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THE SIGNIFICANCE OF COLOR DOPPLER SONOGRAPHY IN SELECTION OF PATIENTS FOR CAROTID ENDARTERECTOMY

SUMMARY

Sonography is the most widespread diagnostic procedure in obstructive disease of the arteries supplying the brain. The combined non-invasive information on morphology and function makes color Doppler sonography the procedure of choice in screening and follow-up of carotid artery disease. The aim of this study was to establish the significance of color Doppler sonography in selection of patients for carotid endarterectomy. Sonographic examinations of carotid arteries were performed in 5124 patients. The series consisted of all the patients with symptoms of carotid disease as well as asymptomatic patients with some risk factor. The examination was done on conventional ultrasound machines and linear 7,5 MHz transducers with color Doppler imaging. Ultrasound examinations aimed at establishing the presence and locus of the plaque, length of involved segment, degree of stenosis, plaque structure and plaque surface configuration. Stenosis degree determination was computer-assisted using two morphological and one hemodynamical methods of stenosis grading. In some cases, ultrasound findings were compared to DSA findings, and all ultrasound findings were compared to intraoperative ones. Out of the total number of examinees, 0.9% patients were selected based on surgically significant stenosis (over 75%). In cases in which angiography of the carotid bed was performed too, ultrasound findings correlated well with angiography. Ultrasound findings correlated well with intraoperative findings, too. The significance of color Doppler sonography in patient selection for carotid endarterectomy lies in the possibility of direct visualization of plaque morphology, determination of its properties, and the composition of configuration of its surface, which cannot be measured with other diagnostic procedures. Moreover, it is possible to measure the length of stenosis-involved segment, to determine precisely the grade of stenosis and to get an insight into homodynamic disorders.

Key words: **carotid endarterectomy, stenosis, color Doppler sonography**

INTRODUCTION

Stroke is one of the leading causes of death in industrialized countries (1,2). Approximately one-third of acute cases have a fatal outcome. In many patients, survival means prolonged and often irreversible disability. The paralysis following a brain attack frequently leads to complete dependence on nursing care and permanent speech disorders that impair the stroke victim's ability to communicate.

Sonography is the most widespread diagnostic procedure in obstructive disease of the arteries supplying the brain. The combined non-invasive information on morphology and function

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makes sonography the procedure of choice in screening and follow-up of carotid artery disease. Over the past years, numerous multicentric studies have investigated the merits of surgical interventions to repair carotid stenosis (e.g. ECST, NASCET, ACAS) (3, 4, 5, 6).

De Bakey was the first to successfully perform carotid endarterectomy back in 1953; Eastcott et al. performed it and were the first to publish the results in 1954. At the Clinic of Surgery, Clinical Centre Nis, the first carotid endarterectomy with eversion technique was performed in 2003.

Aim of the study was to establish the significance of color Doppler sonography in patient selection for carotid endarterectomy.

MATERIAL AND METODS

In the period from January 2003 to December 2005 at the Institute of Radiology in Nis, sonographic examinations of carotid arteries were performed in 5124 patients. The series consisted of all the patients with symptoms of carotid disease (TIA, RIND, complete brain stroke) as well as asymptomatic patients with some risk factors. Out of the total number of examinees, 49 (0.9%) patients were selected based on surgically significant stenosis (over 75%) and referred to the Council for Carotid Endarterectomy where the team of doctors (radiologist, neurologist, vascular surgeon) decided on further diagnostic and surgical proceedings. The examinations were performed on conventional sonographic machines with linear probes of 7.5 MHz with color Doppler imaging and longitudinal, transversal and oblique sections.

Sonographic examination aimed at establishing the presence of plaque, position of plaque related to bifurcation, length of involved segment, degree of stenosis, plaque composition, plaque surface configuration, and at establishing hemodynamic blood flow changes based on graphical flow curve. Diagnosis of stenosis by color Doppler sonography is generally based on a recognizable reduction of the perfused lumen and the flow disturbances described. Visualization in longitudinal and transversal planes can help locate the stenosis and provide a description of its length and geometry. Stenosis degree determination was computer-assisted using two morphological and one hemodynamical method of stenosis grading. In some cases, ultrasound findings were compared to DSA findings, and all ultrasound findings were compared to intraoperative findings.

RESULTS

Most common, position of atherosclerotic plaques was at the bifurcation of common carotid artery and the initial portion of internal carotid artery (ICA) in 36 patients (73%). In 13 patients (27%), stenosis was present in ICA in its proximal segment at 8-25 mm distance from the source. The length of stenosis-involved segment ranged from 4 mm to 15 mm. Only one female patient had short concentric stenosis of 4 mm, which was difficult to measure and determine its degree.

Out of the total number of patients, 28 (57.1%) had stenosis of one ICA of over 75%, 12 (24.5%) patients had stenosis of both ICAs, with at least 75% stenosis in one or both of them, while 9 (18.4%) cases had 75% stenosis of one and occlusion of the other ICA. In most of them, calculation of the diameter and area of stenosis degree were utilized. *(Figure 1 and 2)*

Figure 1. Calculation of the local-diameter degree of stenosis

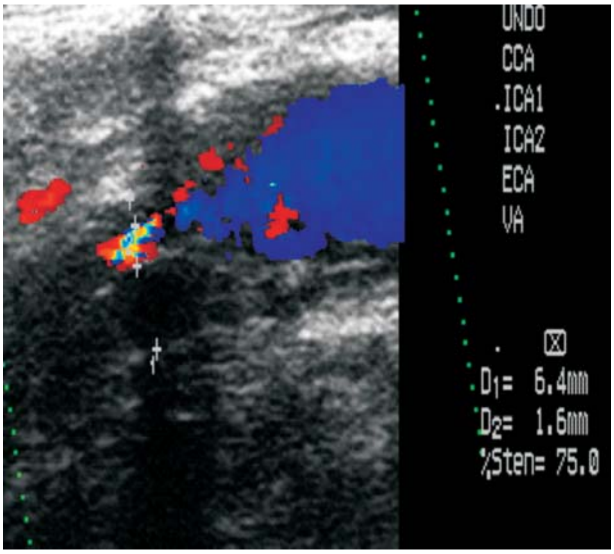
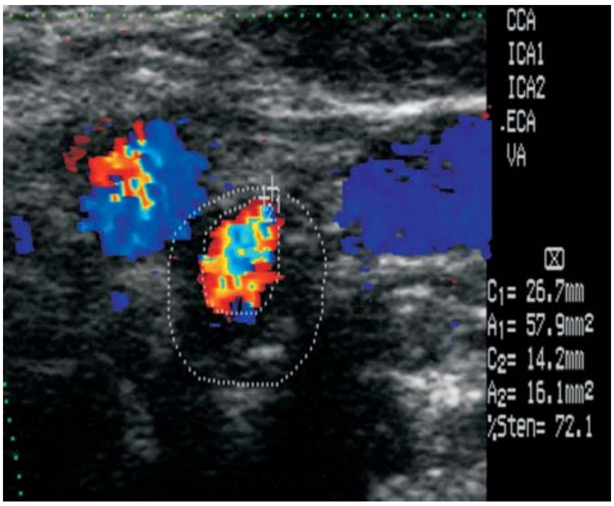
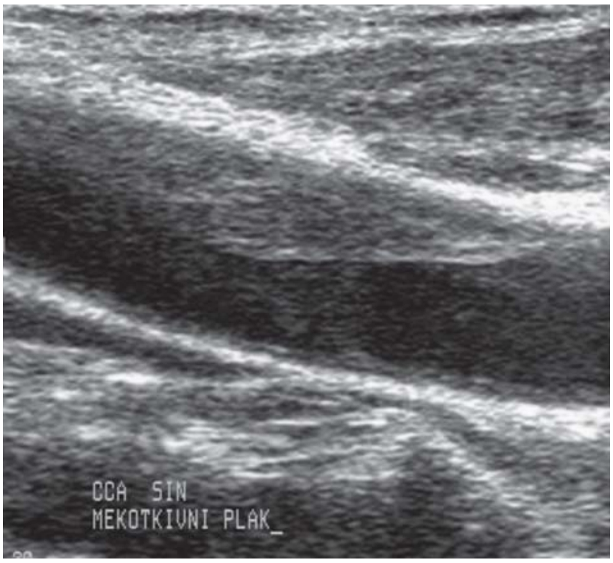


Figure 2. Calculation of the local-area degree of stenosis



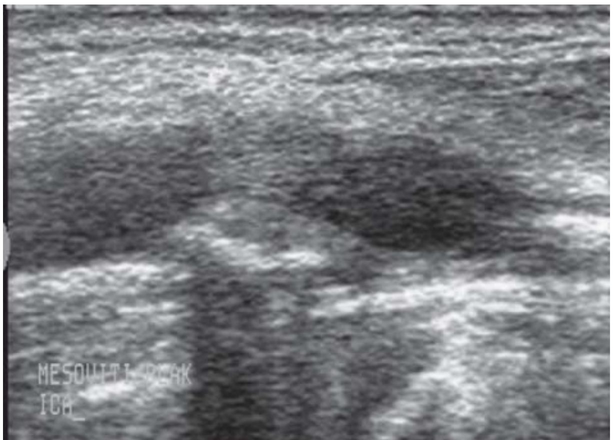
Most of the plaques were soft tissue ones (lipid, fibrolipid) present in 25 (51%) patients. *(Figure 3)*

Figure 3. Eccentric soft lipid plaque in the common carotid artery



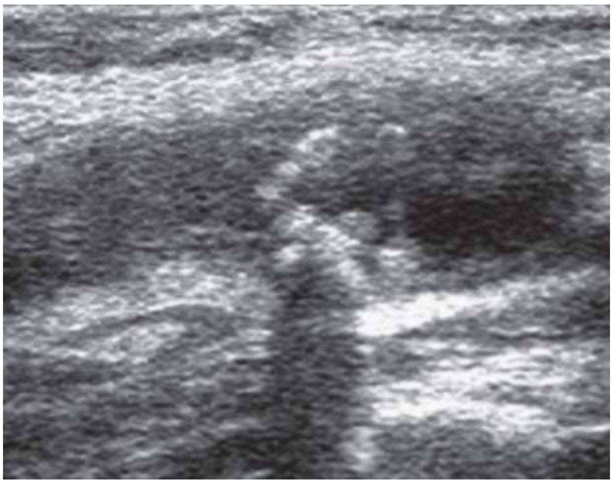
They were hypoechogenous on sonography and, therefore, sometimes hard to identify in B-mode due to their blood-like characteristics. When preserved, intimal layer related to the lumen was visualized as linear echogenous structure. Hemorrhages within the plaque also had hypoechogenous features. In one patient, in addition to high-percent ICA, stenosis caused by lipid plaque, soft tissue plaque were found in CCA, too. After lipid ones, most common were mixed-type plaques: calcified and with soft tissue component (fibrous or lipid) in 17 (34,7%) patients. *(Figure 4)*

Figure 4. Mixed plaque in the internal carotid artery



There were also entirely calcified plaques in 7 (14,3%) patients. *(Figure 5)*

Figure 5. Calcified plaque in the carotid bulb



Very echogenous plaques with calcifications produced acoustic shadowing. Calcifications prevented the demonstration of artery wall, and sometimes, it was difficult to determine the degree of stenosis.

Configuration of plaque surface is especially important for preoperative evaluation of the patients with lesions of the arteries supplying the brain. Ulceration of intraluminal plaque surface was found in 3 patients (6.1%), out of which one had high-percent stenosis, and two of them moderate stenosis of 50%. When there is intimal injury or exulceration, plaque surface is irregular, with occassional crater-like cavities. The significance of the plaques with irregular or crater-like surface or exulceration is reflected through the fact that the surface is thrombogenous. The thrombi create drop off the surface and produce distal embolism. The problem of identification of exulcerated plaque is practically far more important if there is moderate or low level stenosis. Ulcerated plaque with less than 60% carotid artery stenosis in symptomatic patients is more prone to ishemic complication, so that two patients required carotid endarterectomy.

In 12 patients in which angiography of carotid basin was performed, ultrasonographic findings correlated with angiography (in position of plaque related to bifurcation, length of involved segment, degree of stenosis, plaque surface configuration). All ultrasound findings correlated well with intraoperative findings, too. No false negative or false positive findings were found.

DISCUSSION

Four-fifths of all ischemic events are heralded by arteriosclerosis. The large majority of pathological changes affect the extracranial arteries that supply the brain and are especially prevalent at the carotid bifurcation. Over the past years, numerous multicentric studies have investigated the merits of surgical interventions to repair carotid stenosis (e.g. ECST, NASCET, ACAS) (3, 4, 5, 6). All studies have proposed limits defining the respective degree of stenosis above which a clinically favourable outcome of surgery can be expected. When specific inclusion criteria were applied, both symptomatic and asymptomatic patients benefited from surgical therapy. Two randomized studies (NASCET, ECST) on the efficacy of carotid thrombendarterectomy (TEA) in symptomatic patients (3, 4, 5, 6, 7) showed that patients with high-grade carotid artery stenosis, defined as a diameter reduction of between at least 70-80%, who were treated with surgery, achieved a greater benefit than the group undergoing conservative treatment. Even asymptomatic patients with carotid stenosis of at least 60% diameter reduction can benefit from carotid surgery. The ACAS study (7, 8) showed that surgery initially led to a significant risk reduction (absolute 5.8%, relative 55%). However, more recent meta-analyses indicate that carotid TEA reduces the absolute risk in asymptomatic patients by only 2%, approximately (4). While stent-supported percutaneous transluminal angioplasty (PTA) of the carotid artery has gained importance in recent years (9), the 5 and 10-year long-term results have not yet been verified in randomized studies. On the other hand, short and mid-term results for carotid stenting are acceptable (10).

The extracranial distribution of most vascular lesions makes them accessible to detection by ultrasound imaging. The examination aims at determining the nature, site, and extent of vascular lesions. Many of the abovementioned therapeutic studies in the past were followed by a great number of diagnostic studies comparing the results of ultrasound and invasive angiographic procedures, since all the data from large multicentric studies had been based solely on the angiographic estimation of degree of stenosis (11-17).

Most commonly, disturbances of cerebral blood flow are caused by the arteriosclerotic narrowing of the vessel lumen due to stenoses or occlusions. Overlapping of risk profiles occurs between cerebrovascular-ischemic and myocardial-ischemic diseases (18). Although it is possible for arteriosclerotic lesions of the arteries supplying the brain to develop anywhere, extracranial lesions particularly favour the carotid bifurcation. Even moderate luminal constrictions can induce hemodynamic changes (e.g., increase in flow velocity, poststenotic vorticity), but, stenosis is not hemodynamically relevant unless the residual lumen is so small that it causes a reduction in flow volume. In general, this is assumed when the cross-sectional area is reduced by 75% or more (19). Here, the degree of stenosis correlates with stroke incidence (20). Critical appraisals are currently looking at how strictly risk assessment in carotid stenoses should focus on the degree of stenosis (21). It is assumed that the majority of ischemic cerebral lesions are caused by embolism arising from extracranial carotid stenoses. The clinical impact of stenosis, e.g., in the carotid region, only becomes apparent once all compensation mechanisms have failed, e.g., when additional stenoses impair the contralateral or intracerebral circulation (22). Over time, progressive arteriosclerosis, intraplaque haemorrhage, or local thrombosis can turn a hemodynamically insignificant stenosis into a flow-reducing stenosis or a complete occlusion.

Some examples of rare causes of arterial lumen constrictions with consecutive cerebral ischemia are various forms of arteritis, moyamoya disease, spontaneous and traumatic dissections, radiation exposure, fibromuscular dysplasia, and tumour-induced vascular compression and infiltration.

Detection of carotid stenoses and occlusions by color Doppler sonography relies chiefly on the combination of B-mode (gray-scale) and color-encoded flow imaging because of the good visualization these vessels offer. The major advantage of the procedure is that the B-mode image defines the outer boundary of the vessel wall and lumen-reducing material, while the color image demonstrates the associated flow pattern. The Doppler spectral analysis is not only used to confirm and quantify findings, but is additionally helpful when vascular segments are not unequivocally distinguishable in the color-coded image.

Although most stenoses are demonstrated at the origin of the internal carotid artery, many arteriosclerotic lesions involve the carotid bulb and the origin of the external carotid artery, thereby producing bifurcation stenoses.

The most subtle arteriosclerotic vascular lesion is the circumscribed plaque with a smooth surface that blends innocuously into the healthy vessel wall. Such early changes can be observed in the posterior part of the carotid bulb (23) and are hallmarked by slight wall thickening and the absence of normal flow reversal near the wall.

Higher degrees of luminal narrowing produce the typical flow disturbances, such as intrastenotic velocity increase, poststenotic flow separation and reversal, poststenotic disturbed flow and turbulence (24). Diagnosis of stenosis by color Doppler ultrasound is generally based on a recognizable reduction of the perfused lumen and the flow disturbances described. Visualization in longitudinal and transverse planes can help locate the stenosis and provide a description of its length and geometry. These images also allow a rough estimation of the extent of luminal constriction similar to the subjective interpretation of angiograms.

There are four morphologically based (1-4, relying on the color image) and four hemodynamically based (5-8, relying on the Doppler spectra) methods for grading stenoses of the internal carotid artery (ICA):

1. Calculate the percentage of cross-sectional area reduction, i.e., the ratio of the perfused lumen area to outer contours (so-called local-area degree of stenosis).

2. Calculate the percentage of local diameter reduction, i.e., ratio of perfused lumen diameter to the outer contours (so-called local-diameter degree of stenosis).

3. Calculate the percentage of distal diameter reduction, i.e., the ratio of the diameter of the perfused intrastenotic lumen to the poststenotic diameter (so-called distal-diameter degree of stenosis).

4. Calculate the percentage of proximal-diameter reduction, i.e., ratio of the diameter of the perfused intrastenotic lumen to the prestenotic diameter the common carotid artery (so-called proximal-diameter degree of stenosis).

5. Obtain an absolute measurement of the internal carotid peak systolic frequency (ICPSF).

6. Obtain an absolute measurement of the internal carotid peak systolic velocity (ICPSV).

7. Obtain an absolute measurement of the internal carotid end-diastolic velocity (ICEDV).

8. Calculate the ratio of intrastenotic internal carotid peak systolic velocity to the prestenotic common carotid peak systolic velocity (ICPSV / CCPSV).

The literature abounds with reports and studies of indices, parameters, and grading methods, suggesting that there is not a single method available that allows precise quantification of the degree of stenosis. This can be explained by the fact that large clinical studies have worked on defining exclusively angiographic limits, although angiography only determines the diameter of the perfused vessel in several projections. It would take a combination of grading methods 2, 3, or 4 just to produce a duplex ultrasound correlation; however, because the stenosis area is sometimes partly obscured, hemodynamic measurement (methods 5-8) has become established in the literature. Naturally, correlating hemodynamic and geometric measures are subjected to limitations. That is why every centre must correlate their duplex ultrasound and angiographic results to establish its own internal thresholds as a basis for indication for the surgical therapy of carotid stenoses (13,14,16). In this study, calculation of the diameter and area of stenosis degree were utilized, and ratio of intrastenotic internal carotid peak systolic velocity to the prestenotic common carotid peak systolic velocity (ICPSV/CCPSV) was calculated.

If the degree of stenosis cannot be established, selective catheter angiography is indicated (15).

A rough classification of the degree of stenosis is usually sufficient for clinical purposes.

Table 1. Hemodynamic quantification of carotid stenoses calculated from the ratio of maximal systolic velocity in internal carotid artery (ICA; intrastenotic) to common carotid artery (CCA)

Degree of stenosis in the ICA (diameter reduction as defined by NASCET;%)	Maximum systolic velocity ICA to CCA (ICPSV/CCPSV)
> 50	> 1,8
> 60	> 2,6
> 70	> 2,8
> 80	> 3,7
> 90	> 5

Comparisons of angiography and Doppler ultrasound (13) reveal that a ratio of <1.5-1.8 (internal carotid peak systolic velocity/peak systolic velocity in the prebulbar segment of the common carotid artery; ICPSV/CCPSV) is equivalent to an internal carotid artery stenosis of less than 50% diameter reduction (diagnostic accuracy of around 90%). An index >1.8 defines stenoses with a >50% diameter reduction. An index >2.6 implies a diameter reduction >60%, and an index >2.8 indicates a stenosis >70% diameter reduction (according to NASCET criteria, respectively). If the index exceeds 3.7, a stenosis of the internal carotid artery with a greater than 80% diameter reduction can be assumed. An index greater than 5 occurs in stenoses >90%. (Table 1). When these limits are applied, a high sensitivity of over 90% and thereby also a high negative predictive value can be expected.

The literature reports good results when absolute intrastenotic velocities were used (12, 13, 17). For example, an accuracy of over 90% in detecting >60% carotid stenoses was registered for the combination of limits >260 cm/s peak systolic velocity and end-diastolic velocity >70 cm/s (17).

A special case of high-grade internal carotid stenosis involves lesions that are so large that they reduce the flow down to a trickle. Such lesions might exhibit none of the typical intrastenotic or poststenotic flow abnormalities and can mimic an occlusion when the poststenotic flow velocity is below the sensitivity range usually selected for the instrument. If color-encoded flow signals are not detected in the internal carotid artery, the instrument sensitivity should be raised by switching the pulse repetition frequency (PRF) and the filter frequency to the lowest settings and turning up the color sensitivity as high as possible. Duplex ultrasound just as always allows reliable differentiation of a very high-grade stenosis (>98% diameter reduction) from an occlusion (25). In such cases, velocity indices cannot be used. If there is still minimum residual flow in the internal carotid artery (few intraluminal color pixels), the examiner must favour more the color image than in velocity measurements.

Total vascular occlusion is characterized by the absence of a flow signal in the vessel lumen which is usually obliterated by hypoechoic thrombotic material. Especially in recent occlusions, a patent vascular stump of a few millimeters in length can frequently be demon-strated, as in an angiogram. Even in long-standing occlusions, it is usually possible to demonstrate a considerable length of the occluded lumen with ultrasound. In very old occlusions, this poses difficulty due to the scar contraction of the vessel. In such cases, diagnosis is aided by evidence of calcifications. It is very important to differentiate clearly between the occluded and the residual perfused vessel. The spectral features of the external carotid artery can be altered by an occlusion of the internal carotid artery. Here, reliable identification of the external carotid artery is only possible by demonstrating the branching vessels or by temporal tapping.

In addition to their hemodynamic effects caused by reduction of blood flow, stenoses of the carotid artery can also be a source of embolism. Even low-grade stenoses might lead to recurrent embolisms because of their surface properties or geometry. Subintimal hemorrhages in arterioscle-rotic plaques can create defects (ulcerated plaque) and cause arteriosclerotic material to be mobilized (26). Local platelet aggregations tend to develop on irregular plaque surfaces, plaque ulcerations and in areas of poststenotic vorticity (flow reversal) with reduced flow rates. In this study it was determined that by using color Doppler sonography, 3 (6,1%) patients had ulcerated plaques.

A statistical correlation exists between plaque morphology and the likelihood of symptoms (27), but not the extent of the symptoms. The current literature is not very clear about the extent to which plaque assessment should be included in therapeutic decision making.

Principally, plaque ulcers posing as crater-shaped defects are detectable with B-sonography. However, the sensitivity is unsatisfactory (33% and 58% for ulcers smaller or larger than 2 mm) (28). There is no consensus as to whether the diagnosis of plaque defects is more accurate with color Doppler sonography or whether there is any obvious clinical correlation between ulcer size, ulcer localization and tendency to embolisms. To date, no useful prospective studies have investigated if a clinically relevant connection exists between specific flow patterns detectable by color Doppler sonography and the risk of cerebral embolism. None of the ultrasound procedures can be expected to provide direct proof of embolism-endangered thrombi, since even thromboembolisms in the millimeter or micrometer range can have significant clinical consequences. Here, transcranial Doppler sonography is the method of choice.

The standard in carotid imaging, by which all non-invasive procedures are judged, is still the selective intra-arterial angiography. All major clinical studies of the recent past have applied angiographic criteria for diagnostic decision making. The main problem with catheter-based angiography is its invasiveness with an angiography-related stroke incidence of 0.4-1.2% in a high-risk population (29). One major advantage of angiography is that it provides a continuous and thereby markedly better reproducible visualization of the vessels. As with all ultrasound methods, the result of the sonographic examination strongly depends on the diligence and experience of the examiner. Severe impairment of renal function precluding the safe use of contrast agents, as well as heparin intolerance and haemorrhagic diathesis could exclude arteriography as a principle mode of carotid artery investigation. Furthermore, these conditions are clinical contraindications for carotid artery stenting. Also, severely tortuous aortic arch and arch vessels, or severe tortuosity and angulations of the carotid artery are anatomical contraindication for stenting. Having these in mind, color Doppler sonography examination, in absence of carotid artery stenting thoughts, is the principle investigation tool for carotid artery disease evaluation. Improvements of CT and MR angiography in centres where they are available further diminish necessity for carotid artery arteriography.

Based on the studies comparing color Do-ppler sonography and angiography, the ultrasound method has a sensitivity of 91-95% and a specificity of 86-97% in the detection and quantification of abnormalities of the carotid artery. In stenosis grading, color Doppler sonography and intra-arterial DSA have shown agreement in at least 90% of the cases when the described signs of stenosis were used (12,13,14,17). Color Doppler sonography is suitable for primary screening of patients with suspected carotid obstructive disease. Presently, many centres base the indication for carotid endarte-rectomy solely on color Doppler sonography (30).

Recently, numerous studies have been con-ducted on the value of magnetic resonance angi-ography (MRA) of supra-aortal arteries. The results available (31) suggest that contrast-enhanced MRA will establish itself as a logical supplement to color Doppler sonography in the diagnosis of carotid artery lesions. Color Doppler imaging will be the primary procedure, with MRA being reserved for selected indications.

CONCLUSION

Advancement of non-invasive diagnosis has radically changed the approach to the diseases which cause brain ischemia. These diseases are being identified earlier and before the appearance of first clinical symptoms. Therefore, the opportunity for preventative conservative and surgical management has been offered. Color Doppler sonography enables simultaneous visualisation of vascular lesions in gray scale (plaque, stenosis, occlusion) and associated flow disturbances with color-coded imaging and spectral analysis. This method has made possible direct plaque visualisation, determination of its properties (composition and surface configuration) which other diagnosic procedures cannot provide. Besides, it is possible to measure the length of stenosis-involved segment and precisely determine the percent of stenosis.

In a large number of cases sonographic diagnosis is a method of choice and often the only approach required to diagnose the lesions in brain-supplying arteries. In most of the patients, diagnosis can be made precisely, enabling informed treatment decisions. In a small number of patients, additional proceedings are needed (such as MRI, intraarterial DSA). The method is invaluable in view of detection of surgically significant stenoses in patients without clinical symptoms (in 4 cases), so the screening of high risk subjects is a possible future opportunity.

It should be mentioned that quality depends on the experience of the examiner and that high standards should be set regarding the education and training of imaging specialists.

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ZNAČAJ KOLOR DOPLER SONOGRAFIJE U SELEKCIJI PACIJENATA ZA KAROTIDNU ENDARTEREKTOMIJU

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SAŽETAK

Ultrazvuk je najraširenija dijagnostička procedura kod opstruktivnih bolesti arterija koje prokrvljuju mozak. Kombinovane neinvazivne informacije o morfologiji i funkciji čine kolor Doppler ultrazvuk procedurom izbora u skriniranju i praćenju bolesti karotidnih arterija. Cilj ove studije je da ustanovi značaj kolor Doppler ultrazvuka u odabiru pacijenata za karotidnu endarterektomiju. Ultrazvučni pregled karotidnih arterija izveden je na 5124 pacijenta. Ovu seriju činili su svi pacijenti sa simptomima karotidne bolesti, kao i oni sa nekim od faktora rizika. Pregledi su izvođeni na konvencionalnim ultrazvučnim aparatima i linearnim 7,5 MHz sondama sa kolor Doppler imidžingom. Ultrazvučni pregledi imali su za cilj ustanovljavanje prisustva i mesta plaka, dužine zahvaćenog segmenta, stepena stenoze, strukture plaka i površinske konfiguracije plaka. Određivanje stepena stenoze bilo je kompjutersko korišćenjem dve morfološke i jedne hemodinamičke metode gradiranja stenoze. U nekim slučajevima su ultrazvučni nalazi upoređivani sa nalazima DSA, a svi ultrazvučni nalazi upoređivani su sa intraoperativnim. Od ukupnog broja ispitanika, 0.9% je izabrano na osnovu hirurški značajne stenoze (preko 75%). U slučajevima u kojima je izvedena i angiografija karotidnog korita, ultrazvučni nalazi bili su u korelaciji sa angiografijom. Ultrazvučni nalazi bili su u korelaciji sa intraoperativnim nalazima. Značaj kolor Doppler ultrazvuka u odabiru pacijenata za karotidnu endarterektomiju leži u mogućnosti direktne vizuelizacije morfologije plaka, u određivanju njegovih karakteristika, konfiguracije njegove površine, što se ne može uraditi drugim dijagnostičkim procedurama. Uz to, moguće je izmeriti dužinu stenozom zahvaćenog segmenta, precizno odrediti gradus stenoze i steći uvid u hemodinamičke poremećaje.

Ključne reči: **karotidna endarterektomija, stenoza, kolor Doppler sonografija**