Chapter 3

Diagnostic Imaging of Carotid Artery

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Additional information is available at the end of the chapter

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Abstract

In the study of carotid arteries, the different imaging techniques allow to analyze various diseases like stenoses, aneurysms, thromboses, dissections, diseases caused by atherosclerotic plaques or congenital abnormalities. The diagnostic modalities that are used to image the carotid artery diseases are digital subtraction angiography (DSA), duplex ultrasound (DUS), computed tomography angiography (CTA), and magnetic resonance angiography (MRA). The goal of the diagnostic imaging is to provide screening and to detect diseases at its earliest and most treatable stage. As initial screening study, the radiologists recommend DUS. It is a safe and painless way to produce pictures of the inside of the body using sound waves. It assesses blood flow in the carotid arteries, measures the speed of the blood flow, and estimates the diameter of a blood vessel and degree of obstruction. Digital subtraction angiography (DSA) has assumed a major role in the evaluation of occlusive cerebrovascular disease. While digital subtraction angiography (DSA) is still considered the gold standard, it has increasingly been replaced by computed tomography angiography (CTA) or magnetic resonance angiography (MRA) during the last years. Modern imaging studies like CTA and MRI allow to obtain three-dimensional reconstruction of anatomic structures and pathological abnormalities. Computed tomography angiography (CTA) of carotid arteries is a standardized procedure with excellent image quality but related with high radiation exposure. The rapid technical evolution in hardware and software allows even smaller imaging centers to perform high-quality vessel imaging. During the last decade, CTA came up with substantial progress in terms of accuracy in stenosis and aneurysm detection. Magnetic resonance angiography (MRA) is increasingly used as a noninvasive method to assess carotid arteries. Diseases like carotid artery dissections could be detected by using MRA or CTA.

Keywords: carotid artery, Doppler ultrasound, digital subtraction angiography, computed tomography angiography, magnetic resonance angiography

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1. Introduction

In general, diagnostic imaging studies of the carotid artery diseases are divided into two large groups: noninvasive in which there is no contact with the patient's bloodstream and invasive in which such a contact exists.

2. Noninvasive methods

2.1. Doppler ultrasound (DUS)

Doppler ultrasound is a nontraumatic method that allows getting information about the linear and volumetric blood flow velocity in the carotid, vertebral, and other arteries; it is used to determine the degree of vessel stenosis and obturations and to outline the pathways of collateral circulation. The capabilities of Doppler ultrasound to determine the condition of carotid and vertebral arteries are verified by brain angiography, the coincidences reaching a high percentage. Doppler ultrasound is based on the Doppler effect, which refers to the change of sound, ultrasound, and light wave frequencies when they are reflected by a moving object. This phenomenon is used in the Doppler ultrasound exam, where erythrocytes and other forms of blood elements in the blood vessels are the moving objects.

2.2. Ultrasound methods for cerebral artery examination

2.2.1. Ultrasound scan

Ultrasound scanning (echography, B-mode) is a two-dimensional imaging in one plane, based on the reflection and diffusion of ultrasound rays from different density tissues. The ultrasound amplitude of the reflected signal is displayed on the screen as a point of varying grayscale intensity—white and black. Scanning is performed by a great number of parallel ultrasound rays, which pass through the scanned object with a frequency of 10–60 pulsations per second. Different frequency instant images of the scanned object appear during these ultrasound pulsations of reflected rays. Thus, vessels can be seen in motion. This real-time pulse scanning method is used in modern equipment. In that way, anatomical structures can be displayed on a two-dimensional plane in ultrasound scanning [1–7].

2.2.2. Continuous-wave Doppler ultrasound

Continuous-wave Doppler ultrasound is the most common modern ultrasound method for examining extracranial cerebral arteries, peripheral arteries, and veins. The diagnostic frequency of the ultrasound emission is from 2 to 20 MHz. Deeper vessels are examined with transducers for a lower frequency of the ultrasound emission [8, 9].

2.2.3. Spectral analysis of the Doppler signal

The objectivization of Doppler ultrasound is performed through spectral quantitative analysis of its frequency and amplitude characteristics. Frequency or velocity analysis of Doppler ultrasound, which is an expression of the blood flow velocity, is most widely used in all Doppler ultrasound exams. The Doppler velocity curve gives an approximate idea about the average velocity of the blood flow, passing through the artery cross section. In case of accelerated or turbulent blood flow due to artery stenosis, the velocity of a part of the erythrocytes changes dramatically and some of them receive a retrograde flow due to vortex formation. These changes may not significantly affect blood flow average velocity and velocity curve, but they change the Doppler frequency spectrum significantly [10].

The amplitude or power spectrum shows the quantitative distribution of the power of movement of all blood components over a certain short interval of time in the cardiac cycle. In stenosis, the frequency or velocity increases, but the power of blood flow decreases due to turbulence, and therefore, the increase and especially the drop in amplitude is slow and the amplitude peak is low and shifted to low frequencies. Spectral width is an important indicator of amplitude analysis as it reflects the frequency, respectively the velocity, corresponding to 70% of the maximum blood flow power. This indicator makes it possible to assess the degree of damage to laminar blood flow in the presence of turbulence.

2.2.4. Transcranial Doppler ultrasound (TCD)

This method makes it possible to simultaneously visualize the intensity and direction of the blood flow at different depths in the intracranial space. It provides information on the condition of the arteries emerging from the Circle of Willis. With this methodology, it is possible to select the most optimal Doppler signal from one or more different depths. This is convenient for monitoring the path of microembolic signals that are presented as high-amplitude signals through arterial blood flow. Transcranial Doppler sonography allows the monitoring of microemboli that emerge from the middle cerebral artery (MCA), proximal to stenosis, and chronic stenosis of the said artery. Fifty-eight patients with chronic stenosis of the MCA were examined. Twenty-three of them (29.5%) have low-grade stenosis, 18 (23%) had moderate-grade stenosis, while 37 (47.5%) were diagnosed with severe stenoses. Thirty-seven of the stenoses were symptomatic, and 41 were with asymptomatic carotid stenosis (ACS). Two ischemic strokes and seven transient ischemic attacks (TIAs) were observed during the follow-up. Twenty-four patients were treated with anticoagulants and 28 received aspirin. Microembolic signals were found in symptomatic and asymptomatic stenoses regardless of the medication received. These results indicate that chronic middle artery stenoses do not represent a significant source of emboli [11]. Transcranial Doppler sonography also allows for the monitoring of intracranial blood vessels in patients who had undergone thrombolysis [12] and also for the emergency diagnosis of ischemic stroke following head trauma [13].

2.2.5. Extracranial Doppler ultrasound imaging

The method makes it possible to visualize extracranial brain vessels using the Doppler effect. Doppler sonography shows Doppler spectral analysis, which includes all velocities of the examined blood flow segment and an analog Doppler curve representing the mean velocity of the examined bloodstream segment.

2.2.6. Color-coded duplex Doppler ultrasound imaging

This method makes it possible to simultaneously analyze the blood flow of the studied artery in several separate blood volumes. A two-dimensional image of the velocity of all blood volumes and blood flow direction is obtained in a plane, the images being encoded in different colors. The resulting images are in real time [14, 15].

2.2.7. Duplex scanning

It is a combination of echography, a real-time B-scanner, and a single-channel pulsed Doppler ultrasound system. In this way, the blood flow in the studied artery can be determined, as well as its speed and direction. The ultrasound determines the diameter of the vessel and the angle at which the ultrasound pulsating waves enter the longitudinal axis of the artery under study. Thus, these methods combine and complement each other. The method is used to examine the extracranial parts of the carotid arteries, the initial parts of the vertebral and subclavian arteries [16].

2.2.8. Spectral analysis of the Doppler signal in cerebral artery stenosis

An increase in the blood flow velocity is observed with acceleration of the systolic and diastolic part of the spectral form and the Doppler curve in the area above the stenosis. The laminar nature of the bloodstream is distorted, it becomes deformed and turbulent. After the stenosis, there is a slowing of blood flow and a turbulence increase [17].

2.2.9. Ultrasound diagnosis of atheromatous plaques

The method is important for clinical diagnosis because atherosclerotic plaques narrow the lumen of the blood vessel on the one hand and, on the other hand, are a source of emboli to the cerebral vessels.

The most informative method for the detection of atherosclerotic plaques, originating from the vascular wall and various calcifications, is echography (B-mode). These plaques are often found in the arterial bifurcations and the end portions of the internal carotid artery [17].

3. Angiographic methods

3.1. Digital subtraction angiography

In the angiographic method, the vascular system of the brain is examined following the introduction of a contrast agent into the arteries. According to the type of arteries examined, we distinguish between carotid and vertebral angiography.

Diagnostic possibilities of digital subtraction angiography (DSA) were investigated in the diagnosis of cerebrovascular disease. A retrospective analysis was performed in 65 patients

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with various forms of cerebrovascular disease, taking into account the clinical characteristics and the risks accompanying them. In 75.4% of the patients, DSA found changes, with 85.5% having ischemic disorders of the cerebral circulation. The main diseases that led to the development of cerebrovascular disease were cerebral artery stenosis or atherosclerotic occlusions mainly in the extracranial vessels. Intraventricular hemorrhage was detected in four patients, and five patients had subarachnoid hemorrhage. Still DSA continues to be a gold standard in the diagnostics of the cerebrovascular disease.

3.2. Computed tomography angiography

Computed tomography angiography is an accurate means of determining intracranial occlusion in patients within the first 6 h of the onset of the cerebrovascular accident.

Computed tomography 3D-CT angiography of cerebral vessels is a technique that is particularly useful in the diagnosis of brain lesions and cerebrovascular disease. However, it does not provide information on the dynamics of blood flow changes. Therefore, a new technique has been developed—dynamic (D3D-CTA) angiography, which gives a 3D image of the vessels and allows assessment of hemodynamics and cerebral perfusion. Twelve patients were examined with CTA D3D (seven with brain tumors, four with arteriovenous malformations, and one with occlusion of the inner carotid artery). For all patients, information on changes in vascular structures, hemodynamics, and cerebral perfusion status was provided. Despite the relatively high risks, related to exposure to radiation, and limited scanning range, this technique is useful in the diagnosis of patients with cerebrovascular disease and brain tumors [18–21].

3.3. 3D-CT arteriography and 3D-CT venography

Although 3D-CT angiography provides valuable anatomical information regarding the lesion and the adjacent vascular and bone structures, it cannot show lesions of the arteries and veins individually. 3D-CT venography allows for a more detailed study of vascular anatomy and allows improvement of the diagnosis and potentially safe surgical approach [20].

3.4. Magnetic resonance angiography (MRA)

It is a method of obtaining blood vessel images by using magnetic resonance. This method allows the assessment of the anatomical and functional characteristics of the bloodstream. Under the influence of a strong magnetic field, rotation of the hydrogen nuclei protons occurs and they change their location, positioning themselves along the magnetic field axis. The effects of the magnetic field and the radiofrequency emission of the protons are not constant and have no certain force, frequency, and time; after the radio frequency influence, the protons again return to the starting position, i.e., T1 and T2. The effects of the magnetic field and the radio frequency impulse of the hydrogen nuclei protons force them to rotate in relatively new axes over a very short period of time, which is accompanied by the emission and absorption of energy and the formation of their own magnetic field. The registration of these energy changes is the basis of the MRI image. The magnetic resonance angiography method allows obtaining images of the vessels without the use of any contrasting agents, but, in order to achieve a clearer picture, various contrast agents based on gadolinium can be used. The method finds less application for evaluation of carotid stenoses [22, 23].

IEFNS set up a working group with the aim of developing basic guidelines for the treatment and prevention of stroke patients in line with local and national requirements of neurologists from Europe. Due to increased population aging across Europe and socioeconomic and health issues, the opinion that the incidence and severity of ischemic strokes will increase in many countries over the next decades was formed. In addition, acute stroke mortality rate varies considerably across European countries, being the highest in many East European countries and considerably lower in West European countries. It was emphasized that the viability of ischemic brain tissue can be extended to 18 or even 24 h, experimental studies showing that the earlier intervention leads to a more favorable outcome. Thrombolysis is recommended to be used within a therapeutic window of up to 3 h after stroke, and it is currently being investigated whether it will be effective until the sixth hour. Neuroprotective agents are recommended up to 12 h from the vascular accident. The factors, delaying the onset of treatment due to later referral to a hospital, can be overcome if neurologists participate in special educational programs to improve initial diagnosis and manage emergency situations.

There is an urgent need for a variety of diagnostic methods: computed tomography, Doppler sonography, electrocardiography, echocardiography, and laboratory tests, including coagulation status testing. Cardiac monitoring, blood pressure, blood gases, and body temperature monitoring are essential. If necessary, angiography, NMR, and EEG monitoring should be performed. After alleviation of the acute stroke, it is advisable to refer the patient to a rehabilitation unit.

A European guideline for the diagnosis of acute strokes was established. It emphasizes the need for neuroimaging techniques in the assessment of acute stroke, one of the leading causes of death and lasting neurological disabilities in developed countries. A comprehensive review of the literature, published in English for the period 1965–2005, was conducted and a set of methods for diagnosing stroke was created. Native CT of the brain is the first method of choice in diagnosis. Magnetic resonance tomography is a more sensitive computed tomography method and is particularly useful in the assessment of ischemic areas as well as in the diagnosis of acute and chronic intracerebral hemorrhages. Perfusion computed tomography and magnetic resonance angiography (MRA) are also very useful. MRT and MRA are the recommended techniques for the screening of brain aneurysms and for the diagnosis of cerebral venous thrombosis and arterial dissection. For noninvasive extra- and intracranial vessels study, extracranial and transcranial Doppler sonography are very useful. The transcranial Doppler sonography examination is very useful for monitoring arterial reperfusion after thrombolysis, for diagnosing intracranial stenosis and the presence of shunts, and for monitoring vasospasm after subarachnoid hemorrhage. Currently, single-photon emission computed tomography (SPECT) and positron emission tomography (PET) have a more limited role in acute cerebral strokes assessment [24].

A number of other scientific publications emphasize the role of neuroimaging techniques in brain stroke patients [24–27].

4. Combination of diagnostic imaging studies for carotid artery diseases

4.1. Transcranial Doppler sonography, CT angiography, digital subtraction angiography, and MR angiography

In modern emergency stroke therapy, many patients may temporarily improve, especially after thrombolysis, and worsen again to the original neurological deficit. Although mechanisms of such deterioration (DFI) may include development of brain edema, reperfusion hemorrhage, or other secondary factors such as cardiopulmonary decompensation, most DFIs are due to indefinite processes. Urgent sonographic assessment of patients with acute neurological deficits and DFI is not well characterized. The aim of the study was to evaluate the incidence and characteristics of vascular lesions in determining the acute spontaneous development of deficits and their potential links with subsequent DFI. Patients with focal neurologic deficit associated with cerebral ischemia, which was evaluated with a total NIH stroke score < 4 within 6 h of onset of symptoms, were prospectively studied.

Transcranial Doppler sonography (TCD) was routinely used and, when necessary, subsequent digital subtraction angiography (DSA), CT angiography (CTA), or MR angiography (MRA) was used. Vascular images were interpreted by a neurologist and a neuroradiologist for the presence of occlusions of large arterial vessels, stenoses, etc. Occlusions of large vessels were evaluated as atherosclerotic, in which Doppler sonography or angiography showed narrowing or occlusion of extra- and intracranial arteries greater than 50%. Stroke cases in which the potential source of emboli had been found were classified as embolic. In other cases, arterial dissection or coagulopathy was accepted as the cause of the stroke, and in some cases, the mechanism remained undetermined. Fifty patients with an average age of 61 + 14 years were studied, the women being 50%. The patients' symptoms had occurred after 165 + 96 min. Transcranial Doppler sonography was performed in all patients, and subsequent angiographic studies (DSA 10%, CTA 4%, MRA 44%) were performed in 68%. In general, large artery occlusions during TCD exam were found in 16% of patients, stenosis was found in 18%, 54% had normal studies, and the study could not be performed in 10%. DFI was observed in 16% of patients, TCD and angiography showed occlusion data in 62%, 22% had stenosis, and 4% of the vascular exams had normal results. DFI occurred in 31% of patients with atherosclerosis in a large arterial vessel, 23% had cardiac embolism, and 9% had small vessels damaged. In conclusion, it is emphasized that DFIs are strongly associated with the presence of occlusion or narrowing of a large arterial vessel of atherosclerotic or embolic origin. The reliability of emergency TCD or angiography in the early diagnosis of vascular lesions is very high. This makes it possible to assess the condition of the patients and to determine the therapeutic strategy [4, 28, 29].

A 3D visualization method was established for the entire vascular system, which includes carotid and vertebral arteries. Spiral CT angiography (SCTA) was used, providing a precise, qualitative, and quantitative assessment of anatomical abnormalities, including the detection of additional lesions and an assessment of the degree of stenosis. Fifteen patients with pathological abnormalities of the arterial vascular system, detected by color-coded duplex ultrasound, were examined using digital subtraction angiography (IA-DSA) and SCTA. The results obtained from 3D SCTA showed a high correlation with those of IA-DSA and SCTA [30].

Severe intracranial artery stenosis is the main cause of acute ischemic stroke. Although the warning symptoms for such stenosis are rarely found, cerebral transient ischemic attacks and ischemic stroke require active and effective diagnosis and treatment. The study described the main diagnostic methods for the diagnosis of arterial stenosis. Digital subtraction angiography makes it possible to trace the entire vascular system by conducting dynamic observations through the introduction of contrast agent. Magnetic resonance angiography also provides information but cannot properly show changes in small blood vessels. Transcranial Doppler sonography makes it possible for the changes in large intracranial vessels, the blood flow velocity, etc., to be detected by noninvasive technique. In computed tomography angiography, performed with intravenous contrasting of iodine contrast media, the vessels of Circle of Willis can be examined.

Medical professionals should use different imaging techniques to evaluate patients with stroke. The main diagnostic methods are used in these cases. Computer tomography allows a series of brain slices to be made, excluding hemorrhage or brain tumor. Abnormal findings can usually be observed during a computed tomography scan from 6 to 8 h after the onset of stroke. Another diagnostic method is magnetic resonance tomography. Its advantage is that it can show brain edema a few hours after the stroke and is better than computed tomography in detecting small cerebral infarctions. Doppler sonography is a noninvasive method for investigating extra- and intracranial vessels. Other methods, used in acute stroke diagnosis, are magnetic resonance and conventional angiography, which is performed under stricter indications [11].

The diagnostic merits of Doppler imaging, CT angiography, and digital subtraction angiography (DSA) for diagnosing carotid stenosis have been compared. DSA is considered a "gold standard" for confirming severe stenoses (70–99%) of internal carotid arteries; yet it is associated with a risk of complications. The aim of the study was to evaluate the accuracy of Doppler sonography, computed tomographic angiography, and their combined use for the detection and quantification of severe carotid stenosis as compared to DSA. 29 patients were included in the study and their results were compared. The results showed that DUS in combination with STA can be used for relatively reliable diagnosis of severe stenoses of the internal carotid artery. Thus, invasive digital subtraction angiography can be avoided in a significant number of patients [31].

Computed tomography angiography (CTA) is a relatively new and minimally invasive method of visualizing the intracranial and extracranial blood vessels. The diagnostic capabilities of the CTA and the gold standard of arterial imaging (DSA) were compared. A total of 40 patients (80 carotid arteries), examined with STA, DUS, and DSA, were prospectively studied. Patients, selected for inclusion, had symptoms of cerebral transient ischemic attacks or stroke. The degree of stenosis and atheromatous changes were studied by the three methods. The results showed that STA had significant correlations with DSA, while the correlation with DUS was less obvious. STA showed good possibilities for detecting light carotid stenoses (0–29%) and arterial occlusions. Stenosis detection of more than 50% was achieved with DSA, while CTA showed a sensitivity of about 50%. In addition, CTA showed quite good correlations with DSA in detecting lesion atheromatous plaques in carotid stenosis. In conclusion, CTA shows very good capabilities for detection of carotid artery occlusions or stenosis up to 50% but is not able to reliably distinguish the differences between moderate (50–69%) and severe (70–99%) stenoses, which is important in determining the methods for the treatment of carotid stenosis [18].

Invasive diagnosing imaging of cervical and intracranial vessels, done with CTA, MRA, and DUS, has been studied in other clinical trials as well [32].

4.2. Transcranial Doppler ultrasound, MR angiography, and digital subtraction angiography

Single-slice CT angiography (CTA) is an established method for imaging the vascular system of the brain (CVS), but it suffers from technical limitations for the visualization of long vascular segments such as intra- and extracranial vessels. The comparatively recently created multislice (MS) technology allows high-quality angiographic images due to increased scanning speeds and improved spatial resolution. The study was aimed at assessing the suitability of multislice CTA (MS-CTA) when examining the vascular system of patients with acute symptoms of arterial and venous occlusion. In 41 patients with a clinical suspicion of acute cerebral ischemia (29 in the hemisphere and 12 in the vertebrobasilar system), as well as in 4 patients with suspicion of cerebral venous thrombosis, MS-CTA was administered. Additionally, Doppler sonography was performed in 34 patients, magnetic resonance angiography in 5 patients, and digital subtraction angiography in 6 patients. All findings for extra- and intracranial blood vessel stenoses were correlated with clinical outcomes. The study showed that MS-CTA is a promising diagnostic tool for rapid and overall assessment of arterial and venous vessels in patients with clinical signs of acute cerebrovascular disease [33, 34].

Transcranial Doppler sonography (TCD) may localize arterial occlusion in patients with stroke. About 190 patients with, or without, proximal extra- and intracranial occlusions were examined by TCD. The obtained data were compared with those from DSA and MRA. Angiographic examination showed occlusion in 48 patients. The TCD showed Doppler signals unusual for the middle cerebral artery in 66.7%; reverse blood flow through the ophthalmic arteries in 70.6%; and blood flow through the anterior communicating artery in 78.6% and through the posterior communicating artery in 71.4%. The study showed that transcranial Doppler sonography data for large artery occlusions can be used to extend complex diagnosis and improve prognostic value for noninvasive screening in stroke patients [35].

For a very long time, medical professionals believed that arteriography is a mandatory method for diagnosing the dissection of the internal carotid artery. With the introduction of transcranial Doppler sonography and magnetic resonance angiography, it is no longer the case. Thirteen patients with dissection of the internal carotid artery were diagnosed by extra- and transcranial Doppler sonography, computed tomography, and magnetic resonance tomography. Digital subtraction angiography, as a “gold standard,” confirmed the diagnosis in all cases. Thus, noninvasive techniques can be sufficiently informative in such patients [36].

The diagnostic capabilities of digital intra-arterial angiography and transcranial Doppler sonography were compared in 48 patients with acute cerebral ischemia in the carotid artery basin on the fourth hour after onset of symptoms. Data from the TCD exam showed correlation with angiographic examination.

The clinical manifestations of vascular hypoplasia were studied in 205 children aged 3–14 years. About 21% of them had transient ischemic attacks (TIAs), and 17% had cerebral infarction; focal or generalized epileptic seizures were found in 56.1%, while 4.9% had migraine headache. Cerebral arterial hypoplasia was diagnosed with angiography, MR angiography, and transcranial Doppler sonography [37].

Acute occlusion of the basilar artery is a common condition, but differential diagnosis is not always easy for patients with acute onset, change in consciousness, and progressive dysfunction of the brainstem. Intra-arterial thrombolytic therapy is a potential life-saving procedure in certain cases of acute occlusion of the basilar artery. Therefore, it is necessary to have reliable and widely available methods for assessing the patency of the basilar artery. Traditionally, digital subtraction angiography has been used for diagnosis in suspected cases of acute occlusion of the basilar artery. However, DSA is a laborious, costly, and invasive method that requires patient cooperation or general anesthesia. Extra- and intracranial Doppler sonography was used to diagnose clinical suspicion of acute occlusion of the basilar artery. Unfortunately, due to DUS technical limitations, especially for the study of distal portions of the vertebral artery, ultrasound diagnosis may be inadequate.

Magnetic resonance angiography has not been used so far in large groups of patients for the examination of the basilar artery occlusion. Difficulties can be explained with the specific patients' condition—disturbed consciousness and intubation in patients with acute cerebral ischemia.

Spiral CT angiography (CTA) is a relatively new instrumental method for noninvasive vascular diagnosis in cases of acute cerebral ischemia. A prospective study was conducted with 19 patients of an average age of 58 + 11 years with clinical suspicion of acute vertebral artery occlusion. Criteria for inclusion of the patients were the clinical manifestations of sudden worsening of consciousness, dizziness, diplopia, dysarthria, oculomotor nerve lesions, and lesions of other cranial nerves or bilateral symptoms. Three patients were in coma. The diagnostic capabilities of CTA, DUS, and DSA, used for these patients, were compared. CTA revealed a complete occlusion of the basilar artery in nine patients and an incomplete occlusion in two of them. Due to severe vertebral artery calcification, one patient could not be examined. Doppler sonography was performed in 7 of 19 patients, with clear evidence of vertebral artery occlusion in 3 of them. In the remaining patients, the data were uncertain and two were false-negative, which was proved by CTA and DSA exams. In addition, CTA provided information on the exact place of basilar artery occlusion. These data allowed for intra-arterial thrombolysis to be used in five patients. In conclusion, CTA was more informative than DUS in assessing the patency of the basilar artery in patients with acute ischemia, especially in the distal artery occlusion. The study emphasizes the advantages of the combination of methods, used for the diagnosis of basilar artery occlusion [38].

The role of CTA, MR angiography, DUS, and DSA for the quantification of atherosclerotic stenosis of the carotid artery was studied in 25 patients. The degree of stenosis was measured according to North American Symptomatic Carotid Endarterectomy Criteria: complete occlusion (100%), severe (70–99%), moderate (30–69%), and mild (0–29%). Degree of stenosis, measured by CTA, MRA, and DUS (Doppler ultrasound), was compared to the DSA results, used as the "gold standard." Ninety-seven percent of the results obtained from MRA were equivalent to DSA and 3% did not match; 96% of CTA data were DSA equivalents, with 4% not matched; 77% of the results of Doppler sonography were equivalent to DSA, and 23% had a mismatch. In conclusion, it is emphasized that CTA and MRA are equally accurate methods for quantification of the degree of stenosis in carotid bifurcation [39].

In 178 patients with cerebrovascular disease, studies were conducted to compare whether invasive CT angiography was an alternative to digital subtraction angiography and noninvasive Doppler sonography. CTA reported nine cases of significant stenosis, which were not thoroughly assessed by the DSA, and in two cases, it did not show any results. In addition, vascular wall calcifications were more easily evaluated by CTA [40].

4.3. Transcranial Doppler ultrasound and CT angiography

Atherosclerotic diseases of the middle cerebral artery (MCA) are often met with Asian population. This abnormality can be diagnosed by noninvasive methods such as transcranial Doppler ultrasound (TCD) and CT angiography (CT). The diagnostic capabilities of these two methods were compared in 70 patients with suspicion of atherothrombotic occlusion of the middle cerebral artery. The study excluded cases of cardiac embolism, significant carotid stenosis, or classical lacunar syndrome. Transcranial Doppler ultrasound was performed within 2 days of hospitalizing the patients; it was followed by STA within 7 days of stroke. CTA showed stenoses of MSA exceeding 50% in 57 patients (81%), whereas only 29 patients (41%) had TCD visualized abnormalities. TCD results correlate well with those of CTA in all patients with proximal stenosis of the M1 segment. In contrast, transcranial Doppler sonography visualizes accurately distal M1 or M2 injuries only in 24% of patients. In this population, CTA showed better abilities than TCD in the diagnosis of thrombosis of MCA. Transcranial Doppler sonography should not be used as a basic method for the detection of MCA stenoses [41].

A pilot study of the diagnostic capabilities of CTA and TCD in the diagnosis of intracranial occlusion of intracerebral arteries was performed. Ten patients with acute ischemic stroke as a result of stenosis or MCA occlusion were studied. Seven stenoses and five occlusions of MCA were found. CTA confirmed all TCD results except for one patient with MCA occlusion, who had multiple embolisms. The results showed that CTA is an easily performed and useful method in the diagnosis of MCA occlusion [42]. A number of other studies have shown the high diagnostic value of TCD and CT angiography in basilar artery stenosis and occlusions [38].

Transcranial color-coded duplex sonography (TCCD), magnetic resonance angiography (MRA), and computed tomography angiography (CT) are relatively new noninvasive or minimally invasive techniques to study intracranial circulation. TCCD makes it possible to improve the accuracy and reliability of data supplied by conventional transcranial Doppler imaging. The main limitation of transcranial color-coded duplex sonography is related to the ultrasound windows that make it difficult to insonate the basilar arteries, especially in their proximal part, and has a lower resolution. MRA provides good morphological information on the condition of the cerebral vessels. CTA is a sensitive method for detecting occlusive changes in the large intracranial arteries. Transcranial color-coded duplex sonography and magnetic resonance angiography, used in combination or alone, can eliminate the need for digital subtraction angiography in most cases of occlusive cerebrovascular disease. Digital subtraction angiography can be used in cases where noninvasive techniques do not provide sufficient information, or for the diagnosis of brain aneurysms and arteriovenous malformations. The role of CTA for the detection of aneurysms by contrast agent injection is well established, whereas in cases of other lesions, the method does not always produce clear results [10].

Patients with acute ischemic stroke, having occurred with intracranial arterial obstructions, are with poor prognosis and a high probability of death up to 24 h. The diagnostic accuracy of Doppler ultrasound (PMD-TCD) and CT angiography is assessed as a standard in the diagnosis of intracranial artery occlusion in patients with ischemic stroke within 24 h. A total of 100 patients were studied. PMD-TCD showed intracranial occlusion in 34 patients, while the STA showed the same result in 33 patients. Six false-positive and four false-negative diagnoses were found by PMD-TCD. This methodology showed a high coincidence with CT angiography in the diagnosis of occlusion of arterial vessels in patients with acute ischemic stroke, especially in the middle cerebral artery basin [43].

4.4. CT angiography and digital subtraction angiography

A study was conducted to determine whether spiral CT angiography allows accurate quantitative assessment of anatomical abnormalities, including the detection of additional lesions, determining plaque morphology, and assessment of carotid artery stenosis. The diagnostic capabilities of spiral CT angiography and digital subtraction angiography were compared in 92 cases of carotid artery stenosis. The degree of stenosis was determined according to the North American Symptomatic Carotid Endarterectomy Trial (NASCET). All stenoses were diagnosed using CT angiography. It showed coincidence with digital subtraction angiography in 59% of the cases with mild stenosis, in 82% of the cases with moderate stenosis, and in 90% of those with severe stenosis. Calcified plaques were easily detected by spiral CT angiography, but discovery of lesion plaques was difficult. The study showed that spiral CT angiography gives enough information for carotid stenoses greater than 30% and for calcified plaque detection but is not sufficiently informative for detecting lesions [44].

Carotid artery examination is important for the evaluation of patients with ischemic stroke and cerebral transient ischemic accidents. CT angiography (CTA) of the head and neck is an easily accessible method that can be part of the routine imaging diagnosis in patients with stroke. In a large academic center, for the period 2000–2002, CTA and DSA examinations of the cervical part of the carotid artery were performed in 81 patients according to the NASCET criteria. For stenoses over 70%, the coincidence of both methods was 96%. The study showed that CTA is an excellent screening test for stenosis of the internal carotid artery [45].

Intravenous recombinant tissue plasminogen activator (TPA) has been shown to be effective in the treatment of acute ischemic stroke within the first 3 h of onset, but unfortunately the occlusion of the vessel may not always be well documented in due time. Digital subtraction angiography, performed within several hours, is a method of quickly and reliably validating the intracranial occlusion of the vessel. CT angiography is also potentially useful for this purpose, as it shows significant coincidence with DSA. About 54 patients with acute stroke were examined using the two methodologies. CTA has shown coincidence with DSA regarding occlusions in 86% of the cases [7].

The possibilities of multidetector CTA as compared to DSA were studied in 35 patients (70 carotid arteries). The degree of stenosis was calculated according to NASCET. CTA was somewhat inaccurate for measuring the absolute minimum diameter in high-grade stenoses, while in stenoses exceeding 50% and above, the coincidence of both methods was 95%. The method confirms the suitability of CTA as a screening method for patients with carotid stenosis. In hemodynamically significant stenoses detected by STA screening, it appears that conventional angiography still needs to be applied [46].

The diagnostic value of CTA in a study of the Circle of Willis in patients with acute stroke was compared to MR angiography and DSA in 145 patients. CT angiograms were estimated as good or excellent in 89% of cases, and MR angiograms were estimated as such in 92% of cases. Arterial stenoses or occlusions were found in 43% of CT angiograms; they were found in 48% of MR angiograms and in 21% of DSA angiograms. The study showed that CTA is an accurate and safe method for assessing arterial stenosis and occlusion of the blood vessels in the Circle of Willis [47].

The diagnostic capabilities of CTA and MRA as noninvasive techniques were compared with DSA in 146 stroke patients. In comparison with DSA, STA and MRA showed inaccurate results in lower-grade stenosis. DSA methodology remains the gold standard in the diagnosis of patients with cerebrovascular injuries [48–50].

The role of cerebral angiography in the diagnosis of cerebrovascular diseases is sometimes questioned by the increasing importance of MR angiography. Studies in patients with atherosclerotic cerebrovascular disease have shown that MRA can almost completely displace brain angiography as a screening method for carotid bifurcation. However, the discovery of “pseudo-occlusion” still requires the use of digital subtraction angiography for accurate diagnosis. DSA is more indicative in detecting distal artery occlusions. Subarachnoid hemorrhage, detected by computed tomography, must necessarily be examined by cerebral angiography, although magnetic resonance angiography may be used as a screening test for aneurysms larger than 3 mm. The cerebral angiography is still indispensable in confirming the diagnosis of cerebrovascular malformations, arterial dissection, and fibromuscular dysplasia [51, 52].

A significant number of patients with cerebral transient ischemic accidents develop ischemic stroke in the first few months and years. A multicenter clinical trial was conducted among 3886 patients who had had transient ischemic accidents with the aim of assessing the risk of developing an early stroke. Risk factors for cerebrovascular disease (high blood pressure, age, diabetes mellitus, carotid stenoses, etc.) were studied. Instrumental methods such as magnetic resonance tomography and Doppler ultrasound were used. The results were assessed by a point system. The authors recommend new studies to be conducted, aiming at verification of the use of the methods applied [53].

Outpatient diagnosis is an important initial step in emergency treatment of stroke. A number of screening tests have been developed to identify patients at high risk of stroke. Early transportation of the patient to the hospital allows thrombolysis to be administered and improves prognosis for the final outcome of the disease [54].

Symptoms, related to the damage to the internal and external carotid arteries, were investigated, and a clinical analysis of the progressive cerebral infarction was performed in 248 patients (142 men and 106 women, average age 67.2 years). Two groups of 60 patients with progressive and 188 patients with nonprogressive cerebral infarction, respectively, were formed, the infarctions having occurred as a result of mild, moderate, and severe carotid stenoses. All patients were examined with Doppler sonography, computed or magnetic resonance tomography. Some risk factors for cerebrovascular disease (hypertonic disease, smoking, alcohol abuse, hyperlipidemia, etc.) were studied.

Since carotid arteries are the major source of blood for the brain, intima-media increased thickness is a sign of early atherosclerosis, which gradually progresses. Thrombotic and embolic processes, as well as cerebral transient ischemic accidents, are often developed with a subsequent cerebral infarction. Studies have shown that the amount of atheromatous plaques in the carotid arteries is essential for the development of severe stenoses and hemodynamic disorders in the brain. At this stage, the treatment of progressive cerebral infarction is conducted with antiaggregants, fibrinolytic agents, etc., and in some cases, endarterectomy is administered, especially in severe stenoses of the carotid arteries. Doppler ultrasound exam of extra- and intracranial vessels should be conducted within the first 24 h of the onset of the vascular accident, followed by subsequent dynamic observation.

Ischemic stroke and cerebral transient ischemic accidents are clinical diagnoses for the confirmation of which, as well as for the exclusion of cerebral hemorrhage, computed tomography and magnetic resonance tomography of the brain are performed. MRT is a more sensitive method but is often not available especially in smaller hospitals. In a clinical study in Australia, it was shown that the mean time (IQR) from hospital arrival to brain scanning should be 1.8 h (0.9–3.6 h); in this case, only 51% of the patients had their brain examined within 4.5 h of stroke. In addition, these patients should also be tested with Doppler ultrasound and electrocardiography.

Emergency diagnostics is also needed for the timely inclusion of thrombolytic therapy with RT-PA [24, 55].

5. Differences in the incidence of carotid stenoses by gender

Gender plays an important role in cardiovascular disease. Epidemiologic studies have demonstrated that men have a higher incidence and prevalence rate of stroke than women. The strokes that do occur in women tend to be more severe, however. In terms of revascularization,

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the available literature suggests that women have higher risk of perioperative adverse events. This thus puts into question how much women actually benefit from carotid revascularization compared with men.

The available literature suggests that women have a higher risk of perioperative adverse events during carotid revascularization. In the Asymptomatic Carotid Atherosclerosis Study (ACAS), women had a higher rate of perioperative events (3.6 vs. 1.7% for men) during CEA. Combining that with a lower rate of events for women (8.7 vs. 12.1% for men) treated with best medical therapy, this led to a much lower 5-year risk reduction for women (17%) compared with men (66%). Among patients with moderate stenosis in the North American Symptomatic Carotid Endarterectomy Trial (NASCET), the number needed to treat with CEA to prevent one ipsilateral stroke was 12 and the number needed to treat to prevent one disabling stroke was 16 for men. The corresponding numbers for women were 67 and 125, respectively, potentially suggesting a lower long-term benefit of surgery for women. The Asymptomatic Carotid Surgery Trial (ACST) produced similar findings, with men deriving a higher 5-year absolute risk reduction (8.21 vs. 4.08%) than women.

The data are somewhat unclear in the recent trials evaluating CAS and CEA. Women in the International Carotid Stenting Study (ICSS) had a higher 120-day event rate for CEA (7.6 vs. 4.2%) but a lower rate for CAS (8.0 vs. 8.7%). The opposite was found in the Carotid Revascularization Endarterectomy vs. Stenting Trial (CREST), with a lower periprocedural event rate for women undergoing CEA (3.8%) than men (4.9%) but higher in CAS (6.8 vs. 4.3%). With potentially higher perioperative event rates, these data raise the question of how much women actually benefit from intervention [50].

A database of 938 carotid arteriogram entries was established prospectively, with accompanying measurements of peak systolic velocity (PSV) and end-diastolic velocity (EDV). The percent of internal carotid artery stenosis seen on arteriograms was calculated according to criteria from the North American Symptomatic Carotid Endarterectomy Trial. Analyses were made in 536 carotid arteries in men and 402 carotid arteries in women. In addition, the single most diseased artery per patient was analyzed by gender. PSV and EDV were averaged for data subsets according to 10% intervals of internal carotid artery stenoses. Velocity for each interval was compared between men and women with the Student *t* test. Receiver operator characteristic curves were developed to define optimal duplex criteria for 60 and 70% stenosis.

For all intervals, PSV and EDV averaged 9 and 6% higher, respectively, in women than in men. Significant gender differences existed between PSV and EDV for 60 and 70% stenosis. When a single vessel per patient was analyzed, these observations persisted, but lost significance for PSV at 60% stenosis. Receiver operator characteristic curves at 90% sensitivity demonstrated that optimal PSV for 60% stenosis was 160 and 180 cm/s, and for 70% stenosis was 185 and 202 cm/s, in male and female patients, respectively.

Women have higher carotid blood flow velocity than men do. Gender differences exist and are notably different at clinically relevant thresholds for intervention. These data indicate that different criteria should be used for interpreting carotid velocity profiles in women than in men and have potentially important implications for patient care [5].

We examined 974 subjects aged 25–88 years (478 men and 496 women) in whom we considered heart rate, smoking status, and the presence of hypertension, diabetes, hypercholesterolemia, and hypertriglyceridemia. Ultrasound examination of the neck vessels included measurement of intimal medial thickness (IMT), vessel diameter, and outflow area/inflow area ratio. We established plaque location, echogenicity and echostructure, and the percentage of stenosis owing to plaque and measured systolic velocity, flow direction, and the depth of detection of these parameters. We used the apnea and hyperpnea test to assess cerebrovascular reactivity. Hypertension and hypercholesterolemia were the most frequent risk factors. Women had a higher heart rate, whereas men had significantly greater IMT. The presence of atheromatous plaque was significantly correlated with age in both sexes, with men having a higher prevalence of carotid plaques. The sexes differed significantly with regard to plaque location, echogenicity, echostructure, and intracranial circulation. Women had a slightly higher blood flow velocity in the intracranial arteries. Risk factors affected plaque formation and extent more in men than in women. These findings suggest that carotid stenosis is a gender-related trait [47].

High-resolution Doppler ultrasonography of 500 carotid bifurcations was performed in 192 women and 308 men before surgical treatment. Carotid stenoses averaged 70 ± 11% (30–95%) in women and 72 ± 12% (40–98%) in men. The prevalence of 90–99% stenosis was greater in men, 14.3 vs. 7.8%. Carotid plaques were longer in men, 2.3 ± 0.8 vs. 1.9 ± 0.6 cm. Mean diameters of the distal internal carotid artery, 4.9 ± 0.9 vs. 4.6 ± 0.8 mm, and of the common carotid artery, 7.6 ± 1.3 vs. 7.1 ± 1.4 mm, were greater in men. The distance from the ear lobe to the bifurcation was also greater in men, 5.9 ± 1.1 vs. 5.3 ± 0.9 cm. Doppler ultrasonography preoperative mapping demonstrated that the parameters measured were greater in men than in women. Detailed planning of carotid plaque treatment must take into consideration individual differences such as those associated with the patient's gender [36].

6. Conclusion

The large number of diagnostic methods and combinations of these allow early and accurate diagnosis of carotid diseases. However, it is not possible in the day-to-day practice to apply several of them at the same time. The combination of noncontrast computed tomography of the brain with Doppler ultrasound exam of the neck and head vessels in most cases provides sufficient data both for morphological changes in brain tissue and for various carotid stenoses, which are one of the well-documented risk factors for cerebrovascular disease.

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