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Comparison of Vertebral Artery Ultrasound, Magnetic Resonance Angiography and Digital Subtraction Angiography in the Diagnosis of Vertebral Artery Stenosis in Patients with Posterior Circulation Ischemia

Comparación de la Ecografía de la Arteria Vertebral, la Angiografía por Resonancia Magnética y la Angiografía por Sustracción Digital en el Diagnóstico de Estenosis de la Arteria Vertebral en Pacientes con Isquemia de la Circulación Posterior

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SUMMARY: The aim of this study was to compare the clinical value of vertebral artery ultrasound (VAU), Magnetic Resonance Angiography (MRA) and Digital Subtraction Angiography (DSA) on vertebral artery stenosis in patients with posterior circulation ischemia. Seventy-three patients with posterior circulation ischemia underwent vertebral artery ultrasound and magnetic resonance angiography as well as digital subtraction angiography, and the diagnosis of vertebral artery stenosis (VAS) and the degree of stenosis (normal, mild stenosis, moderate stenosis, severe stenosis, and occlusion) were recorded and compared between digital subtraction angiogram and vertebral artery ultrasound and magnetic resonance angiography. The vertebral artery stenosis rates on digital subtraction angiography and vertebral artery ultrasound were 87.30 % (55/63) and 49.20 % (31/63), respectively, and the difference was statistically significant. The rates of vertebral artery stenosis on digital subtraction angiography and, magnetic resonance angiography was 90.38 % (47/52) and 88.46 % (46/52), respectively, and the differences was not statistically significant. The sensitivity, accuracy, negative predictive value, and positive predictive value of vertebral artery ultrasound in diagnosing vertebral artery stenosis were 51.35 %, 54.76 %, 18.18 %, and 95.00 %, respectively, lower than those of magnetic resonance angiography, which were 91.89 %, 90.48 %, 57.14 %, and 97.14 %, respectively. Of the noninvasive imaging techniques, vertebral artery ultrasound does not accurately characterize vertebral artery stenosis and its degree of stenosis. Magnetic resonance angiography effectively screens for vertebral artery stenosis and its degree of stenosis, and can be used as a reliable tool for vertebral artery stenosis in posterior circulation cerebral infarction, and can be used in conjunction with digital subtraction angiogram in order to improve diagnostic convenience and accuracy.

KEY WORDS: Vertebral Artery Ultrasound; Magnetic Resonance Angiography; Digital Subtraction Angiography; Vertebral Artery Stenosis.

INTRODUCTION

Stroke is a serious neurological disorder with a high mortality and disability rate. It is usually caused by blockage or rupture of the cerebral blood vessels, leading to insufficient blood supply or bleeding of the brain tissue, which can lead to damage to the brain tissue. Stroke can present with paralysis, aphasia, visual impairment, cognitive impairment, etc. which seriously affects the quality of life of patients. According to the World Health Organization, stroke is the second leading cause of death and the third leading cause of disability worldwide (Zhang *et al*., 2018). Ischemic stroke caused by transient or permanent occlusion of cerebral vessels accounts for a large part of stroke (Zhao, 2022). Among them, acute ischemic stroke can cause severe brain and neuronal damage within a short period of time of th-ñe attack (Balch *et al*., 2020), Posterior circulatory stroke accounts for 20 % of all acute ischemic strokes(Gurley & Edlow, 2019), and vertebral artery stenosis(VAS) is an important cause of posterior circulation ischemic stroke (Xu *et al*., 2022).

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The vertebral artery is a blood vessel that supplies the posterior side of the brain and is usually the first major branch of the subclavian artery on the left and right sides of the body (Tay *et al*., 2005), which can be divided into four anatomically distinct segments (V1-V4), where segments V1-V3 are categorized as the extracranial vertebral arteries, and segment V4 is considered to be the intracranial vertebral artery (Khan *et al*., 2007). Insufficient blood supply to the vertebral artery is a significant factor in stroke, resulting in 20 % of posterior circulation ischemic stroke (Cloud & Markus, 2003). Its symptoms are characterized by dizziness, visual difficulties, nystagmus, nausea, ataxia, etc. (Searls *et al*., 2012). If VAS is left undiagnosed and unmanaged,it increases the risk of diseases such as cerebrovascular accidents, myocardial infarction and sudden death (Burle *et al*., 2022), so it is important to accurately evaluate the degree of VAS in patients, and to grasp the hemodynamic characteristics of patients.

Digital subtraction angiography, magnetic resonance angiography, and vertebral artery ultrasound are the current clinical methods for vertebral artery stenosis. DSA also known as intra-arterial angiography(IAA), is regarded as the gold standard for the diagnosis of VAS stenosis disease (Madonis & Jenkins, 2021), and although DSA is considered to be the most accurate technique for the diagnosis of VAS, as an invasive imaging technique, it has the greatest risk, cost, and time-consumption (Nguyen-Huynh *et al*., 2008), and it may cause some pain and risk to patients? making it more restricted in clinical application. VAU as well as MRA, as non-invasive imaging techniques, are widely used in the clinic because of their safety, non-invasiveness, and lower cost (Naylor *et al*., 2018).

The accuracy of different diagnostic methods and the effect on patient prognosis are different. This study analyzes and compares the diagnostic efficacy of vertebral artery ultrasound and magnetic resonance angiography in patients with vertebral artery stenosis.

MATERIAL AND METHOD

Participants. The study population consisted of 73 patients with posterior circulation ischemia admitted to the Department of Neurology of Shanxi Provincial Hospital of Cardiovascular Disease from August 2021 to February 2022, of whom 50 were male and 23 were female, with a mean age of 63.50 (±8.343) years. Among the 73 patients, 63 were DSA and VAU, 52 were DSA and MRA, and 42 were DSA, VAU and MRA.

The participants must meet the diagnostic criteria in the China Guidelines for the Diagnosis and Treatment of Acute Ischemic Stroke 2018, and their diagnosis must be confirmed by clinical symptoms, signs, and imaging tests. The participants were the confirmed diagnoses, with complete clinical and imaging data.

Inclusion criteria. Meet the diagnostic criteria in the "Chinese Guidelines for the Diagnosis and Treatment of Acute Ischemic Stroke 2018", and confirmed by clinical symptoms, signs and imaging examination; The first diagnosis; After admission, VAU, MRA and DSA were performed, and all suggested the presence of VAS; The clinical data and imaging data were complete.

Exclusion criteria. Patients with mental illness; Patients with systemic infection; Patients with liver and kidney dysfunction; Patients with hematological diseases; Patients with abnormal immune system and coagulation function; Patients with infectious diseases; Patients with severe organic brain diseases; Patients with a history of alcohol and drug dependence; Patients with malignant tumors.

Vertebral artery ultrasonography. Philips IU-22 color Doppler ultrasound diagnostic apparatus was used. All patients were examined in supine position and cephalad lateral examination of the contralateral side to fully expose the vertebra. The probe was placed in the vertebra and scanned upward along the anterior/posterior edge of the sternocleidomastoid muscle. Transverse and longitudinal two-dimensional images were selected to observe the extravertebral artery (ECA) and intravertebral artery (ICA). Transverse and longitudinal scans were performed on the extracranial segment from the intravertebral artery to the common vertebral artery to observe the course of the vertebral vessels and blood flow filling, detect the degree of vascular stenosis, whether there were plaques in the vertebral artery canal, and determine the location and size of plaques.

Digital Subtraction Angiography. Siemens DSA machine was selected for the examination. The patient was placed in supine position. Routine bilateral inguinal and perineal skin disinfection was performed. 1 % lidocaine was used for local infiltration anesthesia. After successful puncture of the right femoral artery with Seldinger technique, 5F arterial sheath was indwelled and 3000 units heparin was systemically heparinized. Under compression injection of bilateral internal and external vertebral arteries, bilateral subclavian and bilateral vertebral arteries, aortic arch + full-DSA was performed with 5F pigtail and uni-directional catheter. Aortic arch and common vertebral artery angiography images were collected. The diameter of common vertebral artery and internal vertebral artery and the diameter of vascular lumen were measured, and the diameter of the narrowest part of vertebral artery was also measured.

Magnetic Resonance Angiography. MRA Verio 3.0T MR scanner (Siemens, Germany) and combined cephalovertebral coil were used to scan the aortic arch to the cranial vault using a fast 3DFLSAH sequence with parameters of TR: 5.05 ms, TE. 1.27 ms, inversion angle 45 °, slice thickness 1.0 mm, matrix 128 mm x 512 mm, field of view 30 cm, and scan time 74 s pixel size 0.78 mm x 1.07 mm x 1.0 mm. A double-simple high-pressure syringe (Nemoto, Japan) was injected with Meglumine acid 25 ml intravenously at 2 m/s. Images were collected for silhouette reconstruction.

Observation index. (1) VAS was detected by DSA, MRA and VAU; (2) Degree of VAS: stenosis grade: VAS rate stenosis rate was judged according to the measurement criteria of North American symptomatic vertebral artery endarterectomy test = (normal vessel diameter - stenosis site diameter)/normal vessel diameter x100. Stricture rate > 50.00 % was mild stenosis. 50.00 % to 69.00 % had moderate stenosis. 70.00 % ~ 99.00 % were severe stenosis and 100.00 % were occlusion (Farina *et al*., 2021). (3) To analyze the diagnostic efficacy of VAU and MRA in VAS: DSA was used as the "gold standard" for the examination, and the diagnostic efficacy of VAU and MRA for VAS was analyzed.

Statistical analysis. Statistical analyses were performed using SPSS version 22.0 software. Statistical significance was assessed at a p-value of<0.05. Descriptive statistics were calculated for all variables of interest and included means and standard deviations.

RESULTS

Analysis of diagnostic results of VAU, MRA and DSA. In 63 patients with posterior cerebral circulation ischemia who underwent both DSA and VAU, VAS was detected by DSA in 87.30 % (55/63) and VAS was detected by VAU in 49.20 % (31/63), and the difference was statistically significant. Among 52 patients with posterior cerebral circulation ischemia who underwent both DSA and MRA**,** VAS was detected by DSA in 90.38 % (47/52) and VAS was detected by VAU in 88.46 % (46/52), and the differences was not statistically significant.

Analysis of VAS diagnosed by VAU and DSA. Among 63 patients with posterior cerebral circulation ischemia who underwent both DSA and VAU, DSA detected normal vertebral artery in 8 cases, mild stenosis in 26 cases, moderate stenosis in 6 cases, severe stenosis in 14 cases, and complete occlusion in 9 cases, and VAU detected normal vertebral artery in 32 cases, mild stenosis in 14 cases, moderate stenosis in 7 cases, severe stenosis in 5 cases, and complete occlusion in 5 cases (Fig. 1), and the two methods had statistical significance in the detection rate of VAS ($\chi^2 = 21.098$, $p < 0.01$).

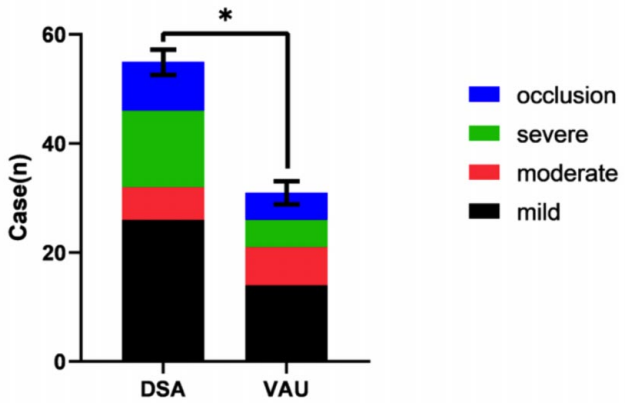

Fig. 1. Comparison between VAU and DSA in diagnosis of vertebral artery stenosis. Note:*p < 0.05, the difference is statistically significant.

Among 52 patients with posterior cerebral circulation ischemia who underwent both DSA and MRA, DSA detected normal vertebral artery in 5 cases, mild stenosis in 19 cases, moderate stenosis in 6 cases, severe stenosis in 13 cases, and complete occlusion in 9 cases, and MRA detected normal vertebral artery in 7 cases, mild stenosis in 18 cases, moderate stenosis in 8 cases, severe stenosis in 14 cases, and complete occlusion in 6 cases (Fig. 2), and there was no statistically significant difference in the detection rate of VAS between the two methods ($\chi^2 = 0.102$, $p > 0.05$).

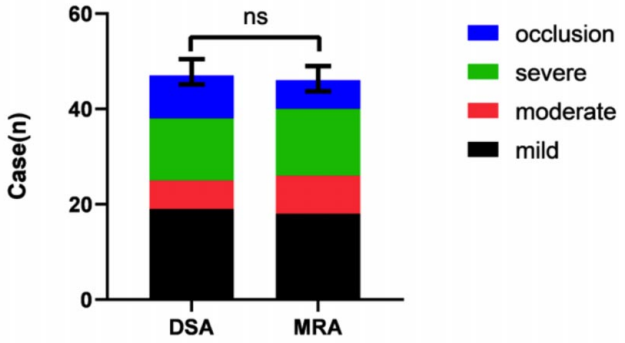

Fig. 2. Comparison between DSA and MRA in diagnosis of vertebral artery stenosis.

Comparison of the consistency of VAS detected by VAU, MRA and DSA. Among 42 patients with posterior circulation ischemia who underwent both DSA, VAU, and MRA. The results of DSA showed that 37 of 42 patients were positive and 5 were negative. The results of vertebral artery ultrasonography showed that 20 patients were positive and 22 patients were negative. MRA revealed 35 positives and 7 negatives. The sensitivity, specificity, accuracy, negative predictive value and positive predictive value of VAU in the diagnosis of VAS were 51.35 %, 80 %, 54.76 %, 18.18 % and 95 % respectively and lower than those of MRA, which were 91.89 %, 80 %, 90.48 %, 57.14 %, and 97.14 %, respectively.

Analysis of typical cases. Figure 3 shows an image of a 61-year-old female patient. A was a DSA image, the report suggests the patient's right vertebral artery V4 stage degree stenosis. B for the patient MRA image report image, suggesting that the right vertebral artery limitation is slightly narrow. Figure C and D were ultrasonic image reports of vertebral artery. The report showed normal course of bilateral vertebral arteries, symmetrical diameter, smooth intima and normal blood flow velocity. No VAS was reported. Among the three imaging examinations, both DSA and MRA revealed stenosis of the right vertebral artery in patients, while VAU reported normal bilateral vertebral arteries. In this case, VAU was considered to be less accurate than MRA in detecting VAS.

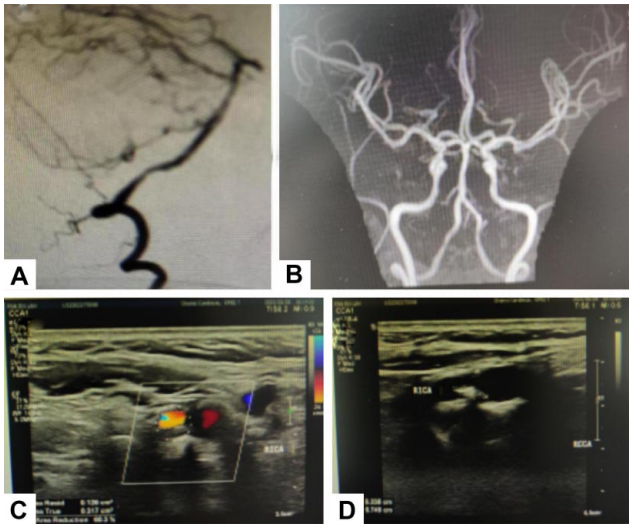

Fig. 3. Images of DSA, MRA, VAU in patients with VAS.
Note:(A) DSA showed mild to moderate stenosis of V4 strands of the right vertebral artery. (B) MRA showed localized slight stenosis of the right vertebral artery. (C,D) VAU showed normal course of bilateral vertebral arteries, symmetrical tube position, smooth intima, and normal blood flow velocity.

DISCUSSION

Stroke is a sudden cerebrovascular disease usually caused by blockage or rupture of blood vessels in the brain. Stroke can lead to neurological impairment, including loss of limb sensation, motor function, speech ability, and cognitive ability. These complications not only have a serious impact on the quality of life of patients, but also impose a heavy burden on families and society. Among them, ischemic stroke accounts for about 87 % of all stroke cases and is characterized by a sudden loss of blood flow due to thrombosis or embolism that obstructs cerebral vessels supplying specific areas of the brain. Ischemic stroke is the leading cause of permanent disability and one of the leading causes of death worldwide (Farina *et al*., 2021). The vertebral artery acts as a blood vessel supplying the posterior part of the brain, and narrowing of this blood vessel is an important cause of stroke.

VAS often occurs in middle-aged and elderly people, mostly manifested as sudden vertigo, nausea and vomiting, unstable standing and other symptoms usually have a short onset time and do not exceed a few minutes, will occur many times within 24 hours, some patients can last for several days, will directly affect the daily life and learning of patients (Neto *et al*., 2020; Feng *et al*., 2020). At present, there are many statements about the pathogenesis of the disease, including vascular calcification, atherosclerosis, vertebral artery dissection, fibromuscular dysplasia, and so on (Khan *et al*., 2007). Diabetes mellitus, hypertension, and hyperlipidemia are common risk factors for VAS (Zhang *et al*., 2017). If not treated in time, it may lead to stroke, Subclavian Steal Syndrome, myocardial infarction, vertebrobasilar insufficiency and even sudden death (Burle *et al*., 2022). Patients with VAS have a higher risk of recurrent stroke compared with patients with carotid artery stenosis (Xu *et al*., 2022) and VAS ≥ 50 % is a strong independent predictor of recurrent stroke (Zhang *et al*., 2017). In addition, stroke patients with ≥ 70 % stenosis of the responsible artery had a higher risk of recurrent stroke. Therefore, early and accurate assessment of whether the vertebral artery is stenotic and the degree of stenosis will affect clinicians' selection of individualized treatment options, thus effectively reducing the risk of stroke occurrence and recurrence, reducing the resulting neurological dysfunction, while reducing the disability rate and mortality.

Vertebral artery can be challenging to identify, diagnose, and treat due to its variability and tortuosity. At present, there are many diagnostic techniques that can evaluate VAS in clinical practice, including VAU, MRA and DSA DSA has high spatial resolution and can identify the responsible vessel distribution and its degree of stenosis, but it is the most invasive, expensive, riskiest and time-consuming diagnostic technique for the examination of VAS (Madonis & Jenkins, 2021), and has certain risks, which may cause a series of complications such as inguinal hematoma, contrast agent reaction, one-time neurological events, permanent neurological deficits, carotid and VA dissections, and femoral or iliac artery dissections, etc. Although the overall incidence of neurological complications is 1.5 %, the incidence of subclinical neurological events is much higher (Kocak *et al*., 2012). It is therefore particularly important to find a safe, accurate, noninvasive and cost-effective diagnostic method.

VAU and MRA are mature non-invasive angiography techniques in clinical application, which can clearly show

the lumen shape, blood flow velocity and vascular wall of vertebral artery. It has certain diagnostic value for the degree and type of stenosis of diseased vessels and is a safe and cost-effective research method (Ahmed *et al*., 2021). However, because the complex location, tortuosity, small diameter, and vertical position of the origin of the vertebral artery make ultrasound detection challenging, VAU has a low detection rate for distal branch lesions of the vertebral artery, and the examination results are greatly affected by the technical level of the operator, and can only be imaged in 60 % of subjects. Although, the use of color flow imaging and establishment of Doppler parameters increases the effectiveness of Doppler imaging (Yurdakul & Tola, 2011). However, in this study, DSA and VAU were found to have low sensitivity in detecting the rate and degree of VAS and could not accurately describe VAS.

MRA is a noninvasive vascular imaging technique that shows the anatomy and flow status of the entire spine and vascular system. MRA has high sensitivity and specificity for the diagnosis of VAS, and can accurately detect vascular stenosis and occlusion. At the same time, technological advances in hardware and software development, coupled with the increasing availability of more powerful magnets, have greatly improved the imaging capabilities of MRA. As a result, clinicians are increasingly relying on MRA as a tool for vascular assessment (Vo *et al*., 2014). In this study, we found that DSA and MRA had high sensitivity in detecting the rate and degree of VAS and could be regarded as a better imaging method for detecting VAS.

To sum up, compared to VAU, the results of MRA and DSA on VAS were more consistent, and have the advantages of simple operation, non-invasive, the clinical diagnosis of vertebral artery stenosis is better. Clinical diagnosis combined with DSA can further improve the accuracy of the diagnosis. This study discussed the consistency of VAU, MRA and DSA diagnosis in patients with circulating ischemia, but the number of patients in this study is small and there may be some limitations.

CONCLUSIONS

In non-invasive imaging techniques, although VAU can provide some information of the vertebral artery, it is often unable to accurately describe VAS and its degree of stenosis due to its imaging principles and limitations. MRA can clearly show the shape and structure of the vertebral artery, accurately evaluate the degree of VAS, and provide a reliable basis for the diagnosis of VAS. In order to improve diagnostic accuracy and convenience, DSA can be used in combination for further evaluation and treatment.

ZHANG, T. M.; CHEN, C.; DING, L.; LIU, H. & SHEN, H. Comparación de la ecografía de la arteria vertebral, la angiografía por resonancia magnética y la angiografía por sustracción digital en el diagnóstico de estenosis de la arteria vertebral en pacientes con isquemia de la circulación posterior. *Int. J. Morphol., 42(2)*:368-373, 2024.

RESUMEN: El objetivo de este estudio fue comparar el valor clínico de la ecografía de la arteria vertebral (VAU), la angiografía por resonancia magnética (ARM) y la angiografía por sustracción digital (DSA) en la estenosis de la arteria vertebral en pacientes con isquemia de la circulación posterior. A 73 pacientes con isquemia de la circulación posterior se les realizó una ecografía de la arteria vertebral y una angiografía por resonancia magnética, así como una angiografía por sustracción digital, y se les diagnosticó estenosis de la arteria vertebral (EVA) y el grado de estenosis (normal, estenosis leve, estenosis moderada, estenosis grave, y oclusión) se registraron y compararon la angiografía por sustracción digital y la ecografía de la arteria vertebral y la angiografía por resonancia magnética. Las tasas de estenosis de la arteria vertebral en la angiografía por sustracción digital y la ecografía de la arteria vertebral fueron del 87,30 % (55/63) y del 49,20 % (31/63), respectivamente, y la diferencia fue estadísticamente significativa. Las tasas de estenosis de la arteria vertebral en la angiografía por sustracción digital y la angiografía por resonancia magnética fueron del 90,38 % (47/52) y del 88,46 % (46/52), respectivamente, y las diferencias no fueron estadísticamente significativas. La sensibilidad, precisión, valor predictivo negativo y valor predictivo positivo de la ecografía de la arteria vertebral en el diagnóstico de estenosis de la arteria vertebral fueron 51,35 %, 54,76 %, 18,18 % y 95,00 %, respectivamente, inferiores a los de la angiografía por resonancia magnética, que fueron 91,89 %, 90,48 %, 57,14 % y 97,14 %, respectivamente. De las técnicas de imagen no invasivas, la ecografía de la arteria vertebral no caracteriza con precisión la estenosis de la arteria vertebral y su grado de estenosis. La angiografía por resonancia magnética detecta eficazmente la estenosis de la arteria vertebral y su grado de estenosis, y puede usarse como una herramienta confiable para la estenosis de la arteria vertebral en el infarto cerebral de circulación posterior, y puede ser utilizada junto con la angiografía por sustracción digital para mejorar el diagnóstico y la exactitud.

PALABRAS CLAVE: Ultrasonido de arteria vertebral; Angiografía por resonancia magnética; Angiografía por sustracción digital; Estenosis de la arteria vertebral.

REFERENCES

Ahmed, M.; McPherson, R.; Abruzzo, A.; Thomas, S. E. & Gorantla, V. R. Carotid artery calcification: what we know so far. *Cureus, 13(10)*:e18938, 2021.

Balch, M. H. H.; Nimjee, S. M.; Rink, C. & Hannawi, Y. Beyond the brain: the systemic pathophysiological response to acute ischemic stroke. *J. Stroke, 22(2)*:159-72, 2020.

Burle, V. S.; Panjwani, A.; Mandalaneni, K.; Kollu, S. & Gorantla, V. R. Vertebral artery stenosis: a narrative review. *Cureus, 14(8)*:e28068, 2022.

Cloud, G. C. & Markus, H. S. Diagnosis and management of vertebral artery stenosis. *QJM, 96(1)*:27-54, 2003.

Farina, M.; Vieira, L. E.; Buttari, B.; Profumo, E. & Saso, L. The Nrf2 pathway in ischemic stroke: a review. *Molecules, 26(16)*:5001, 2021.

Feng, Y.; Liu, J.; Fan, T.; Zhang, W.; Yin, X.; E, Y.; Yajun, E.; Tan, W. & Huo, Y. Vertebral artery stenoses contribute to the development of diffuse plaques in the basilar artery. *Front. Bioeng. Biotechnol., 8*:168, 2020.

Gurley, K. L. & Edlow, J. A. Avoiding misdiagnosis in patients with posterior circulation ischemia: a narrative review. *Acad. Emerg. Med., 26(11)*:1273-84, 2019.

Khan, S.; Cloud, G. C.; Kerry, S. & Markus, H. S. Imaging of vertebral artery stenosis: a systematic review. *J. Neurol. Neurosurg. Psychiatry, 78(11)*:1218-25, 2007.

Kocak, B.; Korkmazer, B.; Islak, C.; Kocer, N. & Kizilkilic, O. Endovascular treatment of extracranial vertebral artery stenosis. *World J. Radiol., 4(9)*:391-400, 2012.

Madonis, S. M. & Jenkins, J. S. Vertebral artery stenosis. *Prog. Cardiovasc. Dis., 65*:55-9, 2021.

Naylor, A. R.; Ricco, J. B.; de Borst, G. J.; Debus, S.; de Haro, J.; Halliday, A.; Hamilton, G.; Kakisis, J.; Kakkos, S.; Lepidi, S.; *et al*. Editor's Choice - Management of Atherosclerotic Carotid and Vertebral Artery Disease: 2017 Clinical Practice Guidelines of the European Society for Vascular Surgery (ESVS). *Eur. J. Vasc. Endovasc. Surg, 55(1)*:3-81, 2018.

Neto, A. C. L.; Bor-Seng-Shu, E.; Oliveira, M. L.; Macedo-Soares, A.; Topciu, F. R. & Bittar, R. S. M. Magnetic resonance angiography and transcranial Doppler ultrasound findings in patients with a clinical diagnosis of vertebrobasilar insufficiency. *Clinics (Sao Paulo), 75*:e1212, 2020.

Nguyen-Huynh, M. N.; Wintermark, M.; English, J.; Lam, J.; Vittinghoff, E.; Smith, W. S. & Johnston, S. C. How accurate is CT angiography in evaluating intracranial atherosclerotic disease? *Stroke, 39(4)*:1184-8, 2008.

Searls, D. E.; Pazdera, L.; Korbel, E.; Vysata, O. & Caplan, L. R. Symptoms and signs of posterior circulation ischemia in the New England Medical Center posterior circulation registry. *Arch. Neurol., 69(3)*:346-351, 2012.

Tay, K. Y.; JM, U. K.-I.; Trivedi, R. A.; Higgins, N. J.; Cross, J. J.; Davies, J. R.; Weissberg, P. L.; Antoun, N. M. & Gillard, J. H. Imaging the vertebral artery. *Eur. Radiol., 15(7)*:1329-43, 2005.

Vo, K. D.; Jeck, D. & Mckinstry, R. *Magnetic Resonance Angiography of Cervical and Intracranial Vessels*. In: Aminoff, M. J. & Daroff, R. B. (Eds.). Encyclopedia of the Neurological Sciences. 2nd ed. Amsterdam, Elsevier, 2014. pp.959-63.

Xu, R.; Zhang, X.; Liu, S.; Wang, X.; Wang, W.; Yang, K.; Wang, T.; Dmytriw, A. A.; Bai, X.; Ma, Y.; *et al*. Percutaneous transluminal angioplasty and stenting for vertebral artery stenosis. *Cochrane Database Syst. Rev., 5(5)*:CD013692, 2022.

Yurdakul, M. & Tola, M. Doppler criteria for identifying proximal vertebral artery stenosis of 50 % or more. *J. Ultrasound Med., 30(2)*:163-8, 2011.

Zhang, C.; Wang, Y.; Zhao, X.; Liu, L.; Wang, C.; Pu, Y.; Zou, X.; Pan, Y.; Wong, K. S.; Wang, Y.; *et al*. Prediction of recurrent stroke or transient ischemic attack after noncardiogenic posterior circulation ischemic stroke. *Stroke, 48(7)*:1835-41, 2017.

Zhang, X.; Elnady, A. M.; Randhawa, B. K.; Boyd, L. A. & Menon, C. Combining mental training and physical training with goal-oriented protocols in stroke rehabilitation: a feasibility case study. *Front. Hum. Neurosci., 12*:125, 2018.

Zhao, Y.; Zhang, X.; Chen, X. & Wei, Y. Neuronal injuries in cerebral infarction and ischemic stroke: From mechanisms to treatment (Review). *Int. J. Mol. Med., 49(2)*:15, 2022.

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