Int. J. Morphol.,
40(5):1344-1348, 2022.

Evaluation of Three-Dimensional High-Resolution Magnetic Resonance Imaging in the Diagnosis of Intracranial Atherosclerotic Stenosis

Evaluación de Resonancia Magnética Tridimensional de Alta Resolución en el Diagnóstico de la Estenosis Aterosclerótica Intracraneal

Yu-Fei Cheng[1]; Chen Chen[2]; Hong Liu[2] & Jiang Wu[2]

CHENG, Y. F.; CHEN, C.; LIU, H. & WU, J. Evaluation of three-dimensional high-resolution magnetic resonance imaging in the diagnosis of intracranial atherosclerotic stenosis. *Int. J. Morphol., 40(5)*:1344-1348, 2022.

SUMMARY: Intracranial artery stenosis (ICAS) was one of the main causes of ischemic stroke onset and recurrence. About 30 % of strokes were caused by intracranial artery stenosis. Intracranial artery stenosis had a high incidence in China and faced a high risk of recurrence for a long time. It affected patient safety and quality of life seriously. At the same time, it caused a heavy financial burden for the patient´s family. Therefore, early detection and accuracy of intracranial artery stenosis evaluation were extremely important. High-resolution magnetic resonance imaging (HR-MRI) had been widely used in clinical examinations, making up for the shortcomings of traditional vascular imaging methods that could only show the degree of luminal stenosis, making it possible to perform lumens, tube wall and plaque features of atherosclerotic intracranial arteries at the same time. There were still some controversies about the credibility of this technique in assessing the intracranial artery lumen stenosis. This article reviewed the application efficacy of HR-MRI technology in evaluating the degree of intracranial atherosclerotic stenosis.

KEY WORDS: High-resolution magnetic resonance imaging; Atherosclerosis; Stroke; Intracranial artery stenosis.

INTRODUCTION

The incidence of stroke in China had exceeded 379 per 100,000, ranking first in the world. About 1.9 million people die from stroke each year. Stroke featured with high mortality, incidence and disability had surpassed tumors and coronary heart disease, becoming the first cause of death among Chinese residents (Wang *et al*., 2020a). Ischemic stroke was the most common type of stroke, accounting for about 60 %-80 % of all strokes. Intracranial artery stenosis played an important role in the occurrence and development of ischemic stroke and was also an independent risk factor for recurrence. With the increasing severity of vascular stenosis, the chance of vascular occlusion and incidence of stroke enhanced. Thus, early detection of stenosis and judgment of stenosis were essential to reduce the incidence of ischemic stroke which was also the most clinically concerned issue at the moment.

Technical overview of high-resolution magnetic resonance imaging (HR-MRI). HR-MRI was a vascular black blood assessment technology developed in recent years. It was a safe, non-invasive, economical and reproducible inspection method with good *in vivo* and *in vitro* consistency. "Black blood" technology, also known as pre-saturation technology, used saturated radio frequency pulses to suppress the blood flow signal in the lumen, and the blood was pre-saturated to produce low signals, which could better observe the vascular plaques (Shuqiang *et al*., 2019). It used a small FOV and a large matrix to achieve a millimeter-level spatial resolution. HR-MRI usually provided a resolution of less than 1 mm, while allowing various multi-contrast imaging techniques, including T1 weighted imaging, T2 weighted imaging, proton density imaging, contrast-enhanced T1 weighted imaging and

[1] Shanxi Medical University, Taiyuan, China.
[2] Shanxi Cardiovascular Hospital Affiliated to Shanxi Medical University, Taiyuan, China.
This work was financially supported by the Applied Basic Research Program of Shanxi Province (201601D011098); Major Disease Risk Assessment Project of Shanxi Medical University (ZDJB201901); Scientific Research Incentive Fund of Shanxi Cardiovascular Hospital(XYS20170205); Health Science Popularization Project of Shanxi Science and Technology Association and Doctoral Research Fund of Shanxi Cardiovascular Hospital, Four «Batches» Innovation Project of Invigorating Medical through Science and Technology of Shanxi Province (2022XM07).

Received: 2022-06-20 Accepted: 2022-06-25

magnetic sensitivity weighted (Dieleman *et al*., 2014). Hence, HR-MRI could show the structure of the arterial wall, the lumen and the wall of the blood vessel, and the shape, length and wall condition of the occluded blood vessel clearly, which effectively complemented the shortcomings of traditional imaging techniques. At present, a multi-sequence method was often adopted when using HR-MRI to identify intracranial artery stenosis to improve the detection rate of stenosis, and the application of HR-MRI in the field of extracranial carotid artery was relatively mature.

Clinical application of HR-MRI technology

The value of HR-MRI in intracranial atherosclerotic stenosis. In recent years, a host of studies had shown that HR-MRI could assess the vascular wall of the intracranial atherosclerotic stenosis, identify vulnerable plaques, provide information on the occurrence of the ischemic cerebrovascular events in the future, and be of great help in preventing stroke. In clinical practice, digital subtraction angiography (DSA), CT angiography (CTA) and other measurement methods were commonly used to compare in order to clarify the clinical reliability of HR-MRI in measuring lumen stenosis. Klein *et al*. (2005) demonstrated that HR-MRI was better than TOF-MRA in measuring the middle cerebral artery stenosis, and the plaque could be displayed more clearly, but there were fewer samples, only 6 cases. Subsequently, Kim(Y. S. Kim *et al*., 2012) confirmed similar conclusions when measuring the basilar artery plaque. He insisted that the measurement results of the two methods of HR-MRI and TOF-MRA had a strong correlation and the difference between HR-MRI and MRA was more obvious especially in the measurement of mild stenosis. Accordingly the prominent advantage of HR-MRI in judging intracranial stenosis was that it could non-invasively display the structure of the tube wall and the plaque composition *in vivo*. Compared HR-MRI, TOF-MRA, and CE-MA with the gold standard DSA, the results showed that HR-MRI and DSA had strong correlation between the measurement of intracranial artery stenosis, which was consistent with other research results (Jun *et al*., 2017; Dengling *et al*., 2021). As the scanning sequence, the resolution and the signal-to-noise ratio of the 3D HR-MRI developed, its advantages in clinical research and tube wall imaging applications were more prominent (Kim *et al*., 2020). HR-MRI as a new imaging method had certain value in the diagnosis of middle cerebral artery stenosis (Lin *et al*., 2021), it could evaluate narrow tube walls and plaques and had good consistency with DSA diagnosis. Subsequently, the comparative study of HR-MRI with DSA as the gold standard and CTA as the reference to assess the degree of MCA stenosis gradually attracted attention. The study suggested that high-resolution HR-MRI could measure the degree of stenosis accurately (Figs.1 and 2) and was more sensitive than CTA in high-risk, symptomatic patient samples. The sensitivity and specificity of HR-MRI in evaluating MCA moderate to severe stenosis (50 %~99 %) and occlusive lesions were higher than CTA, and there was also a good correlation between HR-MRI and DSA measurement results (Liu *et al*., 2013). At present, DSA was still considered as the "gold standard" for evaluating the middle cerebral artery stenosis, but it had a certain high risk and traumatic nature. It was recommended to use it as the final diagnosis or interventional treatment, not preliminary diagnosis.

The reliability and reproducibility of HR-MRI in the examination of intracranial atherosclerotic. The prerequisite for the stability of HR-MRI assessment to obtain accurate results was the basis for the wide application of this technology in clinical practice. Compared with DSA, HR-MRI quantified the intracranial artery stenosis with accuracy and repeatability, and it could detect more non-stenotic plaques (Tian *et al*., 2021). When examining 12 major arteries including the entire circle of Willis, HR-MRI

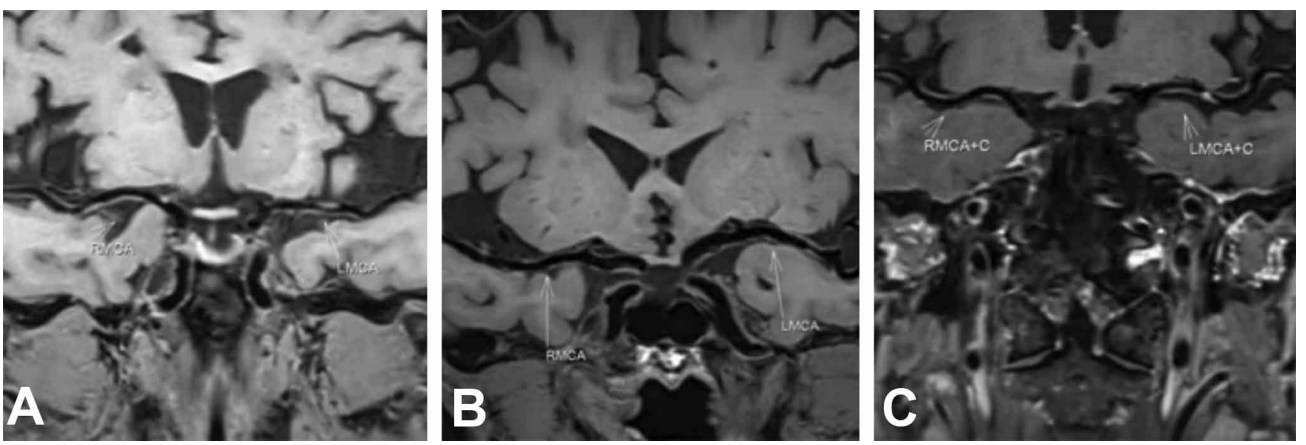

Fig. 1. Different degrees of intracranial arterial stenosis identified by HR-MRI. A -Mild stenosis of middle cerebral artery by HR-MRI; B-Moderate stenosis of middle cerebral artery by HR-MRI; C- Severe stenosis of middle cerebral artery by HR-MRI.

showed better diagnostic accuracy, diagnostic sensitivity and reliability than DSA, and It could advance the diagnostic performance of non-stenotic intracranial atherosclerosis (Park *et al*., 2017). This may be due to the fact that HR-MRI was more sensitive than luminal imaging methods (such as MRA, CTA or DSA) in detecting changes in intracranial large arteriosclerosis (Kim *et al*., 2012). HR-MRI may be used as a supplement to conventional methods to assess the atherosclerotic burden of the entire circle of Willis. The repeatability of HR-MRI in the study of atherosclerotic plaque in the brain indicated that there was a excellent consistency between intra observer and inter observer on the irregularity of plaque surface and bleeding in plaque, and the total repeatability was almost excellent for the identification of plaque position (Fig. 3). In addition, the intra-observer and inter-observer reproducibility was good for the measurement of the blood vessel area and lumen area of the reference site (Yang *et al*., 2014; Zhao *et al*., 2019). The reproducibility study of HR-MRI examination presented that the evaluation of plaque enhancement level within and between observers had a high consistency (Kappa>0.75). Moreover, the reproducibility of HR-MRI evaluation of intracranial atherosclerotic plaque enhancement was good, and plaque enhancement was more common in responsible plaques which may be an important risk factor for ischemic stroke (Xueqin *et al*., 2018). There were also other research suggested that the recurrence of ischemic stroke was related to higher plaque burden (Ran *et al*., 2020). HR-MRI could provide plaque characteristic information because of its good repeatability and credibility visualization, and could be used as a reliable method to evaluate the intracranial atherosclerotic stenosis comprehensively.

Evaluation of HR-MRI to identify plaque. Atherosclerotic plaques consisted of a fibrous cap and a lipid necrotic core that formed a hypoxic microenvironment and stimulates angiogenesis (Guo *et al*., 2018). In the process of atherosclerosis, some plaques were easy to fall off and blocked blood vessels in a short time. Such plaques were called vulnerable plaques. The distribution of atherosclerotic plaque played a crucial role in the occurrence of cerebral ischemic events (Ryu *et al*., 2014). Plaque location distribution had unique characteristics and was related to clinical symptoms. Atherosclerotic plaques were mainly located in the dorsal and lateral walls in symptomatic patients, and plaques in asymptomatic patients may be located in the abdominal wall (Yu *et al*., 2017). Studies had shown that the distribution of plaque tissue in the blood vessel could affect the distal branches. If plaque existed at this location, the detachment of the plaque could cause the risk of blockage, and traditional imaging cannot determine the relationship between the plaque and the opening of the perforating artery (Jia *et al*., 2015).On the contrary, HR-MRI could not only visualize the components of intracranial atherosclerosis, but also determine the opening of branch vessels, clarify the relationship between plaque and arterial opening, and provide more comprehensive plaque characteristics for clinical diagnosis and treatment (Wang *et al*., 2014). Hence, HR-MRI was considered to be an ideal tool for evaluating plaque characteristics and displaying plaque morphology, which could provide a reference for the clinical diagnosis and treatment of intracranial atherosclerosis. HR-MRI had important value in evaluating the distribution and thickness of intracranial atherosclerotic plaque, and could measure the risk of cerebral infarction in patients with intracranial atherosclerosis to a certain extent (Zhiqiang *et al*., 2020).

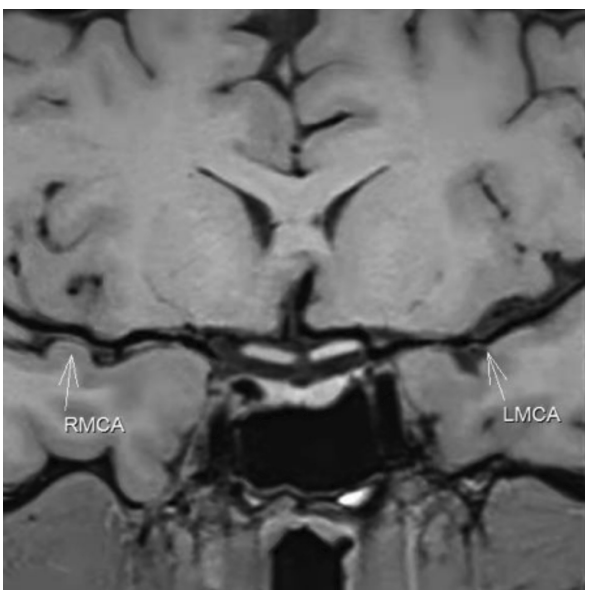

Fig. 2. Severe stenosis of left middle cerebral artery and moderate stenosis of right middle cerebral artery by HR-MRI

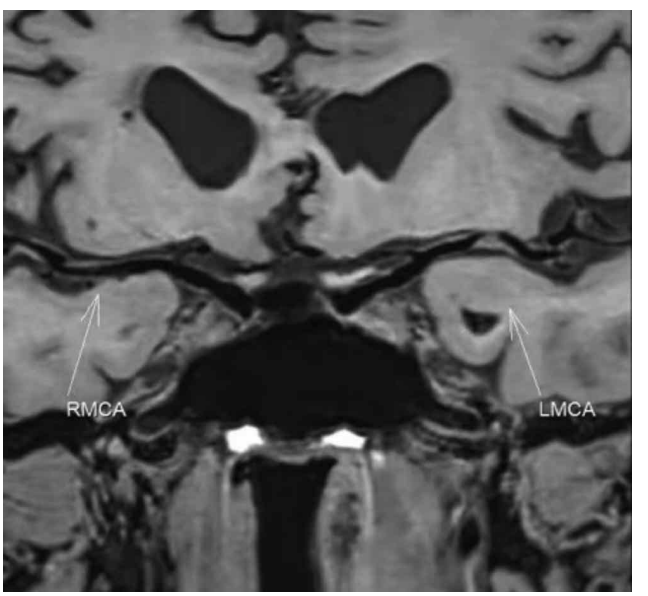

Fig. 3. Atherosclerotic plaque in the Middle cerebral artery by HR-MRI

Diagnosis and identification. The treatment plan and secondary prevention of ischemic stroke were closely related to the classification of the cause, and the treatment of the cause directly affected the prognosis. Therefore, accurate diagnosis and identification of the cause were extremely important. Moyamoya's disease (MMD) was a rare cerebrovascular disease that was characterized by progressive stenosis and occlusion of the main artery of the brain, accompanied by the development of collateral branches called moyamoya disease (Wang *et al*., 2020b). However, MRA, CTA, and DSA examinations of smoke vessels were not typical, and could easily be confused with the diagnosis of intracranial atherosclerotic stenosis (Jiang *et al*., 2013). Especially young patients with risk factors for atherosclerosis, whose cerebral angiography shows the typical features of MMD, it is not easy to distinguish MMD from moyamoya disease-like arterial diseases such as ICAD. Studies have presented that the HR-MRI imaging characteristics of MMD and ICAD were different. The characteristics of the vascular wall of MMD stenosis: uniform signal intensity, concentric thickening, irregular narrowing of the lumen and significant reduction of outer diameter, and the stenosis pattern of IAS was prone to more eccentricity and heterogeneous wall thickening. HR-MRI could clarify the vascular wall imaging results of different causes of intracranial artery stenosis, helped distinguish MMD from other intracranial artery stenosis occlusive diseases, especially ICAD, and evaluate the pathological changes of the vessel wall (Yu *et al*., 2015; Ya *et al*., 2020). Kim *et al*. (2013) also drew similar conclusions, but the sample size was small, and larger longitudinal prospective studies involving histopathological analysis were needed in the future. High-resolution magnetic resonance imaging may help to further classify smoke vessels (Wu *et al*., 2021). At present, the gold standard for diagnosing moyamoya disease was DSA, but DSA still has several limitations. DSA cannot fully display the condition of the vessel wall, and the accuracy of the diagnosis of vascular stenosis will be reduced. HR-MRI was of great significance in displaying the structure of the intracranial artery wall and identifying the cause of arterial stenosis (Turan *et al*., 2014), which provided a plan for clinicians to determine, diagnose and treat diseases, and also helped improve the prognosis of patients.

CONCLUSIONS

In summary, HR-MRI had marvelous reliability and repeatability in the diagnosis of intracranial atherosclerotic stenosis. It could help the diagnosis and differential diagnosis of the cause of stroke quickly according to the information of intracranial artery wall provided by HR-MRI which clinical value had remarkable values. HR-MRI vascular wall imaging had the advantages of high reproducibility and non-invasiveness, making it the first choice for accurate assessment of intracranial artery stenosis, which was helpful for accurate stroke classification and guided stroke treatment and prognostic evaluation although HR-MRI still has certain shortcomings.

CHENG, Y. F.; CHEN, C.; LIU, H. & WU, J. Evaluación de la resonancia magnética tridimensional de alta resolución en el diagnóstico de la estenosis aterosclerótica intracraneal. *Int. J. Morphol., 40(5)*:1344-1348, 2022.

RESUMEN: La estenosis de arterias intracraneales (ICAS) es una de las principales causas del ictus isquémico, como así también de su recurrencia. Alrededor del 30 % de los ataques cerebrovasculares son causados por estenosis de la arteria intracraneal. La estenosis de arterias intracraneales tiene una alta incidencia en China y enfrenta un alto riesgo de recurrencia, afectando gravemente la seguridad y la calidad de vida de los pacientes. Al mismo tiempo, supone una importante carga financiera para la familia de los pacientes. Por lo tanto, la detección temprana y la precisión de la evaluación de la estenosis de arterias intracraneales es extremadamente importante. La resonancia magnética de alta resolución (HR-MRI, por sus siglas en inglés) es utilizada ampliamente en los exámenes clínicos, compensando las deficiencias de los métodos tradicionales de imágenes vasculares que solo pueden mostrar el grado de estenosis luminal, haciendo posible el estudio de las características del lumen, pared vascular y la placa ateroesclerótica, de las arterias intracraneales afectadas, al mismo tiempo. Aún existen algunas controversias sobre la credibilidad de esta técnica en la evaluación de la estenosis del lumen de arterias intracraneales. En este artículo se revisó la eficacia de la aplicación de la tecnología HR-MRI para evaluar el grado de estenosis aterosclerótica intracraneal.

PALABRAS CLAVE: Resonancia magnética de alta resolución; Aterosclerosis; Ataque cerebrovascular; Estenosis de arterias intracraniales.

REFERENCES

Dengling, Z.; Cheng, L.; Xiaohui, C.; Yi, Z.; Ziwei, D. & Shenghong, J. Evaluation of stenotic degree for intracranial atherosclerotic artery with 3D high resolution MRI. *J. Clin. Radiol., 40(4)*:664-9, 2021.

Dieleman, N.; van der Kolk, A. G.; Zwanenburg, J. J.; Harteveld, A. A.; Biessels, G. J.; Luijten, P. R. & Hendrikse, J. Imaging intracranial vessel wall pathology with magnetic resonance imaging: current prospects and future directions. *Circulation, 130(2)*:192-201, 2014.

Guo, L.; Akahori, H.; Harari, E.; Smith, S. L.; Polavarapu, R.; Karmali, V.; Otsuka, F.; Gannon, R. L.; Braumann, R. E.; Dickinson, M. H.; *et al*. CD163+ macrophages promote angiogenesis and vascular permeability accompanied by inflammation in atherosclerosis. *J. Clin. Invest., 128(3)*:1106-24, 2018.

Jia, Z. J.; Zhao, R.; Yang, Z. G.; Huang, Q. H.; Deng, X. Q.; Hong, B. & Liu, J. M. Intracranial atherosclerotic middle cerebral arterial stenosis research based on 3.0 Tesla high-resolution magnetic resonance imaging: recent progres]. *Nan Fang Yi Ke Da Xue Xue Bao, 35(1)*:154-9, 2015.

Jiang, T.; Perry, A.; Dacey Jr., R. G.; Zipfel, G. J. & Derdeyn, C. P. Intracranial atherosclerotic disease associated with moyamoya collateral formation: histopathological findings. *J. Neurosurg., 118(5)*:1030-4, 2013.

Jun, H.; Fuqiang, G.; Shiyue, C. & Qi, L. Comparison of 3.0T high-resolution MRI and DSA of middle cerebral artery atherosclerotic stenosis. *J. China Clin. Med. Imaging, 25(8)*:551-4, 2014.

Kim, D. K.; Verdoorn, J. T.; Gunderson, T. M.; Huston Iii, J.; Brinjikji, W.; Lanzino, G. & Lehman, V. T. Comparison of non-contrast vessel wall imaging and 3-D time-of-flight MRA for atherosclerotic stenosis and plaque characterization within intracranial arteries. *J. Neuroradiol., 47(4)*:266-71, 2020.

Kim, Y. J.; Lee, D. H.; Kwon, J. Y.; Kang, D. W.; Suh, D. C.; Kim, J. S. & Kwon, S. U. High resolution MRI difference between moyamoya disease and intracranial atherosclerosis. *Eur. J. Neurol., 20(9)*:1311-8, 2013.

Kim, Y. S.; Lim, S. H.; Oh, K. W.; Kim, J. Y.; Koh, S. H.; Kim, J.; Heo, S. H.; Chang, D. I.; Lee, Y. J. & Kim, H. Y. The advantage of high-resolution MRI in evaluating basilar plaques: a comparison study with MRA. *Atherosclerosis, 224(2)*:411-6, 2012.

Klein, I. F.; Lavallée, P. C.; Schouman-Claeys, E. & Amarenco, P. High-resolution MRI identifies basilar artery plaques in paramedian pontine infarct. *Neurology, 64(3)*:551-2, 2005.

Lin, G. H.; Song, J. X.; Fu, N. X.; Huang, X. & Lu, H. X. Quantitative and qualitative analysis of atherosclerotic stenosis in the middle cerebral artery using high-resolution magnetic resonance imaging. *Can. Assoc. Radiol. J., 72(4)*:783-8, 2021.

Liu, Q.; Huang, J.; Degnan, A. J.; Chen, S.; Gillard, J. H.; Teng, Z. & Lu, J. Comparison of high-resolution MRI with CT angiography and digital subtraction angiography for the evaluation of middle cerebral artery atherosclerotic steno-occlusive disease. *Int. J. Cardiovasc. Imaging, 29(7)*:1491-8, 2013.

Park, J. E.; Jung, S. C.; Lee, S. H.; Jeon, J. Y.; Lee, J. Y.; Kim, H. S.; Choi, C. G.; Kim, S. J.; Lee, D. H.; Kim, S. O.; *et al*. Comparison of 3D magnetic resonance imaging and digital subtraction angiography for intracranial artery stenosis. *Eur. Radiol., 27(11)*:4737-46, 2017.

Ran, Y.; Wang, Y.; Zhu, M.; Wu, X.; Malhotra, A.; Lei, X.; Zhang, F.; Wang, X.; Xie, S.; Zhou, J.; *et al*. Higher plaque burden of middle cerebral artery is associated with recurrent ischemic stroke: a quantitative magnetic resonance imaging study. *Stroke, 51(2)*:659-62, 2020.

Ryu, C. W.; Kwak, H. S.; Jahng, G. H. & Lee, H. N. High-resolution MRI of intracranial atherosclerotic disease. *Neurointervention, 9(1)*:9-20, 2014.

Shuqiang, L.; Jiquan, Z.; Kanrong, Y.; Lixian, C. & Xiaoyi, F. Progress in the application of high resolution magnetic resonance imaging in atheromatous plaques. *Hainan Med. J., 30(12)*:1596-9, 2019.

Tian, X.; Tian, B.; Shi, Z.; Wu, X.; Peng, W.; Zhang, X.; Malhotra, A.; Mossa-Basha, M.; Sekhar, L.; Liu, Q.; *et al*. Assessment of intracranial atherosclerotic plaques using 3D black-blood MRI: comparison with 3D time-of-flight MRA and DSA. *J. Magn. Reson. Imaging, 53(2)*:469-78, 2021.

Turan, T. N.; Rumboldt, Z.; Granholm, A. C.; Columbo, L.; Welsh, C. T.; Lopes-Virella, M. F.; Spampinato, M. V. & Brown, T. R. Intracranial atherosclerosis: correlation between in-vivo 3T high resolution MRI and pathology. *Atherosclerosis, 237(2)*:460-3, 2014.

Wang, X.; Wang, Y.; Nie, F.; Li, Q.; Zhang, K.; Liu, M.; Zeng, F.; Shang, M.; Liang, M.; Yang, Y.; *et al*. Association of genetic variants with Moyamoya disease in 13 000 individuals: a meta-analysis. *Stroke, 51(6)*:1647-55, 2020b.

Wang, Y. J.; Li, Z. X.; Gu, H. Q.; Zhai, Y.; Jiang, Y.; Zhao, X. Q.; Wang, Y. L.; Yang, X.; Wang, C. J.; Meng, X.; *et al*. China Stroke Statistics 2019: A Report From the National Center for Healthcare Quality Management in Neurological Diseases, China National Clinical Research Center for Neurological Diseases, the Chinese Stroke Association, National Center for Chronic and Non-communicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention and Institute for Global Neuroscience and Stroke Collaborations. *Stroke Vasc. Neurol., 5(3)*:211-39, 2020a.

Wang, Y.; Lou, X.; Li, Y.; Sui, B.; Sun, S.; Li, C.; Jiang, P.; Siddiqui, A. & Yang, X. Imaging investigation of intracranial arterial dissecting aneurysms by using 3 T high-resolution MRI and DSA: from the interventional neuroradiologists' view. *Acta Neurochir. (Wien), 156(3)*:515-25, 2014.

Wu, F.; Han, C.; Liu, Y.; Liu, Z.; Yang, X.; Wu, Y.; Du, J.; Wu, Y.; Saba, L. & Zhang, Q. Validation of choroidal anastomosis on high-resolution magnetic resonance imaging as an imaging biomarker in hemorrhagic moyamoya disease. *Eur. Radiol., 31(7)*:4548-56, 2021.

Xueqin, B.; Qiuping, L.; Peng, L.; Hao, L.; Haoyu, Z.; Wei, F. & Jiang, L. Intracranial atherosclerotic plaque enhancement associated with ischemic stroke: a study with three-dimensional high-resolution magnetic resonance vessel wall imaging. *Fudan Univ. J. Med. Sci., 45(3)*:341-6, 2018.

Ya, J.; Zhou, D.; Ding, J.; Ding, Y.; Ji, X.; Yang, Q. & Meng, R. High-resolution combined arterial spin labeling MR for identifying cerebral arterial stenosis induced by moyamoya disease or atherosclerosis. *Ann. Transl. Med., 8(4)*:87, 2020.

Yang, W. Q.; Huang, B.; Liu, X. T.; Liu, H. J.; Li, P. J. & Zhu, W. Z. Reproducibility of high-resolution MRI for the middle cerebral artery plaque at 3T. *Eur. J. Radiol., 83(1)*:e49-55, 2014.

Yu, J.; Li, M. L.; Xu, Y. Y.; Wu, S. W.; Lou, M.; Mu, X. T.; Feng, F.; Gao, S. & Xu, W. H. Plaque distribution of low-grade basilar artery atherosclerosis and its clinical relevance. *BMC Neurol., 17(1)*:8, 2017.

Yu, L. B.; Zhang, Q.; Shi, Z. Y.; Wang, M. Q. & Zhang, D. High-resolution Magnetic Resonance Imaging of Moyamoya Disease. *Chin. Med. J., 128(23)*:3231-7, 2015.

Zhao, D. L.; Li, C.; Chen, X. H.; Ju, S.; Deng, G.; Xie, B. & Teng, G. J. Reproducibility of 3.0T High-Resolution Magnetic Resonance Imaging for the Identification and Quantification of Middle Cerebral Arterial Atherosclerotic Plaques. *J. Stroke Cerebrovasc. Dis., 28(7)*:1824-31, 2019.

Zhiqiang, L.; Zhaoxia, Z.; Shanshan, W.; Yafang, W.; & Quan, W. Evaluation of high-resolution MRI on distribution, thickness and stability of intracranial atherosclerosis plaques. *J. Brain Nerv. Dis., 28(9)*:578-82, 2020.

Corresponding author:
Chen Chen
Shanxi Cardiovascular Hospital Affiliated
to Shanxi Medical University
18 Yifen Street
Taiyuan 030024
CHINA

E-mail: 13934161870@163.com