Int J Clin Exp Med 2021;14(2):1146-1151
www.ijcem.com /ISSN:1940-5901/IJCEM0124301

Original Article

A CTA analysis of the correlation between DVA and HRVA before atlantoaxial internal fixation

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Received October 16, 2020; Accepted November 17, 2020; Epub February 15, 2021; Published February 28, 2021

Abstract: Objective: To apply CT angiography in the analysis of the correlation between the dominant vertebral artery (DVA) and the high-riding vertebral artery (HRVA) and to explore the application of atlantoaxial internal fixation in clinical practice. Methods: This study was conducted with a cohort of 158 cervical vertebral disease patients who were admitted to the department of orthopedics and traumatology of our hospital for CT angiographies of the vertebral artery between December 2016 and July 2020. In total, 316 vertebral arteries were included. According to whether there were DVAs or not, these patients were divided into the DVA group (n=95) or the balanced vertebral artery group (n=63). The DVAs and HRVAs were counted. Meanwhile, the number of HRVAs was compared between the DVA group and the non-DVA group. The correlations between the diameter of the DVA and the distance between the vertebral artery foramen and the outer wall of the spinal canal, and the distance between the bulb of the vertebral artery foramen and the surface of the superior articular were analyzed. Results: Among the 158 patients, 95 had DVAs (60.13%) and 54 had HRVAs (35.06%). The incidence of HRVAs in the DVA group was higher than it was in the balanced vertebral artery group (45.26% vs. 17.46%, P<0.001). The DVA diameters in the DVA group were significantly larger when compared with the non-DVA group. The distances between the vertebral artery foramen and the outer wall of the spinal canal in the DVA group were lower than they were in the non-DVA group (P<0.001). Similarly, the distances between the bulb of the vertebral artery foramen and the surface of the superior articular were smaller (P<0.001). The DVA diameter negatively correlated with the distance between the vertebral artery foramen and the outer wall of the spinal canal and the distance between the bulb of the vertebral artery foramen and the surface of the superior articular (both P<0.05). Conclusion: Patients with DVA have higher incidences of HRVAs. The diameter of the vertebral artery is negatively correlated with the distance between the bulb of the vertebral artery foramen and the surface of the superior articular.

Keywords: CT angiography, dominant vertebral artery, high-riding vertebral artery, correlation

Introduction

The atlas and axis are essential for the connection between the cervical spine and the brain. Their characteristics are determined by their anatomy and structural position [1]. In clinical practice, the decreased stability of the atlas and axis is induced by a variety of factors [2-5]. Among them, fracture is an important one. The incidence of atlas fractures has been increasing yearly [6]. Unstable atlas fracture refers to an atlas fracture combined with a transverse ligament rupture. When there is no transverse ligament rupture, the atlas fracture is called stable atlas fracture [7]. The biomechanical property of the posterior atlantoaxial pedicle screw internal fixation is stable. Therefore, it has become the main surgical method for reconstructing the stability of the upper cervical spine. Also, it has become an essential surgery for the treatment of unstable atlas fractures [8]. The surgery is effective. However, some patients fail to undergo the operation due to the difficulty or failure of the nail placement, which is caused by factors like the anatomical location, complex injuries, and individual differences [9, 10]. The anatomical structure around the axis and vertebral artery is complex. In addition, the pedicle's volume is small, and the vertebral artery passes through it. There is frequent anatomical variation, increasing the surgical difficulty and risk [11].

The dominant vertebral artery (DVA) is the vertebral artery that has over an 0.8 mm difference in its diameter on both sides. In clinical practice, it is seen as a common variation of the vertebral artery. It was reported in previous studies that about 38%-73% of the population has a DVA. In other words, its incidence in the normal population is high [12]. The high-riding vertebral artery (HRVA) is another common variation of the vertebral artery. Its manifestations are too backward, inward, and a high position bending under the upper articular process of the axial vertebral artery. The existence of an HRVA also indicates a high risk for an intraoperative vertebral artery injury [13, 14].

An HRVA can cause changes in the height and width of the C2 isthmus. To adapt to the changes, the pedicle becomes abnormal. As a result, the difficulty and risk of the pedicle screw placement are increased [15]. Similarly, the volume of the pedicle is reduced when there is a DVA, which is negatively correlated with the width of the pedicle [16]. Based on the above research results, we found that the presence of a DVA and an HRVA can make the pedicle morphology abnormal. However, whether or not the difference in diameter on both sides of the DVA can cause an HRVA when it reaches a certain value is unknown. At present, there are no published studies on the relationship between DVAs and HRVAs, so the correlation between DVAs and HRVAs remains to be confirmed. Here, we applied CT angiography (CTA) to observe the vascular morphology and surrounding bone markers, hoping to clarify the correlation between DVAs and HRVAs.

Materials and methods

General information

This study was approved by the Ethics Committee of Quanzhou First Hospital Affiliated to Fujian Medical University and all patients signed the informed consent. In total, 158 patients with cervical vertebral diseases who were admitted to the department of orthopedics and traumatology of Quanzhou First Hospital Affiliated to Fujian Medical University for a CTA of the vertebral artery from December 2016 to July 2020, were enrolled in this study. The cohort had a total of 316 vertebral arteries. The patients in the study cohort ranged in age from 24-68 years and had an average age of 55.6±9.3 years.

Inclusion criteria: Patients with cervical vertebral diseases who wanted to undergo a CTA examination, patients who had complete clinical data, patients whose CTA images were clear, and patients whose CT scan ranges were C1-C7.

Exclusion criteria: Patients with a previous axial pedicle fracture, patients who had autoimmune diseases such as ankylosing spondylitis, patients who had cervical a spine tumor or another malignant tumor that metastasized to the spine, patients with congenital spinal deformities, patients who had congenital or acquired vertebral artery stenosis or sclerosis, patients with diseases that affect the measurement of vertebral artery or bone markers, and patients who had contraindications to CTA examinations.

Methods

The diagnostic criterion of a DVA is a difference in the diameters of the two vertebral arteries more than 0.8 mm [15]. The diagnostic criteria of an HRVA includes: (1) the distance between the vertebral artery foramen (tube) and the outer wall of spinal canal (a) is less than 4.5 mm, (2) the distance between the bulb of the vertebral artery foramen (tube) and the surface of the superior articular (e) is less than 4.5 mm [16]. All the patients in the study cohort underwent a CTA examination. Thereafter, three qualified readers, who were attending physicians or physicians with a higher qualification, measured the bilateral vertebral artery lumen diameters (d), the distances between the vertebral artery foramens and the outer walls of the spinal canal (a), and the distances between the bulbs of the vertebral artery foramens and the surfaces of the superior articulars (e). These were independently measured three times to obtain an average value.

Outcome measures

The number of DVAs was recorded. Their incidence rate was then calculated. The diagnostic criterion of a DVA is a difference in the diameters of the two vertebral arteries more than 0.8 mm.

The number of HRVAs was recorded. Their incidence rate was then calculated. The diagnostic criteria of an HRVA are the values of a and e both less than 4.5 mm.

Table 1. Distribution of the DVAs (n)

	In total (n=158)	Male (n=98)	Female (n=60)	χ^2/t	P
Age (years)	55.6±9.3	56.7±9.1	54.3±9.6	1.576	0.117
Left DVA	70	41	29	1.411	0.494
Right DVA	25	18	7		
Balanced DVA	63	39	24		

Note: DVA: dominant vertebral artery.

Table 2. Distribution of the HRVAs (n)

	In total (n=158)	Male (n=98)	Female (n=60)	χ^2	P
Left HRVA	22	7	10	13.300	0.004
Right HRVA	17	7	8		
Bilateral HRVA	28	9	13		
No HRVA	114	75	29		

Note: HRVA: high-riding vertebral artery.

Table 3. Correlation between the DVAs and the HRVAs (n)

Group	With HRVA	Without HRVA	χ^2	P
DVA group (n=95)	43	52	13.016	<0.001
BVA group (n=63)	11	52		

Note: DVA: dominant vertebral artery; HRVA: high-riding vertebral artery; BVA: balanced vertebral artery.

According to whether there was a DVA or not, the patients were assigned to the DVA group or the balanced vertebral artery (BVA) group. The incidences of HRVA were compared between the two groups.

In the DVA group, the correlation between the axial pedicle and the diameters of the dominant and non-dominant sides of the left and right arteries were analyzed.

Statistical methods

All the data were analyzed using SPSS statistical software version 17. The normally distributed measurement data were calculated as the mean ± standard deviation ($\bar{x}$ ± sd); the abnormally distributed measurement data were expressed using the median (P25, P75). Independent sample t tests were used for the intergroup comparison when the data were normally distributed and had a homogeneous variance; otherwise, the data were analyzed using rank sum tests. The enumeration data were analyzed using Pearson chi-square tests. The correlation analyses were performed using Pearson product-moment correlation coefficients. Specifically, the linear correlations between a and e were analyzed. A difference was statistically significant when the *P* value was less than 0.05.

Results

Distribution of the DVAs

Among the 158 patients, 63 had BVAs and 95 had DVAs. Specifically, 70 had a left DVA, and 25 had a right DVA. The incidence rate of DVA was 60.13%. There was no significant difference in the distribution of the DVAs in the male and female patients (all P>0.05, **Table 1**).

Distribution of the HRVAs

Among the 158 patients, 54 had an HRVA (35.06%). As for the 316 patients with vertebral arteries, 76 had an HRVA (24.05%). The number of female HRVA patients among all the women was higher than the number of male HRVA patients among all the men (51.67% vs 23.47%, P<0.01, **Table 2**).

Correlation between DVA and HRVA

The incidence rate of HRVAs in the DVA group was higher than the incidence rate in the BVAs group (45.26% vs 17.46%, P<0.001, **Table 3** and **Figure 1**).

Correlation between the DVA diameter and the pedicle-related parameters

As shown in **Table 4**, the diameters of the DVAs were significantly higher than the diameters of the non-DVAs; the distances between vertebral artery foramens and the outer walls of the spinal canals in the DVA group were lower than they were in the non-DVA group (P<0.001). Similarly, the distances between the bulbs of the vertebral artery foramens and the surfaces of the superior articulars were decreased (P<0.001). The correlation analysis showed that the DVA diameter is negatively correlated with the distance between the vertebral artery foramen and the outer wall of the spinal canal and the distance between the bulb of the verte-

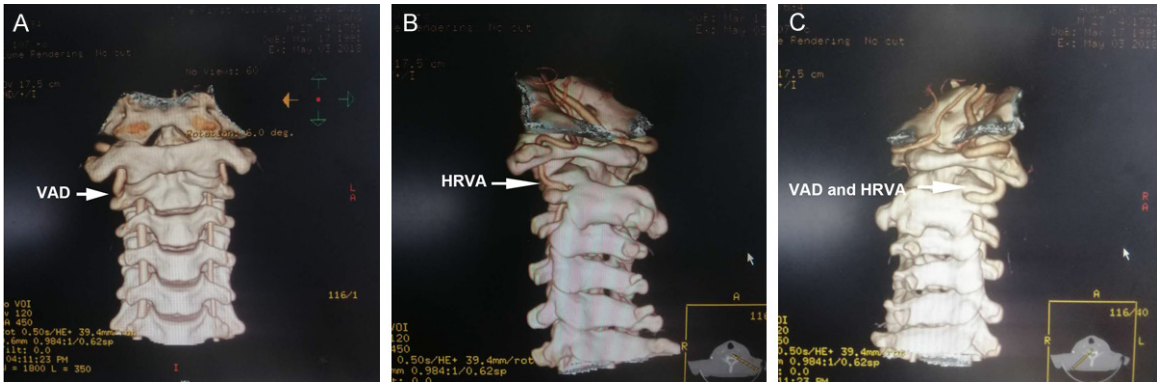

Figure 1. Image of a right DVA combined with an HRVA. A: An image of a DVA; B: An image of an HRVA; C: An image of a right DVA combined with an HRVA. DVA: dominant vertebral artery; HRVA: high-riding vertebral artery.

Table 4. Correlation between the diameters of the DVAs and the parameters related to the pedicles

Group	DVA group (n=95)	Non-DVA group (n=95)	t	P
Bilateral vertebral artery lumen diameter (d, mm)	3.72±0.54	2.34±0.39	20.193	<0.001
Distance between the vertebral artery foramen and the outer wall of the spinal cana (a, mm)	4.46±1.39	5.67±1.26	6.286	<0.001
Distance between the bulb of the vertebral artery foramen and the surface of the superior articular (e, mm)	3.79±1.29	5.47±1.34	8.803	<0.001

Note: DVA: dominant vertebral artery.

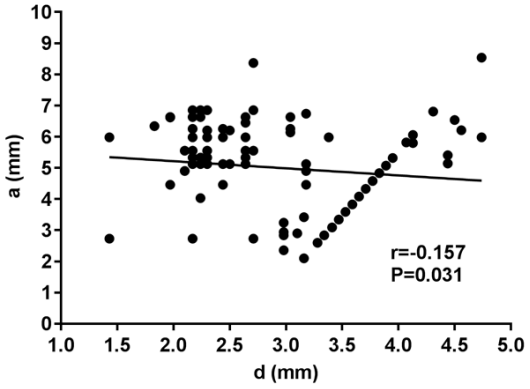

Figure 2. The diameter of the vertebral artery (d) is negatively correlated with the distance between the vertebral artery foramen and the outer wall of the spinal canal (a).

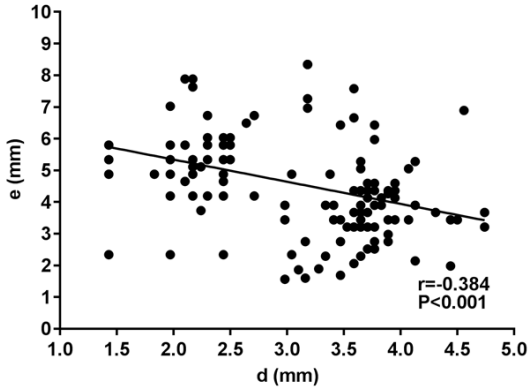

Figure 3. The diameter of the vertebral artery (d) is negatively correlated with the distance between the bulb of the vertebral artery foramen and the surface of the superior articular (e).

bral artery foramen and the surface of the superior articular (both P<0.05, **Figures 2** and **3**).

Discussion

Clinical studies have found that CTA has a significant value in the determination of vascular variation and the imaging of the surrounding tissues [17]. Dysplasia of the vertebral artery or one side DVA refers to a vertebral artery that has a significant difference in the diameter measured using CTA when compared with the other vertebral artery [18]. Variation in the vertebral artery is commonly observed in clinical practice. It was reported that the variation was caused by an X chromosome abnormality, which caused a variation in the vertebral artery as early as the embryonic period [19]. In previous studies, the reported incidence rates of DVAs are inconsistent, with a range of 38.5 to 73.0% [20]. Comparing the left and right DVAs,

it was found that the incidence of a left DVA was twice than that of a right DVA [20]. In our study, 95 of 158 patients had DVAs (60.13%), and most DVAs were seen on the left side. This is similar to the above results. It was reported that patients with a cerebral hemorrhage and brain tumor, but without rheumatic diseases or related genetic diseases were prone to HRVA, the other variation of the vertebral artery. Also, it was reported that the incidence rate of HRVAs is between 10-20% [21]. Another study reported that the incidence rate of HRVAs in women above 70 years old was significantly increased [22]. In our study, the incidence rate of HRVAs (35.06%) was higher than the rates found in previous studies. The above studies were not reported by Chinese researchers, however. In other words, there are few relevant reports in China. This might be related to the sample size or the high incidence of HRVAs in the Chinese population. Our study also showed that the incidence rate of HRVAs in females is significantly higher than the incidence rate of HRVAs in males, which is consistent with the result reported above.

Previous studies have shown that the presence of DVAs can result in basilar vertebral artery curvatures. The diameter of the DVA is lengthened. Therefore, its blood flow is significantly increased when compared with non-DVAs. The change in the long-term chronic force can gradually extend a DVA to a non-DVA, and can bend and even angulate a DVA [23]. In our study, we thought that the presence of a DVA was more likely to induce a DVA variation. HRVA was thus developed. We further investigated the correlation between the parameters of its bone markers and the diameter of the vertebral artery. We found that the diameter of the DVA is negatively correlated with the width and height of the pedicle. Similarly, it was reported that the presence of a DVA made the width of the ipsilateral pedicle decrease [16]. This might be caused by the following reasons. First, congenital factors: in the embryonic period, the formation and development of the vertebral artery occurred earlier than the transverse foramen. Accordingly, the development of the vertebral artery could influence the development of the transverse foramen [24]. Second, acquired factors: the blood flow and pressure in the vertebral artery are larger and can produce pulsation, which might cause an erosion of the surrounding bones during walking. In addition, there are variations in the vertebral artery like DVA. In order to adapt to the morphological variations of vertebral artery, the transverse foramen and pedicle changed accordingly. Therefore, the width of the pedicle became smaller, while the area of the transverse foramen increased when the diameter of the DVA increased [25]. We speculated that increased risk of HRVA, which was caused by the presence of DVA, might be related to the change of the bone morphology in DVA.

However, this is a retrospective study conducted with a limited sample. A multi-centered study will be completed with a larger study cohort to explore the correlation between DVA and HRVA.

In summary, patients with DVAs have an increased incidence of HRVAs. The diameter of the vertebral artery is negatively correlated with the distance between the bulb of the vertebral artery foramen and the surface of the superior articular.

Disclosure of conflict of interest

None.

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References

[1] Wu C and Zhou X. Pathomechanics of atlantoaxial instability. Atlantoaxial Fixation Tech 2018.

[2] Li T, Yin YH, Qiao GY, Wang HW and Yu XG. Three-dimensional evaluation and classification of the anatomy variations of vertebral artery at the craniovertebral junction in 120 patients of basilar invagination and atlas occipitalization. Oper Neurosurg (Hagerstown) 2019; 17: 594-602.

[3] Sanchis-Gimeno JA, Llido S, Perez-Bermejo M and Nalla S. Prevalence of anatomic variations of the atlas vertebra. Spine J 2018; 18: 2102-2111.

[4] Xie W, Gao P and Ji L. Three-dimensional spiral CT measurement of atlantal pedicle and its clinical application. Exp Ther Med 2017; 14: 1467-1474.

[5] Ríos L, Palancar C, Pastor F, Llidó S, Sanchís-Gimeno JA and Bastir M. Shape change in the atlas with congenital midline non-union of its posterior arch: a morphometric geometric study. Spine J 2017; 17: 1523-1528.
[6] Phuntsok R, Ellis BJ, Herron MR, Provost CW, Dailey AT and Brockmeyer DL. The occipitoatlantal capsular ligaments are the primary stabilizers of the occipitoatlantal joint in the craniocervical junction: a finite element analysis. J Neurosurg Spine 2019; [Epub ahead of print].
[7] Nowell M and Nelson R. Traumatic posterior atlantoaxial dislocation with associated C1 Jefferson fracture and bilateral vertebral artery occlusion without odontoid process fracture or neurological deficit. Eur Spine J 2019; 28: 9-12.
[8] Huang DG, Hao DJ, He BR, Wu QN, Liu TJ, Wang XD, Guo H and Fang XY. Posterior atlantoaxial fixation: a review of all techniques. Spine J 2015; 15: 2271-2281.
[9] Larsen AMG, Grannan BL, Koffie RM and Coumans JV. Atlantoaxial fusion using C1 sublaminar cables and C2 translaminar screws. Oper Neurosurg (Hagerstown) 2018; 14: 647-653.
[10] Rajinda P, Towiwat S and Chirappapha P. Comparison of outcomes after atlantoaxial fusion with C1 lateral mass-C2 pedicle screws and C1-C2 transarticular screws. Eur Spine J 2017; 26: 1064-1072.
[11] Yuan F, Yang HL, Guo KJ, Li JS, Xu K, Zhang ZM and Tang TS. A clinical morphologic study of the C2 pedicle and isthmus. Eur Spine J 2013; 22: 39-45.
[12] Zhang DP, Zhang SL, Zhang HT and Zhang SJ. Vertebral artery dominance, brainstem auditory evoked potential, and vertigo of vascular origin. Neurol Res 2012; 34: 498-503.
[13] Maki S, Koda M, Iijima Y, Furuya T, Inada T, Kamiya K, Ota M, Saito J, Okawa A, Takahashi K and Yamazaki M. Medially-shifted rather than high-riding vertebral arteries preclude safe pedicle screw insertion. J Clin Neurosci 2016; 29: 169-172.
[14] Qian R, Li Z and Li M. Vertebral arteriovenous fistula: a rare complication following transpedicular occipitocervical fixation in a patient with atlantoaxial dislocation. J Neurol Surg A Cent Eur Neurosurg 2018; 79: 533-535.
[15] Dong ZQ, Zhao GP, Bi HH, Zhao QH and Wang HJ. Finite element analysis of posterior atlantoaxial vertebral fixation of fracture with vertebral artery type high across II dentate. Chin J Biom Eng 2020; 39: 459-465.
[16] Li T, Yang J, Xu S, Wang GJ and Wang Q. CT observation of lower cervical pedicle morphology with vertebral artery dominance. Chin J Spinal Spinal Cord 2016; 28: 309-313.
[17] Minja FJ, Mehta KY and Mian AY. Current challenges in the use of computed tomography and MR imaging in suspected cervical spine trauma. Neuroimaging Clin N Am 2018; 28: 483-493.
[18] Wang F, Hu XY, Wang T, Fang XM, Dai Z, Guo DL, Mao XQ and Cui ZM. Clinical and imaging features of vertebrobasilar dolichoectasia combined with posterior circulation infarction: a retrospective case series study. Medicine (Baltimore) 2018; 97: e13166.
[19] Carey S, Wrogemann J, Booth FA and Rafay MF. Epidemiology, clinical presentation, and prognosis of posterior circulation ischemic stroke in children. Pediatr Neurol 2017; 74: 41-50.
[20] Hong JM, Chung CS, Bang OY, Yong SW, Joo IS and Huh K. Vertebral artery dominance contributes to basilar artery curvature and perivertebrobasilar junctional infarcts. J Neurol Neurosurg Psychiatry 2009; 80: 1087-1092.
[21] Vaněk P, Bradáč O, de Lacy P, Konopková R, Lacman J and Beneš V. Vertebral artery and osseous anomalies characteristic at the craniocervical junction diagnosed by CT and 3D CT angiography in normal Czech population: analysis of 511 consecutive patients. Neurosurg Rev 2017; 40: 369-376.
[22] Wakao N, Takeuchi M, Nishimura M, Riew KD, Kamiya M, Hirasawa A, Kawanami K, Imagama S, Sato K and Takayasu M. Vertebral artery variations and osseous anomaly at the C1-2 level diagnosed by 3D CT angiography in normal subjects. Neuroradiology 2014; 56: 843-849.
[23] Hart RG, Pearce LA, Bakheet MF, Benavente OR, Conwit RA, McClure LA, Talbert RL and Anderson DC. Predictors of stroke recurrence in patients with recent lacunar stroke and response to interventions according to risk status: secondary prevention of small subcortical strokes trial. J Stroke Cerebrovasc Dis 2014; 23: 618-624.
[24] Yan M, Wang C and Wang SL. Anatomic characteristics and variation of normal vertebral artery. Chin J Spinal Spinal Cord 2012; 22: 171-174.
[25] Burnett KR and Staple TW. Case report 132. Tortuous vertebral artery causing erosive defect of C2. Skeletal Radiol 1981; 6: 51-53.