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Application of ultrasound in the evaluation of internal carotid artery stenosis

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Abstract: *Internal carotid artery stenosis (ICAS) is one of the most important factors leading to ischemic stroke due to various etiologies. The choice of clinical individualized treatment plan varies according to the severity of the lesion. With the continuous improvement of current diagnosis and treatment standards, higher demands are placed on the evaluation of ultrasonic imaging characteristics of ICAS. Ultrasound can not only identify the etiology of ICAS, grade the severity of stenosis, and evaluate cerebral blood perfusion, but also conduct long-term follow-up to evaluate treatment effectiveness and the control of risk factors. Accurate classification and evaluation of ICAS lesions by ultrasound imaging provide scientific and reliable objective information for clinical diagnosis and treatment, thereby assisting in the selection of clinical individualized treatment. Therefore, this article reviews the clinical application and progress of ultrasound in the evaluation of ICAS.*

Keywords: *internal carotid artery stenosis; Doppler ultrasound; Literature review*

1. Introduction

Studies show that stroke is the third leading cause of death after heart disease and cancer, and one of the leading causes of disability [1],the proportion of ischemic stroke is as high as more than 80% [2]. Internal carotid artery stenosis (ICAS) is an important cause of ischemic stroke. Early diagnosis and treatment of ICAS can reduce the incidence of ischemic attack (TIA) or cerebral infarction in ICAS patients[3]. According to the relevant guidelines published by the European Society of Cardiology in 2018[4],carotid ultrasound is recommended as the preferred method for the assessment of carotid artery disease. In recent years, the main ultrasound evaluation methods available in clinical practice include two-dimensional gray scale ultrasound, color doppler ultrasound, spectral doppler ultrasound, transcranial doppler sonography (TCD) and the emerging three-dimensional energy doppler. Different ultrasound techniques can provide important objective information for the clinical treatment of ICAS in terms of etiology, lesion degree, long-term follow-up, efficacy evaluation, and selection of individualized treatment.

2. Etiological identification of ICAS

According to the different causes of ICAS, it can be divided into atherosclerotic ICAS and non-atherosclerotic ICAS, among which the ICAS caused by atherosclerosis accounts for about 70%[5]. Carotid ultrasound examination to evaluate the changes of carotid vascular morphology and blood flow spectrum can be used as the basis for the identification of the cause of ICAS.

2.1 Atherosclerotic ICAS

Atherosclerotic ICAS is mainly due to the uneven thickening of the intima-media membrane(IMT) of the internal carotid artery (ICA) and the formation of atherosclerotic plaque, which leads to the narrowing of the ICA lumen diameter. By inquiring about the history of related risk factors, it is helpful to determine whether it is atherosclerotic internal carotid artery stenosis. It has been reported that elderly men, hypertension, coronary heart disease, diabetes, hyperlipidemia, and smoking history are more likely to develop carotid artery stenosis [6-8]. Chronic hypertension and hyperlipidemia lead to changes in vascular wall structure, lipid deposition and plaque formation. Diabetes and smoking can cause vascular endothelial damage, promote platelet aggregation to form thrombus, and lead to internal carotid artery stenosis. Statins, while lowering fat, can also stabilize plaques, thereby reducing stroke risk. It has also

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been reported that ankle-brachial index (ABI) ≤0.9 indicates atherosclerotic stenosis [9]. Increased Achilles tendon thickness (ATT) has also been found to be an independent predictor of carotid atherosclerosis [10].

For ICAS in arteriosclerotic patients, inhomogeneous thickening of the IMT and the formation of atherosclerotic plaques can be observed on ultrasound. The characteristics of atherosclerotic plaques, including echo, size, surface features, ulcerative plaques, and calcification, are evaluated in two-dimensional grayscale ultrasonography. Hypoechoic plaque, ulcerative plaque and uneven thickness of fiber cap on plaque surface are important factors to increase the risk of stroke[11, 12], and should be given some clinical tips. In color Doppler mode, peak blood flow velocity (PSV) is taken from the narrowest area, at which point the PSV is proportional to the severity of the vessel stenosis. At the same time, it should be noted that the angle of the Doppler beam and the flow direction should be as parallel as possible, between 0 and 60°, with close to 0° as the best [13]. Accurate measurement of blood flow velocity is helpful in differentiating the degree of stenosis.

2.2 Non-atherosclerotic ICAS

Non-atherosclerotic ICAS usually occurs in various diseases, such as carotid artery dissection (CAD), major artery inflammatory disease, and congenital fibromuscular dysplasia(FMD). The two-dimensional gray-scale ultrasound has typical ultrasonic characteristics, and according to the different ultrasonic image manifestations and the characteristic related medical history inquiry, the relevant etiological identification can be made. CAD is a common cause of ICA stenosis in young adults, usually with a sudden onset and often accompanied by neck pain and a history of neck massage. Two-dimensional gray scale ultrasound showed that the ICA lumen was divided into true and false two-lumen structures by endovascular probe and avulsion of the intima linear structure, or that between the endovascular wall and the media or the media and the outer membrane were filled with mostly low-echo thrombus, resulting in the formation of intervascular hematomas [14]. The typical arterial wall is characterized by diffuse uniform thickening of the whole wall. Depending on whether the lesion is in the active stage, the incidence of ICAS is usually more common in young Asian women, accompanied by abnormalities in related immunological test indicators. Carotid fibromyodysplasia is a congenital disease. The ultrasonography showed that the inner diameter of ICA was reduced, the echo of the tube wall was enhanced, and the "beaded" changes of the lumen were seen in some patients. There are also some special factors that lead to internal carotid artery stenosis, such as the recently reported ICAS due to osseous carotid duct dysplasia [15].

3. Evaluation of ICAS lesion degree

At present, there are different diagnostic criteria for internal carotid artery stenosis, the main diagnostic criteria are pipe diameter method and flow rate method, and there is no unified global standard for evaluation parameters of different methods. The main diagnostic criteria are the North American Symptomatic carotid endarterectomy test (NASCET) [16], the European Carotid Surgery Test (ECST) [17] and the CC method[18] (see Table 1). The main difference between the three methods is the determination of the measuring position of the original pipe diameter. ECST method: The degree of stenosis is the ratio of the residual diameter of the ICA stenosis to the original lumen of the stenosis. NASCET method: The degree of stenosis is determined by the residual diameter of the ICA stenosis and the distal lumen relative to the ICA. CC method: The degree of stenosis was determined by the residual diameter of the ICA stenosis and the proximal common carotid artery (CCA) lumen relative to the ICA. ECST method and CC method are generally considered to have high sensitivity in clinical practice, but ECST method usually overestimate the degree of stenosis. There is a good correlation between NASCET method and ECST method, but ECST method usually leads to overestimation of the degree of stenosis, especially in ICAS lesions with a stenosis of about 70%, which is only 50% by NASCET method but 70% by ECST standard[19]. The conversion from ECST method to NASCET method can be performed using the formula NASCET=(ECST-40%)/0.6 [20]. The results were evaluated by NASCET and ECST standards, which improved the accuracy of pipe diameter method in evaluating the degree of stenosis.

The more widely used diagnostic criteria of flow velocity method are mainly from the American Society of Ultrasound Radiology in 2003[21], the Australian Society of Ultrasound Medicine in 2006 and the Department of Ultrasound Diagnosis of Xuanwu Hospital, Capital Medical University in 2006[22]. The study compared the three diagnostic criteria for the assessment of ICAS with high sensitivity and specificity[23], and there are some disputes about the determination of the critical value. A new study in the United States shows that different critical values of the diagnostic standard flow rate will make a big

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difference in the results [24]. In order to correct the critical flow velocity, some Chinese scholars used discriminant analysis (Fisher difference method) and principal component analysis to conduct statistical analysis of the peak flow velocity in the stenosis segment of internal carotid artery, and deduced the function formula to judge the critical value[2525]], supplementing the diagnostic parameters of color Doppler for internal carotid artery stenosis. Although the study has a high coincidence rate with digital subtraction angiography (DSA), the practical application is complicated and increases the burden of daily work. Domestic and foreign scholars also generally believe that when the degree of ICAS is less than 50%, it usually does not cause significant changes in the hemodynamics of adjacent vessels. When the ICAS degree was greater than 50%, the hemodynamics of the ipsilateral common carotid artery changed, which mainly showed that the diastolic blood velocity (EDV) decreased, and the resistance index RI on the affected side was higher than that on the healthy side [26]. When the degree of stenosis reaches 70%-99%, it can be detected that the distal perfusion of ICA decreases, and the blood flow spectrum morphology changes with low pulsation, and the ratio of applied flow velocity is more accurate [27].

Table 1 Three diagnostic criteria of color Doppler flow imaging (CDFI)

ICAS degree	American Society of Ultrasound Radiology standards			Australian Society of Ultrasound Standards			Capital Medical University Xuanwu Hospital standard			
	PSV (cm/s)	EDV (cm/s)	PSV/PS VCCA	PSV (cm/s)	EDV (cm/s)	PSV/PS VCCA	PSV (cm/s)	EDV (cm/s)	PSV/PS VCCA	PSV/PSV DIS
< 50%	< 125	< 40	< 2.0	< 125	< 40	< 2.0	< 155	< 60	< 2.0	< 1.6
50-69%	125-230	40-100	2.0-4.0	125-270	< 110	2.0-4.0	155-220	60-100	2.0-3.5	1.6-3.5
70-79%	125-230	40-100	2.0-4.0	≥270	110-140	≥4.0	≥220	≥100	≥3.5	≥3.5
80-99%	≥230	≥100	≥4.0	≥270	≥140	≥4.0	≥220	≥100	≥3.5	≥3.5

PSV: peak systolic velocity at stenosis; EDV: end-diastolic flow rate; CCA: Common carotid artery

The combined application of different ultrasound techniques can improve the accuracy of diagnosis of ICAS lesions. According to the expert consensus of the 2003 Association of Ultrasound Radiologists, all ICA examinations should be performed using grayscale, color Doppler, and spectral Doppler [19]. The internal carotid artery in the extracranial segment is thick, which can visually display the two-dimensional lumen structure and color blood flow filling effect. At the same time, the combination of spectral Doppler technology and other indicators such as blood flow velocity is more conducive to accurate evaluation of the degree of stenosis, especially to improve the diagnostic accuracy of moderate or above stenosis. Some scholars at home and abroad have isolated two-dimensional ultrasound and CDFI detection, and the consistency of the classification of stenosis degree between the classification based on pipe diameter and the classification based on flow rate is only about 60% [28].The accuracy of the diagnosis of ICAS degree by themselves was low [29]. In most patients with carotid artery stenosis, the diameter method has a high repeatability, but there are differences due to the difference in the two-dimensional section evaluated by the examiner. Using the velocity rule alone will be affected by the difference of hemodynamic factors and there will be errors. Therefore, it is more recommended to combine the method of tube diameter and blood flow velocity to conduct the final evaluation of ICAS degree[30] , so as to carry out accurate classification and provide effective objective basis for the selection of clinical treatment plans. In recent years, some scholars have proposed to use three-dimensional energy Doppler ultrasound technology to evaluate the degree of stenosis of ICAS, and there is no statistical difference in the consistency of DSA [31]. However, the application of 3D energy ultrasound is not realistic in primary hospitals, and it is relatively time-consuming, and there is no unified diagnostic standard, which needs further research.

Through the joint detection of the great blood vessels of the neck and the major intracranial arteries -- the integrated evaluation of the neck and brain, the influence of internal carotid artery stenosis and intracranial major artery stenosis on intracranial perfusion can be more accurately evaluated, so as to provide an objective basis for the selection of early clinical treatment. The combined application of carotid color Doppler and transcranial Doppler ultrasound can evaluate the intracranial hemodynamic changes and the establishment of collateral circulation caused by carotid artery stenosis, which is conducive to immediate intervention and prevention of ischemic stroke [32]. At the same time, the integrated cervico-cerebral examination can assist in the diagnosis of the degree of ICAS through the evaluation of intracranial blood perfusion, in particular, it can effectively reduce the presence of overestimated lesions mentioned above. The combination of transcranial color Doppler (TCCD) and transcranial Doppler (TCD) can effectively improve the accuracy of the diagnosis of intracranial internal carotid artery stenosis. Studies have shown that the sensitivity, specificity and accuracy of TCCD combined with TCD in the diagnosis of internal carotid artery stenosis are as high as 95% [33].Foreign scholars have also proposed that TCD embolus detection is helpful to evaluate whether ICAS will

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produce TIA-related clinical symptoms [34].

4. Evaluation of the progression of ICAS lesions

Internal carotid artery stenosis is a common vascular disease whose progression can lead to ischemic stroke, which can seriously affect patients' quality of life. Ultrasound evaluation of the progression of internal carotid artery stenosis is of great clinical value and can provide a reliable basis for diagnosis and treatment for clinicians. The methods of ultrasonic evaluation of the progression of internal carotid artery stenosis include the technical parameters, measurement indexes and evaluation criteria of ultrasound examination. During the ultrasound procedure, information such as the patient's medical history, physical examination and laboratory tests is needed to assess the condition more accurately. Specifically, ultrasound evaluation of the progress of internal carotid artery stenosis mainly includes the following steps: (1) To determine the diagnostic criteria of internal carotid artery stenosis, such as diameter stenosis rate, blood flow velocity and other indicators. (2) Choose the right ultrasonic instrument and probe, adjust the instrument parameters, in order to obtain the best image quality. (3) Internal carotid artery ultrasound was performed on the patients, and relevant data such as vessel diameter, blood flow velocity, and plaque nature were recorded. The main indexes of ultrasonic evaluation of the progression of internal carotid artery stenosis include peak systolic flow rate, spectral Doppler direction, color Doppler flow imaging, vessel wall thickness, plate thickness, etc. When the internal carotid artery is narrowed, the blood flow velocity of the blood vessel increases. By measuring the blood flow spectrum of the internal carotid artery, information about the blood flow velocity and direction can be obtained. Spectral Doppler can show whether the blood flow speed is normal, but also can show whether the direction of the blood flow is normal. When the internal carotid artery stenosis worsens, the thickness of the blood vessel wall will also change. Ultrasound can measure the wall thickness of the internal carotid artery to determine if progress is occurring. (4) The degree and progression of internal carotid artery stenosis should be evaluated based on the measured data, and differential diagnosis such as cervical spine disease and intracranial tumors should be paid attention to. (5) According to the evaluation results, the corresponding treatment plan is formulated, such as drug therapy, surgical treatment, etc., and the curative effect is evaluated regularly.

In the application of ultrasound to evaluate the progression of internal carotid artery stenosis, several studies have demonstrated its reliability and effectiveness. For example, a retrospective study based on a large number of cases showed that ultrasound evaluation of the progression of internal carotid artery stenosis played an important guiding role in the early diagnosis and prognosis of ischemic stroke [35]. In addition, ultrasound evaluation of the progression of internal carotid artery stenosis can help doctors develop more accurate treatment plans, thereby improving treatment effectiveness and reducing the incidence of complications. However, there are still some limitations in its application, such as high experience and technical requirements for operators, and different evaluation standards in different hospitals and regions. Future research directions should include improving operation technology, developing more unified evaluation criteria, and carrying out multi-center and large sample research. At the same time, it is also necessary to pay attention to the application prospects of new ultrasound technologies such as three-dimensional ultrasound and contrastus-enhanced ultrasound in the evaluation of internal carotid artery stenosis.

Because of its cheap, safe and repeatable characteristics, ultrasound examination also has high application value in the evaluation of the progression of ICAS lesions and the treatment effect. Some scholars have conducted ultrasonic follow-up of 50-69% of patients with carotid artery stenosis (CAS) for up to 36 months, and found that low-echo plaque and 70-99% contralateral carotid artery stenosis or occlusion lesions are independent risk factors for plaque progression within 3 years[35]. It can be seen that ultrasonic characteristics are another scientific objective basis for evaluating the progression trend of ICAS in the future. In order to predict the occurrence of cardiovascular and cerebrovascular diseases in ICAS patients, some foreign scholars have proposed a carotid artery stenosis ultrasonic scoring scale[36] and conducted long-term follow-up, which once again verified the irreplaceable application value of carotid artery ultrasound in the evaluation of long-term treatment effect and disease progression in ICAS patients. Recent studies have reported that EDV and peak time (AT) are also independent risk factors for the progression of ICA stenosis [37]. It is hoped that future prospective studies will be designed to further validate the control of different risk factors and the influence of different treatment regiments on the progression of ICAS lesions, so that these indicators can be included in guidelines for prediction and treatment.

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5. Brief summary

As an examination method recommended in the guidelines for carotid artery stenosis, ultrasound has the advantages of strong economy, safety and convenience, high repeatability, and comprehensive evaluation of various indexes. The comprehensive evaluation of the two-dimensional structure and hemodynamics of the lumen of ICAS by vascular ultrasound technology can provide reference and objective information for the identification of etiology, the definition of the lesion site, the diagnosis of the degree of stenosis, and the choice of treatment for clinical ICAS patients. The combined application of various ultrasound techniques provides a variety of parameters for the assessment of ICAS and its impact on intracranial blood perfusion, effectively improving the accuracy of diagnosis and better helping the clinical selection of appropriate treatment methods for personalized diagnosis and treatment.

Ultrasound evaluation of carotid artery stenosis has broad application space in the future. As ultrasound technology continues to advance, we can expect that the accuracy of ultrasound diagnosis of carotid artery stenosis will continue to improve. For example, techniques such as high-resolution ultrasound, three-dimensional ultrasound, and contrastus-enhanced ultrasound can improve the recognition and classification of carotid artery stenosis and reduce misdiagnosis and missed diagnosis. At the same time, future ultrasound evaluation of carotid stenosis may be extended to assess the comprehensiveness of the condition. By measuring the degree of carotid artery stenosis, hemodynamic characteristics, size and nature of atherosclerotic plaque and other indicators, we can more comprehensively assess the patient's condition and risk, and provide a more comprehensive clinical diagnosis and treatment basis. By comparing the results of ultrasound examination before and after treatment, it can evaluate the treatment effect, detect the progression of disease, guide the adjustment of treatment plan, and improve the treatment effect and the quality of life of patients. With the continuous development and popularization of medical technology, ultrasound evaluation of carotid artery stenosis is expected to be further popularized and remote. For example, through technologies such as telemedicine and mobile health, remote ultrasound examinations and diagnoses can be easily performed, improving the coverage and convenience of medical services.

In conclusion, the future development prospect of ultrasound evaluation of carotid artery stenosis is broad, and it is expected to be further developed and applied in the aspects of accuracy, comprehensiveness, monitoring treatment effect, non-invasive evaluation and popularization, etc., so as to provide a more comprehensive, accurate and convenient basis for clinical diagnosis and treatment.

References

[1] Control CfD, Morbidity PJM, report mw. Prevalence of disabilities and associated health conditions among adults--United States, 1999. 2001;50(7):120-125.
[2] Rosamond W, Flegal K, Furie K, et al. Heart disease and stroke statistics--2008 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. 2008;117(4):e25-146.
[3] Varetto G, Gibello L, Sperti F, et al. Early Carotid Endarterectomy Provides a Better Neurological Outcome in Symptomatic Patients: A Single-Center Experience. 2017;45:62-68.
[4] Aboyans V, Ricco J-B, Bartelink M-LEL, et al. 2017 ESC Guidelines on the Diagnosis and Treatment of Peripheral Arterial Diseases, in collaboration with the European Society for Vascular Surgery (ESVS): Document covering atherosclerotic disease of extracranial carotid and vertebral, mesenteric, renal, upper and lower extremity arteriesEndorsed by: the European Stroke Organization (ESO)The Task Force for the Diagnosis and Treatment of Peripheral Arterial Diseases of the European Society of Cardiology (ESC) and of the European Society for Vascular Surgery (ESVS). 2018;39(9):763-816.
[5] Wangsheng L. The cause and effect of chronic internal carotid artery occlusion: Chinese expert consensus interpretation of chronic internal carotid artery occlusion recanalization treatment. Chinese Medical Information Herald. 2019;34(2):22-23.
[6] Hua Y, Zheng Y, Ling C, et al. Association of risk factors for atherosclerosis with carotid artery stenosis and ischemic stroke. Chinese Journal of Cerebrovascular Diseases. 2004;1(2):69-72.
[7] Steinvil A, Sadeh B, Arbel Y, et al. Prevalence and predictors of concomitant carotid and coronary artery atherosclerotic disease. 2011;57(7):779-783.
[8] Wu J, Wang Y, Wang A, et al. Association between non-high-density lipoprotein cholesterol levels and the prevalence of asymptomatic extracranial internal carotid artery stenosis in a Chinese community-based study. 2019;26(5):740-746.
[9] Xie Y. Clinical study of ankle-brachial index to evaluate the degree of cerebral artery stenosis in

ISSN 2618-1584 Vol. 5, Issue 10: 35-41, DOI: 10.25236/FMSR.2023.051006

patients with ischemic stroke. Chinese Journal of senile cardio-cerebrovascular diseases. 2011;13(11):970-973.
[10] Genkel V, Kuznetsova A, Lebedev E, et al. Achilles Tendon Thickness Is an Independent Predictor of Carotid Atherosclerosis and Is Associated With a Carotid Plaque Burden. 2020;71(8):734-739.
[11] Spanos K, Tzorbatzoglou I, Lazari P, et al. Carotid artery plaque echomorphology and its association with histopathologic characteristics. 2018;68(6):1772-1780.
[12] Karapanayiotides T, Stroke GDJ. Fibrous cap thickness and stability of carotid atheromata. 2006;37(10):2451; author reply 2452.
[13] Polak JF, Alessi-Chinetti JM, Medicine FWKJJouimojotAIoUi. Doppler Velocity Estimates of Internal Carotid Artery Stenosis: Angle Correction Parallel to the Color Doppler Lumen Versus Parallel to the Artery Wall. 2019;38(12):3211-3218.
[14] Traenka C, Streifler J, Lyrer P, et al. Clinical Usefulness of Serial Duplex Ultrasound in Cervical Artery Dissection Patients. 2020;49(2):206-215.
[15] Chen L, Cao H, neurology MZJJ. The Trade-off Between the Bony Carotid Canal and Internal Carotid Artery. 2021;78(5):611-612.
[16] Collaborators NASCET, Barnett HJM, Taylor DW, et al. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. 1991;325(7):445-453.
[17] European Carotid Surgery Trialists'Collaborative Group. Randomised trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST) %J Lancet (London, England). 1998;351(9113):1379-1387.
[18] Williams MA. Predicting the normal dimensions of the internal and external carotid arteries from the diameter of the common carotid. 1987;1(2):91-96.
[19] Murray CSG, Nahar T, Kalashyan H, et al. Ultrasound assessment of carotid arteries: Current concepts, methodologies, diagnostic criteria, and technological advancements. 2018;35(12):2079-2091.
[20] Staikov IN, Arnold M, Mattle HP, et al. Comparison of the ECST, CC, and NASCET grading methods and ultrasound for assessing carotid stenosis. European Carotid Surgery Trial. North American Symptomatic Carotid Endarterectomy Trial. 2000;247(9):681-686.
[21] Grant EG, Benson CB, Moneta GL, et al. Carotid artery stenosis: gray-scale and Doppler US diagnosis--Society of Radiologists in Ultrasound Consensus Conference. 2003;229(2):340-346.
[22] Hua Y, Liu B, Ling C, et al. Assessment of diagnostic accuracy of 50% -69% and 70%- 99% in carotid artery stenosis by ultrasonography. Chinese Journal of Cerebrovascular Diseases. 2006;3(5):211-218.
[23] Jia H, Liu X, Wu S, et al. CDFI three parameter criteria to evaluate the diagnostic value of ICAS. Medical review. 2015;21(6):1096-1098, 1093.
[24] Columbo JA, Zwolak RM, Arous EJ, et al. Variation in Ultrasound Diagnostic Thresholds for Carotid Stenosis in the United States. 2020;141(12):946-953.
[25] Li J, Liu G, Peng X. Discriminant analysis and principal component analysis of ultrasonic detection parameters of extracranial stenosis of internal carotid artery. Chinese Journal of Cerebrovascular Diseases. 2008;5(6):246-250.
[26] Bing H, Hua Y, Ling C, et al. Hemodynamics of ipsilateral common carotid artery in patients with moderate and severe internal carotid artery stenosis or occlusion. Chinese Journal of Cerebrovascular Diseases. 2008;5(12):536-540.
[27] Hariri N, Russell T, Kasper G, et al. Shear rate is a better marker of symptomatic ischemic cerebrovascular events than velocity or diameter in severe carotid artery stenosis. 2019;69(2):448-452.
[28] Larsson AC, physiology SRJC, imaging f. Diameter-based measurements of the degree of carotid artery stenosis using ultrasonography. 2021;41(2):217-220.
[29] Haiying G, Hengquan Z, Hui Y, et al. Evaluation of the diagnostic value of two dimensional gray scale flow imaging in the elderly patients with moderate to severe internal carotid artery stenosis. Zhejiang Medical Journal. 2014(21):1784-1786.
[30] Sabeti S, Schillinger M, Mlekusch W, et al. Quantification of internal carotid artery stenosis with duplex US: comparative analysis of different flow velocity criteria. 2004;232(2):431-439.
[31] Macharzina RR, Kocher S, Hoffmann F, et al. Accuracy of Carotid Artery Stenosis Quantification with 4-D-Supported 3-D Power-Doppler versus Color-Doppler and 2-D Blood Velocity-Based Duplex Ultrasonography. 2020;46(5):1082-1091.
[32] Shuqin G, Xianghong G, Yanling L, et al. Influence of extracranial stenosis of internal carotid artery on blood supply to the brain was analyzed by color Doppler ultrasonography combined with transcranial Doppler ultrasound. Chinese medical equipment. 2015(9):37-39,19.
[33] Ling C, Li K, Hua Y, et al. Ultrasound imaging evaluation of internal carotid artery stenosis and occlusion. Chinese medical imaging technology. 2002;18(7):647-650.
[34] Mackinnon AD, Aaslid R, Stroke HSMJ. Ambulatory transcranial Doppler cerebral embolic signal

ISSN 2618-1584 Vol. 5, Issue 10: 35-41, DOI: 10.25236/FMSR.2023.051006

detection in symptomatic and asymptomatic carotid stenosis. 2005;36(8):1726-1730.
[35] Liu Y, Hua Y, Liu R, et al. Ultrasonographical Features Associated with Progression of Atherosclerosis in Patients with Moderate Internal Carotid Artery Stenosis. 2018;9(4):375-381.
[36] Tang Y, Wang M-Y, Wu T-T, et al. The role of carotid stenosis ultrasound scale in the prediction of ischemic stroke. 2020;41(5):1193-1199.
[37] Strosberg DS, Haurani MJ, Satiani B, et al. Common carotid artery end-diastolic velocity and acceleration time can predict degree of internal carotid artery stenosis. 2017;66(1):226-231.