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Original Article

Effects of carotid artery stenosis and plaque localization on the incidence of cerebral infarct and diameter of vertebral artery: a duplex ultrasonography and MRI evaluation

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Abstract: Objective: Our aim was to determine the relationship between carotid plaque localization, degree of carotid artery (CA) stenosis and the presence of acute cerebral infarction in patients with neurological symptoms. We also aimed to determine whether there are differences in the diameter of the vertebral arteries in patients with CA stenosis. Materials and methods: A total of 86 patients with neurological symptoms were included in this study. Brain magnetic resonance imaging including diffusion weighted images demonstrated the findings of acute or chronic infarct, whereas B mode and carotid duplex Doppler ultrasonography showed the CA plaque structure, echogenicity, location and degree of stenosis. The sonographic findings were compared between patients with acute and/or chronic infarcts. Statistical analyses were performed with the SPSS 12.0 software package, and the independent-samples t-test was used to compare the parameters. Results: We found a statistically significant relation between a high degree of stenosis (> 50%) at the level of the right (P = 0.021) and left (P = 0.023) common carotid artery (CCA) bifurcation with acute cerebral infarction. However, there was no significant correlation between the diameters of the vertebral arteries with the degree of stenosis in the carotid arteries. Conclusions: Our data suggest that high-grade stenosis at the level of the CCA bifurcation was highly associated with the presence of acute cerebrovascular events.

Keywords: Plaque echolucency, carotid stenosis, intracranial arterial diseases, cerebral infarction

Introduction

Cerebrovascular events which result in carotid artery (CA) disease are the most common causes of death after heart disease and cancer in developed countries. Most cases of ischemic stroke evolve to secondary and extracranial carotid and vertebral artery (VA) disease [1, 2]. A strong relationship has been reported between CA disease and stroke in several studies and the grade of stenosis and plaque composition are major determinants for the formation of symptoms [3-6]. Unstable plaques, recognized as echolucent on B-mode ultrasonography (US), can be a source of thromboembolism and may be the reason for cerebral ischemic symptoms [7, 8]. In our study, we aimed to investigate the relationship between carotid plaque localization, degree of CA stenosis, and the presence and severity of acute cerebral infarction in patients with neurological symptoms. We also aimed to determine whether there are changes in the diameter of the VA in patients with CA stenosis.

Materials and methods

The study protocol was approved by the institutional review board, and written informed consent was obtained from all patients.

Study population

A total of 86 patients (44 women, 42 men; mean age 65.5 ± 10.3 years, range from 27 to 88 years) with neurological symptoms (such as hemiparesis, monoparesis, hemisensory deficits, visual loss/deficits, diplopia, dysarthria, ataxia, vertigo, nystagmus and aphasia) were included in this retrospective study. Clinical indications for carotid duplex US were major or minor stroke history; while the patients that had vascular stenosis, occlusion and retrograde flow in the vertebral arteries, benign or malignant masses located in the brain, cranial venous thrombosis, and the history of surgery in the CA or VA were excluded from this study.

Colour duplex ultrasonography (CDUS)

CDUS scanning was performed by a single radiologist using the same machine with 7-18 MHz linear array transducers (Toshiba Aplio 500 system; Toshiba Corporation, Japan). The patients were placed in a supine position with their heads turned to the contralateral side by about 10° during the examination. The presence and structure of the plaques were evaluated by B-mode US and CDUS, and the grade of stenosis was assessed according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method and criteria [9].

CDUS showed that the CA plaque structure, echogenicity, localization and stenosis, and plaque localizations were classified as common carotid artery (CCA), carotid bifurcation and internal CA (ICA). The plaque compositions were defined as soft, hard and mixed plaques, according to their structure and echogenicity. The degrees of stenosis in the carotid arteries were calculated and classified as < 50%, 50-70%, 70-90% and occlusion. We divided the groups into lower degree stenosis (< 50%) and high degree stenoseis (> 50%). The VA diameters were measured in the C4-5 or C5-6 intertransverse segments.

Magnetic resonance imaging (MRI)

MRI was performed on a 1.5 T Gyroscan Intera system (Philips, Bothell, WA), where diffusion-weighted images (DWI), T1- and T2-weighted, and fluid-attenuated inversion recovery images were obtained. These studies demonstrated the findings of acute or chronic infarction. Acute stroke was defined as a brain area with restricted diffusion and hyperintensity on DWI as a result of acute developed cytotoxic oedema. Patients with chronic stroke were diagnosed on the basis of chronic ischemic changes either in conventional and/or DWI. The differentiation between acute and chronic infarction was made based on the DWI.

Statistical analysis

The diameters of the vertebral arteries of the patients were calculated as the mean ± standard deviation. The independent samples t-test was used to compare the plaque structure, plaque localization of the CA, diameter of the VA and acute infarction rate of the patients. US findings were compared between the patients with acute and chronic infarction, and the statistical analysis was performed with the SPSS 12.0 software package for Windows (SPSS software, version 12.0.1 for Windows, SPSS Inc., Chicago, IL). The independent-samples t-test was used to compare the parameters, and *P*-values < 0.05 were considered to be a statistically significant difference.

Results

A total of 86 patients (age range 27-88 years, mean age 65.5 ± 10.3 years) were included in this study. Forty-two of the patients (49%) were male and 44 (51%) of them were female.

Seventy-three patients (age range from 44 to 88 years, mean age 68.5 ± 9.9 years) had plaques in the carotid arteries or acute/chronic cerebral infarcts. Thirteen patients (age range from 27 to 68 years, mean age 46.7 ± 10.7 years) had neither plaques on the CDUS in the carotid system nor any infarction on the MRI.

A total of 51 cases had atherosclerotic plaques in the carotid system, 31 of them (61%) had plaques in the right bifurcation and 36 of them (71%) had plaques in the left bifurcation. Soft plaques were found in 14 (28%) of the patients in the right carotid bifurcation and 16 (31%) of them in the left carotid bifurcation.

The mean diameter of the right VA was found to be 3.51 ± 0.79 mm in the patients with CA plaques or cerebral infarctions; however, it was 3.40 ± 1.17 mm in the patients without plaques in the CA system or cerebral infarctions (3.47 ±

Table 1. Relationship between cerebral infarct on magnetic resonance imaging and high degree of stenosis (> 50%) at the level of bifurcation of the right and left common carotid arteries

	Stenosis degree	No infarct	Acute infarct	Chronic infarct	Total	x^2	P
Right bifurcation stenosis	50-70%	0	3	1	4	19.532	0.021*
	≥ 70%	0	2	0	2		
Left bifurcation stenosis	50-70%	0	2	0	2	14.665	0.023*
	≥ 70%	0	0	0	0		
TOTAL		0	7	1	8		

*significant statistical relationship between groups. chi-square test of independence.

Table 2. The mean diameter of vertebral arteries in terms of age group

	Age	n	Mean (mm)	± SD
Right VA diameter	≤ 70	43	3.605	0.782
	≥ 71	30	3.380	0.809
Left VA diameter	≤ 70	43	3.686	0.788
	≥ 71	30	3.867	0.627

VA: vertebral artery.

Table 3. Comparison of mean vertebral artery diameters in patients with carotid stenosis and patients without carotid stenosis

	Patient	n	Mean (mm)	± SD	t	P
Right VA diameter	with stenosis	73	3.51	± 0.795	0.434	0.665
	without stenosis	13	3.40	± 1.171		
Left VA diameter	with stenosis	73	3.76	± 0.726	0.568	0.571
	without stenosis	13	3.63	± 0.615		

VA: vertebral artery, independent samples t-test.

1.02 mm in males, 3.36 ± 1.28 mm in females), which was not statistically significant (P > 0.05).

The mean diameter of the left VA was found to be 3.76 ± 0.72 mm in the patients with CA plaques or cerebral infarctions; however, it was 3.63 ± 0.61 mm in the patients without plaques in the CA or cerebral infarctions (3.90 ± 0.27 mm in males, 3.52 ± 0.70 mm in females), which is not statistically significant (P > 0.05).

When comparing patients younger and older than 70 years old, a statistically non-significant increase in the mean diameter of the left VA was found in both age groups; however, the increase was more significant in patients older than 70 years (**Table 1**).

With regard to the mean diameters of the right and left vertebral arteries in patients with carotid plaques and without carotid plaques, the comparison was not statistically significant (P > 0.005). There was no correlation between the diameters of the vertebral arteries and the degree or localization of the stenosis in the carotid arterial system. The data comparing the mean VA diameters in the patients with CA and without CA plaques are presented in **Table 2**.

A statistically significant relationship was found between the high degree of stenosis (> 50%) at the level of the right (P = 0.021) and left (P = 0.023) bifurcations of the CCA with acute cerebral infarction (**Table 3**).

Discussion

In the present study, we showed that soft plaque formation and high-grade carotid stenosis at the level of the CCA bifurcation was strongly associated with the presence of acute stroke; however, there was no association between the presence of carotid artery plaques or cerebral infarction and the vertebral artery diameter.

CDUS is widely used to screen extracranial CA and VA stenosis and occlusion in patients with cerebrovascular ischemia. It is a relatively inexpensive method that can be performed at the bedside, which provides real-time information about the status of cervicocranial arterial patency, atherosclerotic changes and various hemodynamic alterations, including collateral flow. The CDUS plays an important role in assessing major carotid stenosis, and in decision-making for various treatments within 2 weeks after the onset of symptoms [1, 10, 11].

Current ultrasound devices with excellent image quality provide important information about plaque echogenicity and surface smoothness, plaque localization and number, degree of stenosis, diameter of carotid and vertebral arteries, and flow dynamics of these vessels. Being familiar with the characteristics of the plaques in the carotid system can help to predict the risk of cerebral ischemia and/or infarction [10, 11].

Cerebral circulation is provided with the help of collateral vessels in cases of severe CA stenosis. The most important of these collaterals is the circle of Willis, and this system plays a critical role in the stenosis or occlusion of the CA and VA.

VAs play an important role in the blood supply to the brain, and these vessels provide collateral blood supply to different parts of the brain via the circle of Willis, where occlusive CA disease occurs. Pathologies of the VA are much more often seen in patients with neurological disorders, and it becomes important to determine the characteristic flow volume and pattern of the vertebral arteries in these patients. Some morphological and hemodynamical alterations occur in the VAs in order to compensate for brain perfusion in patients with CA stenosis or occlusion. Nicolau *et al*. [11] presented a study about the effects of ICA occlusion on the blood flow velocity of ipsilateral VAs. In their study, they suggested that the vertebral blood flow velocity of normally functioning VAs can be altered by ICA occlusion. In a recently published case report, Demir *et al*. [12] presented a man with bilateral ICA occlusions and bilateral, extremely large calibration VAs. Both of these studies revealed that ICA occlusions have an effect on VA diameter and blood flow velocity. In another study conducted by Kizilkilic *et al.* [13] similar flow parameters of vertebral arteries were found in both sexes and both groups of patients with carotid stenosis more or less equal at 50%. In our study, the increasing diameter of the VA was not statistically significant in patients with CA stenosis.

Carotid plaques are believed to be a marker of generalized atherosclerosis and a potential source of thromboembolism. Carotid plaque composition, localization and degree of stenosis are important predictive factors of cerebrovascular events. It has been reported that carotid plaque characteristics are strongly related with the risk of stroke and the morphological characteristics, structural components and localization of the plaque, detected by a carotid US study, may provide important information about the risk of future neurological events [7, 10]. Many authors have previously suggested that low echogenic components in the plaques demonstrate a high correlation with intraplaque haemorrhage, and these plaques are accepted to have a strong association with the increased risk of cerebrovascular events [10, 14, 15]. In their study, Ku et al. [16] showed that carotid bifurcations with relatively large branch angles would have larger outer wall areas subjected to nonaxial shear stress, and possibly, more extensive intimal plaque formation. They also found that low mean shear stress and marked oscillations in the direction of wall shear stress may be critical factors in the development and localization of atherosclerotic plaques. In our study, we found that the increasing of the rate of acute cerebral infarction in patients with a high degree of stenosis at the level of the carotid bifurcation due to soft plaque was statistically significant ($P < 0.05$).

In this study, one radiologist performed all ultrasonographic measurements, thus eliminating inter-observer variability. Nevertheless, our study suffers from several limitations. First, the number of patients was relatively small. Second, we did not compare our results in the stroke patients with those of a control group of healty subjects, which would have been useful.

The findings of our study show that there was a non significant correlation between the degree of carotid artery stenosis and the vertebral artery diameter. Also we found a statistically significant association between soft plaque formation and high-grade carotid stenosis at the level of the CCA bifurcation is strongly associated with the presence of acute stroke. Accordingly, a B-mode and colour Doppler carotid US study, which is a very cheap, safe and noninvasive radiological modality, has a pivotal role in detecting CA stenosis and the assessment of plaque morphology, structure and localisation, improving prognostic risk prediction and treatment options.

Disclosure of conflict of interest

None.

Authors' contribution

All authors confirm that they have participated sufficiently in the conception and design of the work, reviewed and approved the final version of this manuscript to take public responsibility for it.

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