ORIGINAL ARTICLE

Diagnostic value of carotid artery stenosis and carotid ulcer plaque characterization based on MRI and CT techniques

Jun Zhang*[1], Changli Liu[1], Shaobin Wang[2]

[1] *Department of Medical Imaging, Baogang Hospital, Baotou, Inner Mongolia, China*
[2] *Department of Neurology, Baotou Mongolian Traditional Chinese Medicine Hospital, Baogang Hospital, Baotou, Inner Mongolia, China*

Received: March 14, 2025 **Accepted:** June 20, 2025 **Online Published:** December 16, 2025
DOI: 10.5430/dcc.v11n2p5 **URL:** https://doi.org/10.5430/dcc.v11n2p5

ABSTRACT

Objective: MRI and CT techniques were used to examine carotid artery stenosis and carotid ulcer plaque in patients with carotid artery stenosis, and the diagnostic value of MRI and CT was explored through comparative studies.
Methods: MRI examinations were performed by using high-resolution Magnetic Resonance Imaging 3D Black Blood Technology, and CT examinations were performed by means of Computed Tomography Angiography. The cases consisted of 68 patients with carotid artery stenosis accompanied by carotid ulcerative plaques admitted to the Department of Neurology of a tertiary hospital from January 2020 to December 2020, who underwent quantitative measurements with both high-resolution magnetic resonance imaging 3D black blood technology (cervical part) and computed tomography angiography, and digital subtraction angiography (DSA) was taken up as the gold standard to compare and analyze the two tests for the diagnostic value of carotid artery stenosis and carotid ulcerative plaque.
Results: In our group of 68 patients with carotid artery stenosis accompanied by carotid ulcerative plaques, there were 10 unilateral lesions and 58 bilateral lesions, with a total of 126 diseased carotid arteries; 3 diseased vessels with poor image quality were excluded, and 123 diseased carotid arteries were included in the comparative study. The two methods were compared in the measurement of lumen area, wall area and external area of the wall of the diseased carotid artery (p = .273, p = .240, p = .941), the difference was not statistically significant; in the comparison of luminal stenosis rate, t = 0.905, p > .05, the difference was not statistically significant; Pearson correlation analysis showed that the two methods were positively correlated with the luminal stenosis rate measured by DSA (r = 0.961, 0.952, p < .001). Using DSA as the gold standard, the sensitivity, specificity, and Youden's J statistic of the two methods for stenosis > 70% were 93.88%, 100.00% and 0.939 for the high-resolution magnetic resonance imaging 3D black blood technology, and 91.83%, 93.24% and 0.851 for the computed tomography angiography technology, respectively; in terms of the diagnosis of carotid ulcerative plaques, the high-resolution magnetic resonance imaging 3D black blood technology detected 38 cases, computed tomography angiography detected 35 cases, DSA detected 33 cases, the sensitivity, specificity and Youden's J statistic of the two methods for the diagnosis of carotid ulcerative plaques were compared, the high-resolution magnetic resonance imaging 3D black blood technology was 100.00%, 91.44%, 0.914, and computed tomography angiography was 78.79%, 90.00% and 0.688.
Conclusions: There was no difference between high-resolution magnetic resonance imaging 3D black blood technology and computed tomography angiography in the measurement of lumen area, wall area and external area of the wall of the diseased carotid artery, and there was no difference in luminal stenosis rate, and there was a higher diagnostic value in luminal stenosis

*Correspondence: Jun Zhang; Email: 967266720@qq.com; Address: Department of Medical Imaging, Baogang Hospital, Baotou, Inner Mongolia, 014010, China.

rate and the diagnosis of carotid ulcerative plaques, but the diagnostic value of carotid ulcerative plaques was higher with high-resolution magnetic resonance imaging 3D black blood technology.

Key Words: High-resolution magnetic resonance imaging, 3D black blood technology, Computed tomography angiography, Carotid artery stenosis, Carotid ulcerative plaques

1. INTRODUCTION

Carotid atherosclerosis is one of high-risk factors for the development of ischemic stroke. Clinical reports show that about 30% to 50% of ischemic strokes are caused by carotid artery stenosis, rupture and other lesions, and that the degree and stability of carotid artery stenosis is a key factor in the occurrence of ischemic stroke events.[1] Therefore, monitoring the degree of carotid artery stenosis and the plaque characteristics is important for the prediction of ischemic stroke. Digital subtraction angiography (DSA) is the gold standard for the diagnosis of vascular disease, but clinical application is limited by the invasive nature of DSA. Currently, ultrasound technology is mainly used in the early lesion screening, but it has a high rate of underdiagnosis in patients with mild stenosis.[2] CT angiography (CTA) for carotid artery lesions has multiple advantages such as wide field of view and high resolution, but its sensitivity for the diagnosis of ulcerated plaques is low.[3,4] In recent years, studies have shown[5,6] that high-resolution magnetic resonance imaging (MRI) 3D black blood technology has gradually highlighted its advantages in the identification and assessment of the degree and stability of carotid artery stenosis, and the load and compositional characteristics of atherosclerotic plaques can be observed more clearly. Currently, there are few clinical comparative reports on the diagnostic value of high-resolution MRI 3D black blood technology and CTA for plaque characterization in patients with carotid artery stenosis. In view of this fact, this study compares the diagnostic value of high-resolution MRI 3D black blood technology and CTA in the plaque characterization of carotid artery stenosis by examining 68 patients admitted to our hospital with a clinically diagnosis of suspected carotid artery stenosis with plaques.

2. DATA AND METHODS

2.1 Clinical data

Sixty-eight patients with clinically diagnosis of suspected carotid artery stenosis with plaques admitted to our Department of Neurology in a tertiary hospital from January 2020 to December 2020 were selected, of which 44 were male and 24 were female, aged 31-80, with a mean of (69.37 $\pm$ 10.21) years old, with the following comorbidities: 35 cases of hypertension, 16 cases of diabetes mellitus, 15 cases of hyperlipidaemia, 28 cases of transient ischemic attack, 48 cases of lacunar cerebral infarction, and 11 cases of massive cerebral infarction. The study was approved and consented by Ethics Committee of our hospital.

Inclusion criteria were as follows: patients who were clinically diagnosed as suspected carotid artery stenosis with unilateral or bilateral carotid artery plaques or the maximum wall thickness > 1.5 mm by color Doppler ultrasonography;[7] patients who underwent high-resolution MRI 3D black blood and CTA examinations, and the interval between the two examinations was less than 1 month; patients who underwent DSA examination to obtain a definite diagnosis; patient with signed informed consent.

Exclusion criteria were as follows: patients who could not cooperate with the examinations; patients with MRI contraindications; patients with a medical history of carotid endarterectomy; patients with a medical history of cerebral or carotid artery intervention; patients with a medical history of radiation therapy to the cervical part; patients with arrhythmia, atrial fibrillation and other diseases that may induce cardiogenic stroke; patients with congenital anatomical abnormalities of the carotid arteries; patients with allergic reaction to contrast agents.

2.2 CTA examination method

GE Bright speed 16-slice spiral CT scan was used. Patients were kept in the supine position, keeping the mandibular branch perpendicular to the horizontal plane, the scanning scope was confirmed in the cervical lateral localization film: the 6^{th} to 7^{th} cervical cones up to the skull base. (1) Conventional spiral CT plain scan, 120 kV, 180 mA, slice thickness 5 mm, no reconstruction interval. (2) Spiral CT enhancement scan, 120 kV, 280 mA, matrix 512 $\times$ 512. (3) Carotid CTA scanning was performed by intravenous injection of 80-100 mL iohexol at a rate of 3.0 mL/s with a delay of 15 s after completion of the injection. The images were transferred to the post-processing ADW4.3 workstation for multi-angle analysis of carotid artery stenosis or plaques by volume rendering, multiplanar reformation, curved planar reformation, and shaded surface display.

2.3 High-resolution MRI 3D black blood examination method

Philips Intera Achieva 3.0 TX superconducting magnetic resonance scanner with an 8-channel carotid phased array surface coil was used. The scanning range was as follows: the carotid bifurcation location was acquired by time-of-flight (TOF) method, covering 2 cm above and below the bifurcation point as the scanning range. Scanning parameters were as follows: the sequential coronal scanning with improved motion sensitized driven equilibrium (iMSDE) over a scanning range of 6° inversion angle, TR 9.2 ms, TE 4.3 ms, echo train length (ETL) 12, NEX 1, fat suppression by spectral attenuated inversion recovery (SPAIR), coverage length 15 cm, matrix 512 $\times$ 512, minimum resolution 0.28 mm $\times$ 0.28 mm. Using the region of interest as a reference, with a 0.1 mm variation from the corresponding slice of the reconstructed image, the images were transferred to a post-processing workstation (GE Healthcare, Milwaukee) for standard axial reconstruction of the original images.

2.4 Image analysis

MRI and CTA images were read independently and double-blinded by two senior imaging physicians with rich experience in the diagnosis of vascular diseases, and when there was a difference in opinion, a third senior imaging reader was added and a consensus was reached through discussion. Image quality evaluation was as follows:[8] Grade I: the inner and outer walls of the arteries could not be determined; Grade II: the structure of the arterial wall was visible, but the border was partially unclear; Grade III: the structure of the arterial wall was clear, but partially unclear; Grade IV: both the structure and the contour of the arterial wall were clearly recognizable; those with an image quality of ≤ 2 points were excluded. The evaluation area was $\pm$ 5 cm from the carotid bifurcation, and the narrowest point was selected for evaluation.

2.5 Evaluation indexes

(1) Quantitative index measurements: the carotid bifurcation level and its upper and lower levels were determined, and the two images were matched and calibrated with DSA to quantitatively measure the lumen area, wall area, and the external area of the wall.

(2) The calculation of stenosis rate: the stenosis rate was assessed according to the criteria of the North American Symptomatic Carotid Endarterectomy Trial (NASCET,[9] i.e., (normal vessel diameter distal to the stenosis - narrowest diameter at the stenosis)/normal vessel diameter distal to the stenosis $\times$ 100%.

(3) Ulcerative plaques:[10] High-resolution MRI 3D black blood examination showed the disruption of continuity on the plaque surface and the maximum diameter of depressions was more than 1 mm; CTA showed the diffusion of contrast agents outside the vasculature and into the periphery of the plaque tissues, with niches on the volume redering (VR) image; and DSA showed well-defined protrusions or niches in the inner wall of the vessel.

2.6 Statistical analysis

SPSS13.0 software was used to analyze the statistical difference. "$\bar{x} \pm$ s" indicated the measurement data that fitted to normal distribution with t-test applied; the number of cases or "%" indicated the categorical data, and the difference $p < .05$ was statistically significant.

3. Results

3.1 Examination results on basis of the gold standard

Taking up DSA as the gold standard, of the 68 patients, 10 had unilateral lesions, 58 had bilateral lesions, and 3 were excluded because the image quality of the high-resolution MRI 3D black blood examination was no more than 2 points, for a total of 123 carotid lesions included.

3.2 Quantitative measurements of high-resolution MRI 3D black blood and CTA

The lumen area, wall area and external area of the wall measured by high-resolution MRI 3D black blood and CTA showed no statistically significant differences ($p > .05$), as shown in Table 1.

Table 1. Quantitative measurements of high-resolution MRI 3D black blood and CTA ($\bar{x}\pm$s, n = 123, mm^2)

Examination Methods	MRI 3D Black Blood Technology	CTA Technology	*t* value	*p* value
Lumen area	75.11±22.30	80.26±31.45	1.102	.273
Wall area	61.52±20.71	57.26±21.38	1.180	.240
External area of the wall	92.05±30.24	91.67±29.10	0.075	.941

3.3 Diagnosis of vascular stenosis by high-resolution MRI 3D black blood versus CTA

The rate of luminal stenosis measured by high-resolution MRI 3D black blood and CTA was (65.70 $\pm$ 12.10)% and (65.34 $\pm$ 11.47)%, respectively, and the difference was not statistically significant (t = 0.905, $p > .05$). The DSA-measured luminal stenosis rate was (66.10 $\pm$ 9.24)%, and Pearson's correlation analysis showed a positive correlation between high-resolution MRI 3D black blood, CTA, and DSA-measured luminal stenosis rate (r = 0.961, 0.952, $p < .001$). Taking up DSA as the gold standard, the sensitivity of high-resolution MRI 3D black blood examination for stenosis > 70% according to NASCET criteria was 93.88% (46/49), the specificity was 100.00% (74/74), and the Youden's J statistic was 0.939. The sensitivity of CTA was 91.83% (45/49), the specificity was 93.24% (69/74), and the Youden's J statistic was 0.851.

3.4 Diagnosis of ulcerative plaques by high-resolution MRI 3D black blood versus CTA

High-resolution MRI 3D black blood detected 38 cases of ulcerated plaques, CTA detected 35 cases of ulcerated plaques, and DSA detected 33 cases. Taking up DSA as the gold standard, the sensitivity, specificity and the Youden's J statistic of high-resolution MRI 3D black blood for diagnosing ulcerated plaques were 100.00% (33/33), 91.44% (85/90) and 0.914, respectively, while the sensitivity, specificity and the Youden's J statistic of CTA for diagnosing ulcerated plaques were 78.79% (26/33), 90.00% (81/90) and 0.688, respectively.

4. DISCUSSION

With the aging in our country, the incidence of cardiovascular and cerebrovascular diseases, especially ischemic cerebrovascular diseases, has been increasing by year, and become an important disease threatening people's health. Carotid artery stenosis is one of the major factors causing ischemic stroke. In recent years, studies have shown[11, 12] that patients with carotid artery stenosis > 50% do not necessarily suffer from cerebral ischemic events, whereas some patients with carotid artery stenosis of less than 50% experience cerebral infarction, and the evidence suggests that the cause of the induced cerebral ischemic events is the rupture of the atherosclerotic plaque. Therefore, it is equally important to assess the degree of carotid atherosclerotic stenosis and the characteristics of the plaque. Ultrasound is often used for the early screening of carotid artery stenosis and atherosclerotic plaques, but the sensitivity and specificity still need to be improved.[13] There is an urgent need to find more effective non-invasive examination methods. Therefore, it is important to explore the value of the high-resolution MRI 3D black blood technology in assessing the degree of carotid atherosclerotic stenosis and plaque characteristics.

3.0 T high field strength magnetic resonator and surface phase-control coil were applied to high-resolution MRI applying 3.0 T high field strength magnetic resonator and surface phase-control coil, its signal-to-noise ratio and resolution have been improved.[14] The high-resolution MRI 3D black blood technology was applied to this study effectively, suppressing the high signal of perivascular fat tissues; At the same time, the preparatory pulse of this technology can better immunize the magnetic field unevenness and signal attenuation phenomenon, so the image quality can be further improved, thus displaying the morphological characteristics of the plaque more clearly.[15] There were a total of 126 diseased vessels in 68 patients in this study, and 2 were excluded due to the image quality, with a pass rate of 97.62% and high image quality.

There was no difference in the comparison of lumen area, wall area, and external area of the wall between high-resolution MRI 3D black-blood and CTA in this study, suggesting that 3D black-blood technology, with image post-processing technology applied, has a comparable accuracy to CTA for vessel measurements and can accurately determine the inner and outer diameters of diseased vessels. Al-Smadi et al.[16] used the high-resolution MRI 3D black blood technology for the assessment of intracranial large artery occlusion and found it to be accurate and reliable for intracranial large artery occlusion. Pearson's correlation analysis in this study showed that the luminal stenosis rates measured by high-resolution MRI 3D black blood and CTA were strongly and positively correlated with the gold standard DSA, with correlation coefficients of 0.961 and 0.952, respectively, and that the sensitivity, specificity, and Youden's J statistic of high-resolution MRI 3D black blood examination for stenosis > 70% of the vessels were 93.88%, 100.00%, and 0.939, respectively, and 91.83%, 93.24% and 0.851 for CTA examination, respectively, suggesting that high-resolution MRI 3D black blood technology has a high diagnostic value for the degree of carotid artery stenosis, and there is no underdiagnosis for severe stenosis. The degree of stenosis in three carotid arteries was underestimated in the present study, probably due to the high-resolution MRI 3D black blood technology with few scanning slices and large reference diameters coupled with pulsation artifacts, which led to underdiagnosis.[17]

In this study, taking up DSA as the gold standard, the sensitivity, specificity and Youden's J statistic of the high-resolution MRI 3D black blood technology for diagnosing ulcerative plaques were 100.00%, 91.44% and 0.914, respectively, and the CTA was 78.79%, 90.00%, and 0.688, respectively, which suggests that the high-resolution MRI 3D black blood technology has a high diagnostic value for ulcerative plaques, with the lower risk of underdiagnosed and misdiagnosed cases. Five of the 38 cases of ulcerative plaques detected by the high-resolution MRI 3D black blood technology were misdiagnosed, and the reason for this analysis may have been misclassification due to the appearance of low signal on the calcified surface of the plaque. Ulcerative plaques are complex, high-resolution MRI 3D black blood technology can obtain high-quality sonograms with the observation of any scanning surfaces and image reconstruction, in order to acquire a holistic view of the plaques and the arterial wall, and it is easier to detect irregular plaques and slightly ruptured plaques.[18, 19] In addition, the high-resolution MRI 3D black blood technology obtains a good signal contrast of the arterial wall by suppressing the luminal blood flow signal and fat signal, which provides a more accurate determination of the nature of plaque load, fibrous cap, inflammation, etc.[20]

As shown in summary, both high-resolution MRI 3D black blood technology and CTA have a high diagnostic value for carotid artery stenosis, but high-resolution MRI 3D black blood technology has a higher diagnostic value for ulcerative plaques, and it can be used as an adjunct to DSA to provide a more reliable clinical basis for the assessment of plaque characteristics in patients with carotid artery stenosis.

ACKNOWLEDGEMENTS
Not applicable.

AUTHORS CONTRIBUTIONS
Jun Zhang: Concepts, design, rationalization of the formulation of scanning sequences and protocols, interpretation and review of the diagnostic results, data analysis, academic guidance, guarantor, manuscript editing and review;
Changli Liu: Concepts, design, scanning for patients with carotid artery plaques, diagnosis, parameter summary, data acquisition, image data organization, statistical analysis, data interpretation, manuscript preparation, manuscript editing and review;
Shaobin Wang: Screening for patients with carotid artery plaques, providing clinical prevention and treatment for stroke, data acquisition, manuscript editing and review.

FUNDING
Not applicable.

CONFLICTS OF INTEREST DISCLOSURE
The authors declare no conflicts of interest.

INFORMED CONSENT
Obtained.

ETHICS APPROVAL
The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

PROVENANCE AND PEER REVIEW
Not commissioned; externally double-blind peer reviewed.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

DATA SHARING STATEMENT
No additional data are available.

REFERENCES
[1] Dilba K, van Dam-Nolen DHK, van Dijk AC, et al. Plaque Composition as a Predictor of Plaque Ulceration in Carotid Artery Atherosclerosis: The Plaque At Risk Study. AJNR Am J Neuroradiol. 2021; 42(1): 144-151. https://doi.org/10.3174/ajnr.A6868

[2] Ning B, Zhang D, Sui B, et al. Ultrasound imaging of carotid web with atherosclerosis plaque: a case report. J Med Case Rep. 2020; 14(1): 145 https://doi.org/10.1186/s13256-020-02446-1

[3] Baradaran H, Foster T, Harrie P, et al. Carotid artery plaque characteristics: current reporting practices on CT angiography. Neuroradiology. 2021; 63(7): 1013-1018. https://doi.org/10.1007/s00234-020-02610-w

[4] Wu K, Bai M. Study on recognition algorithm for plaque in coronary CTA on the basis of deep residual network. China Medical Equipment. 2019; 16(11): 1-5.

[5] Lu Y, Huang R, Li Y. Comparison of simultaneous non-contrast angiography and intraplaque hemorrhage imaging with conventional black blood technique in the high resolution craniocervical artery imaging. Radiologic Practice. 2019; 34(8): 863-868.

[6] Guggenberger K, Krafft AJ, Ludwig U, et al. High-resolution Compressed-sensing T1 Black-blood MRI: A New Multipurpose Sequence in Vascular Neuroimaging? Clin Neuroradiol. 2021; 31(1): 207-216. https://doi.org/10.1007/s00062-019-00867-0

[7] Chen J. The value of applying color doppier flow imaging to checking carotid artery function changes in hypertensive patients. Journal of Chongqing Medical University. 2009; 34(8): 1130-1132.

[8] Chen Z, Zheng X, Liu B, et al. Image quality evaluation of cervical arterial plaque by peripheral pulse gating and black blood techniques. Chinese Journal of CT and MRI. 2014; 11(1): 54-56.

[9] North American Symptomatic Carotid Endarterectomy Trial. Meth-

ods, patient characteristics, and progress. Stroke. 1991; 22(6): 711-20. https://doi.org/10.1161/01.STR.22.6.711

[10] Cai JM, Hatsukami TS, Ferguson MS, et al. Classification of human carotid atherosclerotic lesions with in vivo multicontrast magnetic resonance imaging. Circulation. 2002; 106(11): 1368-1373. https://doi.org/10.1161/01.CIR.0000028591.44554.F9

[11] Ha SH, Chang JY, Lee SH, et al. Mechanism of Stroke According to the Severity and Location of Atherosclerotic Middle Cerebral Artery Disease. J Stroke Cerebrovasc Dis. 2021; 30(2): 105503. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105503

[12] Roth L, Van der Donckt C, Emini Veseli B, et al. Nitric oxide donor molsidomine favors features of atherosclerotic plaque stability and reduces myocardial infarction in mice. Vascul Pharmacol. 2019; 118-119: 106561. https://doi.org/10.1016/j.vph.2019.05.001

[13] Fedak A, Ciuk K, Urbanik A. Ultrasonography of vulnerable atherosclerotic plaque in the carotid arteries: B-mode imaging. J Ultrason. 2020; 20(81): e135-e145. https://doi.org/10.15557/JoU.2020.0022

[14] Zhu Y, Xiong W, Yin Y. Application value analysis of 3.0T MRI carotid plaque high resolution imaging on patients with IS. Chinese Journal of CT and MRI. 2019; 17(11): 7-9.

[15] Elsheikh S, Urbach H, Meckel S. Contrast Enhancement of Intracranial Aneurysms on 3T 3D Black-Blood MRI and Its Relationship to Aneurysm Recurrence following Endovascular Treatment. AJNR Am J Neuroradiol. 2020; 41(3): 495-500. https://doi.org/10.3174/ajnr.A6440

[16] Al-Smadi AS, Abdalla RN, Elmokadem AH, et al. Diagnostic Accuracy of High-Resolution Black-Blood MRI in the Evaluation of Intracranial Large-Vessel Arterial Occlusions. AJNR Am J Neuroradiol. 2019; 40(6): 954-959. https://doi.org/10.3174/ajnr.A6065

[17] Gang M, Lee H, Kwak HS, et al. Strong enhancement on three-dimensional black-blood enhanced magnetic resonance imaging: Comparison intracranial stenosis and complete occlusion. Eur J Radiol. 2021; 137: 109580. https://doi.org/10.1016/j.ejrad.2021.109580

[18] Cho SJ, Jung SC, Suh CH, et al. High-resolution magnetic resonance imaging of intracranial vessel walls: Comparison of 3D T1-weighted turbo spin echo with or without DANTE or iMSDE. PLoS One. 2019; 14(8): e0220603. https://doi.org/10.1371/journal.pone.0220603

[19] Wei H, Zhang M, Li Y, et al. Evaluation of 3D multi-contrast carotid vessel wall MRI: a comparative study. Quant Imaging Med Surg. 2020; 10(1): 269-282. https://doi.org/10.21037/qims.2019.09.11

[20] Zhao L, Dong L, Shen Q, et al. Study on the inflammatory response of early atherosclerosis by black blood dynamic enhanced MR technique. Journal of Cardiovascular and Pulmonary Diseases. 2019; 38(8): 874-878, 892.