ORIGINAL RESEARCH

Diagnostic value of cervical vascular ultrasound combined with CT angiography in carotid artery plaque in patients with cerebral infarction

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Abstract

Objective

To clarify diagnostic value of cervical vascular ultrasound (CVUS) combined with CT angiography (CTA) in carotid artery plaque in patients with cerebral infarction.

Methods

A total of 110 patients with cerebral infarction upon admission to our hospital from January 2021 to December 2023 received enrollment and performed CVUS and CTA examination. Digital subtraction angiography (DSA) received application as the gold standard to compare the diagnostic efficiency of different detection methods.

Results

DSA examination was performed on the bilateral carotid arteries (220 carotid arteries) of 110 patients, and 194 plaques were detected, including 73 soft plaques, 93 hard plaques and 28 mixed plaques. A total of 174 carotid artery stenosis cases were detected, including 73 mild stenosis cases, 42 moderate stenosis cases, 36 severe stenosis cases and 23 complete stenosis cases. The accuracy rate of CVUS combined with CTA in detecting carotid artery plaque was 93.81% (182/194), higher than that of CVUS (75.77%, 147/194) and CTA (76.80%, 149/194), with significance ($P<0.05$). The accuracy of CVUS combined with CTA in detecting carotid artery stenosis was 94.83% (165/174) higher than that of CVUS (78.74%, 137/174) and CTA (84.48%, 147/174), with significance ($P<0.05$).

Conclusion

CVUS combined with CTA has a high diagnostic accuracy for carotid artery plaque lesions in patients with cerebral infarction, providing the basis for clinical diagnosis and follow-up treatment.

Keywords: cerebral infarction, carotid artery plaque, cervical vascular ultrasound, CT angiography

Introduction

Cerebral infarction is a common neurological disorder associated with substantial morbidity and mortality and remains a major cause of disability and death worldwide[1]. It occurs predominantly in middle-aged and older adults and may lead to severe neurological deficits; therefore, early detection and timely diagnosis are essential to improve functional outcomes and reduce mortality[2].

Carotid atherosclerosis is an independent risk element for cerebral infarction, carotid plaque is major sign of carotid atherosclerosis, which is earlier than the cerebral artery and coronary artery lesions in the brain, which is conducive to early clinical detection of patients with lesions[3]. Cervical vascular ultrasound (CVUS) is a commonly used blood flow velocity and orientation measurement method, which can be performed at the bedside[4,5]. It has the advantages of real-time imaging, non-invasiveness, repeatability, low cost, and high patient acceptability[5,6]. CT angiography (CTA) can provide detailed anatomical information on the head and neck vasculature and is useful for evaluating plaque location, morphology, and the degree of carotid stenosis[7,8]. Previous studies and current clinical pathways have mainly relied on a single imaging modality or a stepwise imaging strategy, with duplex ultrasonography often used as the initial examination and CTA added to provide supplemental anatomical information when necessary; however, evidence remains limited regarding the complementary value of combining CVUS and CTA for both plaque characterization and stenosis assessment in patients with cerebral infarction[5,8,9].

Therefore, our study was designed to elucidate diagnostic value of CVUS in combination with CTA in carotid artery plaque in with cerebral infarction patients.

Data and methods

General data

A total of 110 patients with cerebral infarction admitted to our hospital from January 2021 to December 2023 were enrolled, including 60 males and 50 females, aged 51-78 years, with a mean age of (68.23±6.43) years. There were 30 cases of hyperlipidemia, 25 cases of diabetes, and 46 cases of hypertension. All patients were informed of the study content and signed written informed consent. Patients were enrolled according to predefined eligibility criteria and all included patients underwent CVUS, CTA, and DSA for diagnostic comparison. Inclusion criteria were as follows: (1) first onset; and (2) no contraindications to CVUS, CTA,

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or DSA. Exclusion criteria were as follows: (1) malignant tumors; (2) incomplete clinical data; (3) poor compliance; and (4) allergy to contrast agent. Exclusion criteria: (1) Patients with malignant tumors; (2) Incomplete clinical data; (3) Poor compliance; (4) Patients allergic to contrast agent.

Methods

All the selected patients underwent CVUS and CTA examinations as follows:

(1) CVUS examination: The instrument used was a Philips IU22 Doppler ultrasonic diagnostic instrument with a probe frequency range of 3-9 MHz. Vasoactive drugs were not allowed for 3 days prior to the test. During the examination, the patient was placed in a supine position with a pillow behind the neck and the head tilted back to fully expose the test site. The bilateral carotid arteries were scanned longitudinally and transversely. The long-axis section of the internal carotid artery was displayed, and the probe was slightly tilted outward so that the carotid bifurcation, external carotid artery, common carotid artery, and intracranial segment of the internal carotid artery could be examined ultrasonographically. On this basis, plaque on the carotid artery wall was morphologically observed. First, a two-dimensional ultrasound examination was performed. The vessels were scanned from the bottom up to observe the condition of the luminal wall, determine whether there was any abnormal echo, and measure the internal diameter of the artery. Blood flow in the arteries was monitored in multiple directions using Doppler ultrasound to determine whether there were distortions, narrowing, plaques, or occlusions. Carotid plaque was identified as a focal protrusion into the lumen with carotid intima-media thickness greater than 1.2 mm[10,11].

(2) CTA examination: The scanning instrument was Siemens 64-slice spiral CT. The patient was placed in a lying position with shoulders down and no swallowing activity was allowed during the examination. Iopamidol was injected intraventically into the elbow of the patient with a high-pressure syringe at a rate of 3 ~ 4 mL/s, from the foot to the head, from the aortic arch to the Wills arterial ring at the base of the skull. The tube voltage was set at 120 kV, the layer distance was 0.45 mm, and the layer thickness was 0.9 mm. The width of the collimator of the detector was arranged at 64× 0.625 mm, and the image was reconstructed on the post-processing workstation. The layer spacing was 2.0 mm and the layer thickness was 2.0 mm. Based on the lesion detection of cross-sectional images, a variety of post-processing reconstruction techniques were used to process the images. Local vascular wall thickening and local lumen narrowing suggested carotid plaque.

(3) DSA examination: Axion Artis dTA angiography machine (Siemens) was used. The patient was placed in a supine position and exposed to both sides of the groin area. After disinfection, local anesthesia was administered with 2% lidocaine hydrochloride. Sledinger technique was used to place 5F catheter sheath and send it through 5F double-J tube guided by catheter sheath. Common carotid artery, aortic arch, intracranial artery, subclavian artery, and vertebral artery were respectively performed to observe and record luminal plaque and stenosis.

Evaluation criteria

(1) CVUS: Plaque: local bulge of the blood vessel wall, carotid intima-media thickness (IMT) ≥ 1.2 mm 27, 28, in which soft plaque: the echo of the blood vessel wall was higher than the echo of the plaque, no sound shadow was in the rear; Hard plaque: the echo of the blood vessel wall was lower than or close to the plaque echo, and the sound shadow could be seen behind; Mixed patch: Low and high echo could be seen within the patch, with or without sound shadow presented behind.

Degree of carotid artery stenosis: mild stenosis: stenosis rate <50%; Moderate stenosis: the stenosis rate was 50% to 69%; Severe stenosis: stenosis rate of 70% ~ 99%; Complete stenosis: Stenosis rate was 100%.

(2) CTA: Soft plaque: low-attenuation plaque, CT value <60 Hu; Hard plaque: calcified high-density shadow could be seen in the plaque, CT value >130 Hu; Mixed plaque: the plaque density was mixed, and the CT value was 60 ~ 129 Hu 12.

Degree of carotid artery stenosis: assessed according to the North American Standards for Symptomatic Carotid Endarterectomy (NASCET) 13: mild stenosis: stenosis rate <30%; Moderate stenosis: the stenosis rate ranged from 30% to 69%; Severe stenosis: stenosis rate of 70% ~ 99%; Complete stenosis: Stenosis rate was 100%.

Because CVUS evaluates luminal narrowing using ultrasound morphology and hemodynamic findings, whereas CTA stenosis was morphologically graded on reconstructed images according to the NASCET standard, the stenosis grading thresholds were defined according to the conventional criteria of each modality. To avoid potential cross-modality bias, DSA was used as the uniform reference standard for all diagnostic efficacy comparisons in this study.

Observation indicators

Digital subtraction angiography (DSA) was used as the reference standard to record carotid plaque, vessel stenosis, and plaque type, and to evaluate the diagnostic efficacy of CVUS alone, CTA alone, and the combined examination.

Statistical analysis

SPSS 23.0 statistical software was used to process the data. Categorical variables were expressed as n (%) and compared using the χ2 test. The primary analysis compared the diagnostic detection results of CVUS alone, CTA alone, and CVUS combined with CTA against DSA as the reference standard. Because the study was designed as a diagnostic accuracy comparison rather than an etiologic or prognostic model, no multivariable adjustment for potential confounders was performed. A two-sided P<0.05 was considered statistically significant.

Results

DSA examination result

DSA examination was performed on the bilateral carotid arteries (220 carotid arteries) of 110 patients, and 194 plaques were detected, including 73 soft plaques, 93 hard plaques and 28 mixed plaques. A total of 174 carotid artery stenosis cases were detected, with 73 cases in mild stenosis, 42 cases in moderate stenosis, 36 cases in severe stenosis and 23 cases in complete stenosis.

Table 1 CVUS results of carotid plaque detection

CVUS	DSA		
	Soft plaque	Hard plaque	Mixed plaque
Soft plaque	54	7	5
Hard plaque	7	76	6
Mixed plaque	12	10	17
Total	73	93	28

Table 2 CTA results of carotid plaque detection

CTA	DSA		
	Soft plaque	Hard plaque	Mixed plaque
Soft plaque	56	9	7
Hard plaque	9	78	6
Mixed plaque	8	6	15
Total	73	93	28

Table 3 CVUS combined with CTA results of carotid plaque detection

CVUS combined with CTA	DSA		
	Soft plaque	Hard plaque	Mixed plaque
Soft plaque	67	2	1
Hard plaque	2	89	1
Mixed plaque	4	2	26
Total	73	93	28

Table 4 CVUS results of carotid stenosis

CVUS	DSA			
	Mild stenosis	Moderate stenosis	Severe stenosis	Complete stenosis
Mild stenosis	60	7	2	1
Moderate stenosis	9	32	4	1
Severe stenosis	3	2	27	3
Complete stenosis	1	1	3	18
Total	73	42	36	23

Table 5 CTA results of carotid stenosis

CVUS	DSA			
	Mild stenosis	Moderate stenosis	Severe stenosis	Complete stenosis
Mild stenosis	63	5	1	1
Moderate stenosis	7	35	5	0
Severe stenosis	2	2	30	3
Complete stenosis	1	0	0	19
Total	73	42	36	23

Table 6 CVUS combined with CTA results of carotid stenosis

CVUS	DSA			
	Mild stenosis	Moderate stenosis	Severe stenosis	Complete stenosis
Mild stenosis	69	2	0	0
Moderate stenosis	4	40	0	0
Severe stenosis	0	0	34	2
Complete stenosis	0	0	2	21
Total	73	42	36	23

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Carotid plaque detection results

The accuracy rate of CVUS combined with CTA in detecting carotid artery plaque was 93.81% (182/194), which was higher than that of CVUS (75.77%, 147/194) or CTA (76.80%, 149/194) alone, implying a marked statistical difference (P<0.05, Table 1-3).

Carotid stenosis detection results

The accuracy of CVUS combined with CTA in detecting carotid artery stenosis was 94.83% (165/174), which was higher than that of CVUS (78.74%, 137/174) or CTA (84.48%, 147/174) alone, implying a marked statistical difference (P<0.05, Table 4-6).

Discussion

At present, the etiology of cerebral infarction is not clear, and the analysis may be related to the obstruction of blood and oxygen supply in the brain caused by atherosclerosis[14]. The rupture of the unstable plaque causes platelets to accumulate on it, and when the clot falls off, it can cause a blockage of the blood vessels in the distal part of the brain, leading to a cerebral infarction[15]. Atherosclerotic plaque is an important risk factor for cerebral infarction and is closely related to the development of the disease[16]. The higher the degree of carotid atherosclerosis, the greater the risk of morbidity and the more serious the disease is[17]. The main reason is that carotid artery stenosis caused by carotid plaque will lead to insufficient blood circulation in the cerebral vessels, causing cerebral atherosclerosis and then inducing ischemic encephalopathy[18]. Because the neck artery is shallow and easy to see, it is a key window to look for arterial disease and is the most prone place in the cerebrovascular system to narrow[19]. Some scholars believe that early detection of carotid artery stenosis and timely treatment can reduce the disability rate and fatality rate of cerebral infarction patients to a certain extent[20].

DSA is the gold standard for clinical diagnosis of carotid artery stenosis, which can clearly show the composition and degree of arterial plaque, etc.[21]. However, this examination is an invasive examination with high risk and is not suitable for patients with poor body status, liver and kidney dysfunction, and severe bleeding tendency[22]. Moreover, the operation is more complicated, and the examination cost is high, which is not easy for patients to accept[23]. Therefore, it is particularly important to seek other more efficient and non-invasive methods of examination.

The CVUS has the advantages of strong repeatability and can indicate the hemodynamic changes of blood vessels and lumen conditions by collecting the audio signal waveform and blood flow image of blood flow[24]. The pathological basis of cerebral infarction and carotid stenosis includes carotid intima thickening, atherosclerosis, arterial plaque formation, and lumen stenosis. CVUS exerts a vital role in evaluation and diagnosis of carotid atherosclerosis and carotid stenosis. CVUS can clearly depict whether intima-media is thickened, and can effectively detect intima-media thickness, providing data support for clinical evaluation of cerebral infarction. The limitation of CVUS is that it cannot detect carotid blindness, especially for patients with high straddle carotid balls[25]. The eddy current caused by carotid reflux, specific anatomical location, and operator's technique may also interfere with the diagnosis of carotid plaque[26].

Through three-dimensional reconstruction, CTA can observe blood vessels from different levels, directions and angles, and has high spatial and temporal resolution, avoid structural overlap, and can accurately evaluate carotid artery stenosis[27]. CTA, with its advantages of fast scanning speed and short imaging time, has received wide application in clinical diagnosis and treatment of head and neck lesions; CTA can clearly display morphological structure, plaque distribution, and composition of head and neck arteries through post-processing techniques, thereby more accurately evaluating characteristics of plaques. However, CTA cannot reflect the biological characteristics of neovascularization, inflammation, ulcers, etc., and cannot reflect the volume and hemodynamic characteristics of plaques[28]. According to the advantages and disadvantages of CVUS and CTA, some scholars believe that the combination of the two can complement each other, give full play to the advantages of the two examination methods, and improve the clinical diagnosis accuracy of carotid plaque, so as to provide important reference information for clinical diagnosis and treatment of diseases[29].

The results of our study revealed that the accuracy of CVUS combined with CTA in detecting carotid plaque and carotid artery stenosis was higher than that of CVUS or CTA alone, suggesting that the CVUS combined with CTA demonstrated high accuracy in diagnosing carotid artery plaque lesions in patients with cerebral infarction, exerting great clinical significance in cerebral infarction diagnostics. Importantly, this statistically significant improvement may also be clinically relevant. In real-world practice, a more accurate combined assessment of plaque characteristics and stenosis severity may help clinicians better identify patients who require closer surveillance, further vascular evaluation, or more individualized management strategies. The reason is that CVUS can determine the thickness of endo-media, the degree of vascular stenosis, and determine the patchiness[30]. At the same time, it can also show the situation of new blood vessels in the plaque, which can further evaluate the risk of plaque, and then determine the situation of carotid artery stenosis, and show whether the carotid artery has plaque and the nature of plaque[31]. CTA can comprehensively evaluate the carotid artery system and help to understand the specific distribution of plaque and stenosis[32]. In our research, combined application of CVUS and CTA complemented each other, observing morphological characteristics of multiple extracranial vessels of carotid artery from different levels, angles, and directions, and clearly displaying the structure of vessel wall and abnormal blood flow in narrowed area. This suggests that CVUS combined with CTA can play a complementary advantage to further improve the detection rate of carotid plaque formation and carotid artery stenosis, facilitate the early detection of carotid artery stenosis, provide a reference for clinical treatment measures, and help control the progression of cerebral infarction.

This study has several limitations. First, it was a single-center study, which may limit the generalizability of the findings. Second, the sample size was relatively modest, and larger multicenter studies are needed to further validate the diagnostic performance of the combined approach. Third, because DSA served as the reference standard, only patients with available DSA results were included in the analysis, which may have introduced selection bias. Fourth, interobserver variability was not assessed in this study; therefore, the reproducibility of CVUS and CTA interpretation requires further evaluation. Fifth, this study mainly focused on cross-sectional diagnostic evaluation and lacked outcome follow-

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up; therefore, the prognostic value of CVUS combined with CTA for subsequent cerebrovascular events or treatment monitoring warrants further investigation. Sixth, no multivariable adjustment for potential confounders or formal sensitivity analyses was performed, which should be considered when interpreting the findings.

Conclusion

CVUS combined with CTA has a high diagnostic accuracy for carotid artery plaque lesions in patients with cerebral infarction, providing the basis for clinical diagnosis and follow-up treatment.

Declarations

Conflicts of interests

The authors declared no conflict of interest.

Availability of data and material

The data sets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical consideration

All assays received performance in compliance with the Helsinki Declaration criteria, and this study received authorization by the Ethics Committee of Kunshan integrated TCM and Western Medicine Hospital. All patients signed a documented, voluntarily informed consent form.

Author contribution

Jingjiao Qian conceived and designed experiments. Hanwen Shi contributed markedly to experiments and arranging data. Pingping Ye, Danni Wang, Xiaojuan Zhou and Linfeng Tang conducted data analysis. Guang Yang wrote draft manuscript. Guang Yang revised manuscript. All authors read and approved final manuscript.

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References

1.Feigin VL, Brainin M, Norrving B, Martins SO, Pandian J, Lindsay P, et al. World Stroke Organization: Global Stroke Fact Sheet 2025. International journal of stroke : official journal of the International Stroke Society 2025; 20 (2): 132-144. doi: 10.1177/17474930241308142.

2.Li XY, Kong XM, Yang CH, Cheng ZF, Lv JJ, Guo H, et al. Global, regional, and national burden of ischemic stroke, 1990-2021: an analysis of data from the global burden of disease study 2021. EClinicalMedicine 2024; 75 102758. doi: 10.1016/j.eclinm.2024.102758.

3.Ni T, Fu Y, Zhou W, Chen M, Shao J, Zhou W, et al. Carotid plaques and neurological impairment in patients with acute cerebral infarction. PLoS One 2020; 15 (1): e0226961. doi: 10.1371/journal.pone.0226961.

4.Yuan C, Wu VW, Yip SP, Kwong DL, Ying M. Ultrasound Evaluation of Carotid Atherosclerosis in Post-Radiotherapy Nasopharyngeal Carcinoma Patients, Type 2 Diabetics, and Healthy Controls. Ultraschall Med 2017; 38 (2): 190-197. doi: 10.1055/s-0034-1399293.

5.David E, Grazhdani H, Aliotta L, Gavazzi LM, Foti PV, Palmucci S, et al. Imaging of Carotid Stenosis: Where Are We Standing? Comparison of Multiparametric Ultrasound, CT Angiography, and MRI Angiography, with Recent Developments. Diagnostics (Basel, Switzerland) 2024; 14 (16): doi: 10.3390/diagnostics14161708.

6.Fernández-Alvarez V, Linares Sánchez M, López Alvarez F, Suárez Nieto C, Mäkitie AA, Olsen KD, et al. Evaluation of Intima-Media Thickness and Arterial Stiffness as Early Ultrasound Biomarkers of Carotid Artery Atherosclerosis. Cardiol Ther 2022; 11 (2): 231-247. doi: 10.1007/s40119-022-00261-x.

7.Manrique-Zegarra M, García-Pastor A, Castro-Reyes E, Guzmán-De-Villoria JA, Herrera Herrera I, Garrido Morro I, et al. CT angiography for diagnosis of carotid near-occlusion: a digital subtraction angiography validation study. Neuroradiology 2022; 64 (9): 1729-1735. doi: 10.1007/s00234-022-02995-w.

8.Cau R, Gupta A, Kooi ME, Saba L. Pearls and Pitfalls of Carotid Artery Imaging: Ultrasound, Computed Tomography Angiography, and MR Imaging. Radiologic clinics of North America 2023; 61 (3): 405-413. doi: 10.1016/j.rcl.2023.01.001.

9.Columbo JA, Stone DH. Appropriateness of care: Asymptomatic carotid stenosis including transcarotid artery revascularization. Seminars in vascular surgery 2024; 37 (2): 179-187. doi: 10.1053/j.semvascsurg.2024.03.002.

10.Korcarz CE, DeCara JM, Hirsch AT, Mohler ER, Pogue B, Postley J, et al. Ultrasound detection of increased carotid intima-media thickness and carotid plaque in an office practice setting: does it affect physician behavior or patient motivation? Journal of the American Society of Echocardiography : official publication of the American Society of Echocardiography 2008; 21 (10): 1156-1162. doi: 10.1016/j.echo.2008.05.001.

11.Jiao Y, Qin Y, Zhang Z, Zhang H, Liu H, Li C. Early identification of carotid vulnerable plaque in asymptomatic patients. BMC Cardiovascular Disorders 2020; 20 (1): 429. doi: 10.1186/s12872-020-01709-5.

12.Saba L, Piga M, Raz E, Farina D, Montisci R. Carotid artery plaque classification: does contrast enhancement play a significant role? AJNR American journal of neuroradiology 2012; 33 (9): 1814-1817. doi: 10.3174/ajnr.A3073.

13.Staikov IN, Arnold M, Mattle HP, Remonda L, Sturzenegger M, Baumgartner RW, 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. J Neurol 2000; 247 (9): 681-686. doi: 10.1007/s004150070110.

14.Dahl A, Lund C, Russell D. [Atherosclerosis and cerebral infarction]. Tidsskr Nor Laegeforen 2007; 127 (7): 892-896.

15.Wang GJ, Dong X, Li Y. Cluster of Differentiation 147 (CD147) serves as a promoter of atherosclerosis in patients with cerebral infarction. Eur Rev Med Pharmacol Sci 2022; 26 (16): 5710-5717. doi: 10.26355/eurrev_202208_29506.

16.Cui B, Yang D, Zheng W, Wu Y, Yang Q, Wang Z, et al. Plaque enhancement in multi-cerebrovascular beds associates with acute cerebral infarction. Acta Radiol 2021; 62 (1): 102-112. doi: 10.1177/0284185120915604.

17.Chen L, Yang Q, Ding R, Liu D, Chen Z. Carotid thickness and atherosclerotic plaque stability, serum inflammation, serum MMP-2 and MMP-9 were associated with acute cerebral infarction. Exp Ther Med 2018; 16 (6): 5253-5257. doi: 10.3892/etm.2018.6868.

18.Saba L, Nardi V, Cau R, Gupta A, Kamel H, Suri JS, et al. Carotid Artery Plaque Calcifications: Lessons From Histopathology to Diagnostic Imaging. Stroke 2022; 53 (1): 290-297. doi: 10.1161/strokeaha.121.035692.

19.Brinjikji W, Huston J, 3rd, Rabinstein AA, Kim GM, Lerman A, Lanzino G. Contemporary carotid imaging: from degree of stenosis to plaque vulnerability. J Neurosurg 2016; 124 (1): 27-42. doi: 10.3171/2015.1.Jns142452.

20.Wang J, Wang L, Shen Y, Gong X, Ju Y. Relationship Between Carotid Artery Angle and Plaque Morphology in Acute Cerebral Infarction Patients. Neurologist 2022; 27 (5): 240-244. doi: 10.1097/nrl.0000000000000410.

21.Del Brutto VJ, Gornik HL, Rundek T. Why are we still debating criteria for carotid artery stenosis? Ann Transl Med 2020; 8 (19): 1270.

doi: 10.21037/atm-20-1188a.

22.Svoboda N, Bradac O, Mandys V, Netuka D, Benes V. Diagnostic accuracy of DSA in carotid artery stenosis: a comparison between stenosis measured on carotid endarterectomy specimens and DSA in 644 cases. Acta Neurochir (Wien) 2022; 164 (12): 3197-3202. doi: 10.1007/s00701-022-05332-5.

23.Brandt AH, Nguyen TQ, Gutte H, Frederik Carlsen J, Moshavegh R, Jensen JA, et al. Carotid Stenosis Assessment with Vector Concentration before and after Stenting. Diagnostics (Basel) 2020; 10 (6): doi: 10.3390/diagnostics10060420.

24.Chiba T, Fujiwara S, Oura K, Oikawa K, Chida K, Kobayashi M, et al. Superb Microvascular Imaging Ultrasound for Cervical Carotid Artery Stenosis for Prediction of the Development of Microembolic Signals on Transcranial Doppler during Carotid Exposure in Endarterectomy. Cerebrovasc Dis Extra 2021; 11 (2): 61-68. doi: 10.1159/000516426.

25.Qin LW, Wang C, Feng XJ, Wang XH, Qin LH, Weeks C. Can cervical vascular ultrasound combined with transcranial Doppler ultrasound accurately diagnose cerebral infarction?: A protocol for a systematic review and meta-analysis. Medicine (Baltimore) 2020; 99 (22): e19997. doi: 10.1097/md.0000000000019997.

26.Oikawa K, Kato T, Oura K, Narumi S, Sasaki M, Fujiwara S, et al. Preoperative cervical carotid artery contrast-enhanced ultrasound findings are associated with development of microembolic signals on transcranial Doppler during carotid exposure in endarterectomy. Atherosclerosis 2017; 260 87-93. doi: 10.1016/j.atherosclerosis.2017.03.026.

27.Huan Y, Chaoyang Z, Kai D, Chunhua S, Xin Z, Yue Z. Predictive Value of Head-Neck CTA Combined with ABCD2 Scale Score for Patients with Cerebral Infarction of Vertebrobasilar Transient Ischemic Attack (TIA). Med Sci Monit 2018; 24 9001-9006. doi: 10.12659/msm.909470.

28.Han C, Peng W, Xie J, Xu J, Xu H. Meta-Analysis of Prognostic Correlation of Thrombectomy for Cerebral Infarction Based on Intelligent Medical Treatment. Biomed Res Int 2022; 2022 4537195. doi: 10.1155/2022/4537195.

29.Saba L, Sanfilippo R, Montisci R, Atzeni M, Ribuffo D, Mallarini G. Vulnerable plaque: detection of agreement between multi-detector-row CT angiography and US-ECD. Eur J Radiol 2011; 77 (3): 509-515. doi: 10.1016/j.ejrad.2009.09.009.

30.Xu L, Wang R, Liu H, Wang J, Liang W, Mang J, et al. Comparison of the Diagnostic Performances of Ultrasound, High-Resolution Magnetic Resonance Imaging, and Positron Emission Tomography/Computed Tomography in a Rabbit Carotid Vulnerable Plaque Atherosclerosis Model. J Ultrasound Med 2020; 39 (11): 2201-2209. doi: 10.1002/jum.15331.

31.Cheung WK, Shah BN, Stanziola A, Gujral DM, Chahal NS, Cosgrove DO, et al. Differential Intensity Projection for Visualisation and Quantification of Plaque Neovascularisation in Contrast-Enhanced Ultrasound Images of Carotid Arteries. Ultrasound Med Biol 2017; 43 (4): 831-837. doi: 10.1016/j.ultrasmedbio.2016.11.018.

32.Baradaran H, Foster T, Harrie P, McNally JS, Alexander M, Pandya A, et al. Carotid artery plaque characteristics: current reporting practices on CT angiography. Neuroradiology 2021; 63 (7): 1013-1018. doi: 10.1007/s00234-020-02610-w.