque on posterior wall of bifurcation of common carotid artery (arrows). The horizontal arrows show the areas of detachment of the plaque fragment under dynamic observation.

With transcranial dopplerography in color mode, a good visualization of the middle cerebral artery was performed in 98 (73.1%) patients, and satisfactory in 27 (20.1%) patients. In 9 (6.7%) patients, the middle cerebral artery was not visualized at all, but the Doppler spectrum without visualization of the artery was obtained in 7 of them. In transcranial dopplerography, hemodynamically significant stenosis of the middle cerebral artery (> 50%) was diagnosed in 28 (20.9) patients (Figure 11). Despite the qualitative visualization of the sites of stenosis of the middle cerebral artery in individual patients, the main method for diagnosing brain pathologies in ischemic stroke was MRI (Figure 12).

Figure 11: Visualization of stenosis of the middle cerebral artery in a patient with left-sided hemispheric ischemic stroke.

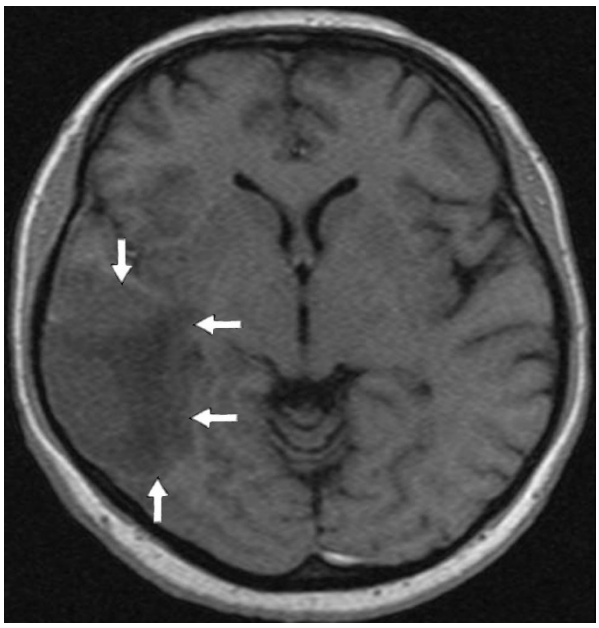

Figure 12: MRI with ischemic stroke in the left MCR basin (left hypodence zone- arrows).

Discussion

The diagnosis of atherosclerotic lesions of the carotid arteries, in particular the character of the changes in the vascular wall, the degree of stenosis, is of great importance for clinicians caring for patients with a stroke or TIA because of its frequent occurrences, a high risk of early recurrent ischemia. In previous studies, the effectiveness of endarteriectomy with stenting of the carotid artery in patients with ischemic stroke due to stenosis of the carotid arteries was demonstrated [14,15]. Research Flaherty M.L. et al. (2013) also shows that Extracranial atherosclerosis ICA is the most important cause of large-scale stroke [12].

Stroke attributed to Extracranial ICA occlusion occurs at approximately half the rate of stroke due to ICA stenosis. The recently completed "Carotid Occlusion Surgery Study" (COSS) failed to show a benefit for Extracranial-intracranial bypass among patients with carotid occlusion judged at high risk of recurrent stroke by PET imaging [16].

The underlying mechanisms of cerebral infarction include artery-to-artery embolism, hemodynamic compromise, local branch occlusion or a combination of those conditions. Histological study of the Middle Cerebral Artery (MCA) has demonstrated that luminal stenosis is frequently caused by ruptured vulnerable plaques, which are characterized by their specific morphology and composition, which comprises a large lipid/necrotic core covered by a thin fibrous cap infiltrated by macrophages and intraplaque hemorrhage [17].

In our studies, the prevalence of ulcerated and embolog- inous plaques was found among patients with ischemic stroke compared with patients who did not have cerebral blood flow disorders.

Conclusion

The relationship between the nature of atherosclerotic plaque, the degree of stenosis of the internal carotid artery and the frequency of occurrence of ischemic stroke are established. Ulcerated and embologenic plaques in the carotid arteries, stenosis of the internal carotid artery more than 70% increase the risk of ischemic stroke. Hemodynamically significant stenosis of the middle cerebral artery can be diagnosed by color Doppler in more than 70% of patients with ischemic stroke.

Conflict of Interest

The authors declared no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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