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Multidetector computed tomography evaluation of origin, V2 segment variations and morphology of vertebral artery

R. Tasdemir, O.F. Cihan, Vertebral artery morphology

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Abstract

Background: The current study aimed to determine the origin of vertebral artery (VA) on both sides and the levels of entry into respective foramen transversarium (FT), to evaluate possible effects of sex on the entry levels, and to investigate the frequency of vertebral artery dominance (VAD) and vertebral artery hypoplasia (VAH) based on the vertebral artery V2 segment.

Materials and methods: For this study, archived images of patients undergoing MDCT (Multidetector Computed Tomography) examination of the chest and head-neck for various reasons at Gaziantep University Medical Faculty Hospital were reviewed retrospectively. Three-dimensional reconstructions were performed for a total of 644 VA images from 322 patients using Horos software, and VA origin, the level of entry to FT and transverse diameters of both VA and FT were measured at the point of entry.

Results: It was found that, among males, the VA originated from the truncus brachiocephalicus on the right side in only 1 patient and from the aortic arch in 2 patients on the left side. Left VA emerging from the aortic arch was observed in 2 females. The right vertebral artery was found to enter the FT at C3 in 1 male, at C4 in 6 patients (5 males, 1 female), at C5 in 19 patients (3 males, 16 females), and at C6 in 300 patients (141 males, 159 females. The left artery entered the FT at C5 in 23 patients (9 males, 14 females) and at C6 in 298 patients (141 males, 157 females). Looking at the relationship between variations of VA origin and the levels of entry to the FT, it was observed that only one of the left VAs originating from the arcus aorta entered the FT at C6 and at C5 in all others. On the right side, there was only one VA originating from the truncus brachiocephalicus, which entered the FT at C3. Of the remaining 248 vertebral arteries originating from the subclavian artery, 5 VAs entered the FT at C4, 14 VAs at C5 and 229 VAs at C6. The measurements of VA diameters showed right VA hypoplasia in 14 patients and left VA hypoplasia in 17 patients. Also, the right VA dominance was found in 110 patients and the left VA dominance in 128 patients. A moderate, positive correlation was observed between VA and FT diameters in both sides. A regression analysis showed that a 1 mm change in the right VA diameter was associated with a 75% change in the FT diameter and a 1 mm change in the left VA diameter caused a 72% change in the FT diameter.

Conclusions: An understanding of VA variations and FT morphometry is crucial for informed clinical practice. This will clearly affect the success rates of physicians in the diagnosis and treatment of pathologies involving cervical region. The presence of any VA variation in a patient should be investigated on CT or MRI images prior to surgery.

Key words: MDCT, morphometry, vertebral artery, foramen transversarium

INTRODUCTION

In classical anatomy knowledge, VA is divided into 4 segments, and the second segment, which we studied, is the region between the C6 and C2 foramen transversarium [15]. The vertebral artery accounts for 28% of the blood supply to the brain [32]. Therefore, any changes in the hemodynamics of the vertebral arteries may result in severe disorders in the cerebellum, brain stem, inner ear and spinal cord. The vertebral artery is the primary source of posterior circulation. Posterior circulation strokes represent about 20% of all ischemic strokes [9, 22], making the vertebral artery very important clinically [16]. Also, considering many functions of the hindbrain, blood flow is vital, and the vertebral arteries are among the most important medium-sized arteries that supply the hindbrain centers controlling cardiac and respiratory functions and balance [19].

Although rare, injury to the vertebral artery leads to severe consequences when it occurs. Traumatic vertebral artery injury poses a clinical challenge because it is difficult to diagnose and there are no established guidelines for its diagnosis and management [7]. In their study examining blunt cerebrovascular injuries, Sticco et al. (2021) reported that blunt vertebral artery injuries accounted for 1.1% of all trauma admissions, and ischemic stroke developed in only 0.71% of these patients [26]. In another study, Cothren and Moore reported that 25% of blunt vertebral artery injuries resulted in stroke, and through a survey of cervical spine surgeons, Lunardini et al. (2014) found that vertebral artery injuries occurred in 0.07%-1.4% of surgeries, and 10% of these injuries were associated with neurologic sequelae or death [6, 14]. Thus, vertebral artery (VA) anomalies along the V2 segment require careful evaluation of CT and MRI images prior to cervical spine surgery [25, 33].

The current study aimed to determine the origin of vertebral artery on both sides and the levels of entry into respective foramen transversarium, to evaluate possible effects of sex on the entry levels, and to investigate the frequency of vertebral artery dominance (VAD) and vertebral artery hypoplasia (VAH) based on the vertebral artery V2 segment.

MATERIALS AND METHODS

For this study, archived images of patients undergoing MDCT (Multidetector Computed Tomography) examination of the chest and head-neck for various reasons between 2015 and 2020 at Gaziantep University Medical Faculty Hospital were reviewed retrospectively. Of ~4000 patient scans identified through archive screening, 504 images suitable for the study purposes were selected.

The exclusion criteria were poor image quality due to motion artefacts or insufficient distribution of the contrast agent within the vertebral artery, patients with a tumor in or injury to the craniocervical junction, patients with a history of surgery and/or interventional procedure to the chest or head-neck region, images where vertebral artery segments were not covered in the field of view and patients aged under 18 or over 80 years of age. Ultimately, a total of 644 VA images from 322 patients satisfactory MDCT images from 171 females and 151 males were included in the study. The mean age of the patients was 52.14 ± 16.52 years. All measurements were obtained by a single investigator. The data were anonymized to avoid identification of the patients.

Image acquisition and processing: Patient images were acquired with a 64-detector MDCT (Light Speed VCT XTe; General Electric, Milwaukee, USA). In our study, 120 ml of non-ionic contrast agent with an iodine concentration of 300 mgI/ml was injected into the right or left antecubital vein with the help of an automated injector (Covidien LF OptiVantage DH, Ohio, USA) as a bolus at a rate of 4 ml/sec, followed by 40 ml of saline at a rate of 4 ml/sec. The following parameters were used for all scans: collimation, 40 mm (64 x 0.625); tube rotation time, 0.35 sec; pitch value, 1; X-ray tube operating at 100-120 kV and 150-600 milliampere; detector thickness, 0.625 mm; reconstruction interval, 0.625 mm.

Three-dimensional (3D) reconstructions of two-dimensional MDCT images were done using the open source Horos v.4.0.0 software (https://horosproject.org/). On the Horos software, the origin of vertebral artery (right and left) and the level of VA entry into the foramen transversarium (FT) were identified, and the transverse diameters of both VA and FT were measured on the right and left at the level where VA enters the foramen transversarium (Fig. 1). Hypoplasia was defined as a VA diameter of less than 2 cm [20, 10]. A difference of 0.3 mm or greater between the right and left VA diameters was considered as the criterion for VA dominance, and VA diameters were assumed to be equal in the case of a difference of less than 0.3 mm [21, 10].

Ethics approval

Ethics approval for the study was obtained from the Ethics Committee for Non-Interventional Clinical Trials of Gaziantep Islam Science and Technology University on July 13, 2021 (No. 2021/37).

Statistical analysis

Statistical analysis of the study data was performed using SPSS for Windows (23.0.0; SPSS Inc., Chicago, IL, USA). Percentage values were derived from the frequencies of the parameters. Chi-square test was used to analyze the relationship between sex and the level of entry of the vertebral arteries into the FT. The normality of data distribution was checked using Kolmogorov-Smirnov test. Pearson correlation analysis was used to investigate whether there was a correlation between VA and FT diameters. Regression analysis was employed to model the relationship between the diameters. A p value less than 0.05 was considered statistically significant

RESULTS

A total of 322 patients (171 females, 151 males) were included in the study and stratified into age groups of 18-44 years (115 subjects), 45-64 years (118 subjects) and 65-80 years (89 subjects). The parameters for the right and left vertebral arteries were measured for each patient individually and a total of 644 vertebral arteries were examined (Table 1).

The origin of the vertebral artery could be evaluated on the right side for 249 patients and on the left side for 241 patients. The right vertebral artery originated from the right subclavian artery in all patients (118 males, 130 females), except for one male patient (0.8%) in whom the VA originated from the truncus brachiocephalicus. The left vertebral artery originated from the arcus aorta in 2 male patients (1.7%) and in 5 female patients (4%). In the remaining patients, the left VA was found to originate from the left subclavian artery as usual (115 males, 98.3%; 119 females, 96%) (Table 2) (Fig. 2).

When we examined the level of entry of the vertebral arteries into respective foramen vertebrae in males, the right vertebral artery entered the foramen transversarium at C3 in 1 (0.7%) patient, C4 in 5 (%3.3) patients, C5 in 3 (2%) patients and C6 in 141 (94%) patients. In females, it was observed that the right VA entered the foramen transversarium at C4 in 1 (%0.6) patient, C5 in 16 (9.4%) patients and C6 in 154 (90.1%) patients. A significant difference was observed between sexes in terms of the entry of the vertebral artery to the foramen transversarium at C4, which was more common in males than in females ($p < 0.05$). Likewise, there was a significant difference between the sexes in the entry of the vertebral artery at C5, which was more common in females than in males ($p < 0.05$). On the left side, the VA entered the foramen transversarium at C5 in 23 patients (9 males, 14 females) and C6 in 298 patients (141 males, 157 females) (Table 3) (Fig. 3).

Looking at the relationship between variations of vertebral artery origin and the levels of entry to the foramen transversarium, it was determined that only one (14.29%) of the left VAs originating from the arcus aorta entered the FT at C6 and at C5 in all others (85.71%). On the right side, there was only one VA originating from the truncus brachiocephalicus, which was found to enter the foramen transversarium at C3. Of the remaining 248 vertebral arteries originating from the subclavian artery, 5 (2%) VAs entered the foramen transversarium at C4, 14 (5.65%) VAs at C5 and 229 (92.3%) VAs at C6.

The measurements of VA diameters showed hypoplasia of the right vertebral artery in 14 (4.35%) patients and hypoplasia of the left vertebral artery in 17 (5.28%) patients (Fig. 4). Based on the difference between the right and left VA diameters, the right VA dominance was found in 110 (34.2%) patients and the left VA dominance in 128 (39.8%) patients. The right and left VA diameters were equal in 84 (26.1%) patients (Table 4).

When we examined the relationship between the VA and FT diameters, a moderate, positive correlation was observed in both sides. A regression analysis of the relationship between the VA and FT diameters showed that a 1 mm change in the right VA diameter was associated with a 75% change in the FT diameter and a 1 mm change in the left VA diameter caused a 72% change in the FT diameter.

DISCUSSION

In our study, we have chosen to evaluate the parameters related to the vertebral artery and foramen transversarium on MDCT images since we considered that such an approach would provide more reliable data than measurements obtained from cadavers and also to achieve a larger sample size.

As the prevertebral segment of the vertebral artery originating from the aortic arch is less protected by bone, it is more vulnerable to injury and carries a high risk for tear during surgery [29]. Knowledge of the origin of the vertebral artery is important in planning vascular or cardiothoracic surgery. Anomaly of vertebral artery origin may result in disruption of cerebral hemodynamics, dissection or aneurysm formation due to congenital structural defect in the artery wall [11]. Therefore, screening of patients with anomalous VA origin for aneurysm may be considered, which may allow for endovascular treatment before subarachnoid hemorrhage or any other devastating event occurs, and reduce morbidity and/or mortality [24]. Data from separate studies indicate that anomalous origins of the left vertebral artery most commonly include those emerging from the aortic arch, with incidence rates ranging from 2.4 to 5.8% [2, 1, 13, 31, 12, 29]. In a study on cadavers, Woraputtaporn et al. (2019) did not observe any variations in the right VA origin, and Canyigit et al. and Yuan reported a rare incidence of such variations [31, 2, 29]. In our study, we observed that the left VA originated from the aortic arch on 5.7% of the images among those we could examine the VA origin. On the right side, the VA originating from the truncus brachiocephalicus was detected in only 1 out of 249 images (0.4%).

It has been reported that anomalies of the cervical vertebra and VA variations may also cause vertebral artery compression along its trajectory. Since cerebral hemodynamics will be impaired in the case of VA compression, this may lead to problems in the short and long-term such as aneurysm formation, risk of thrombosis, occlusion, dissection and atherosclerosis [5, 19]. Zhang et al. (2020) examined the incidence of anomalies of the V2 segment of the vertebral artery and reported that variations occurred mostly at C5, with a higher incidence (70.3% in total) compared to previous studies [33]. Woraputtaporn et al. (2019) investigated the variations of VA entrance to the foramen transversarium and observed that most of the left vertebral arteries entered the FT at C5 (4.1%), whereas the right vertebral artery entered at C4 and C5 in only one case each, and %99.2 of the right vertebral arteries entered the FT at C6 [29]. In a study on 515 cadavers, Yamaki et al. (2006) examined vertebral artery variations and found that most of the variations occurred at the C5 level on both the right (8.8%) and left (49.9%) sides, followed by C7, C4 and C3 respectively bilaterally [30]. In a large-scale study involving both patients and cadavers, it was reported that 43% of the left vertebral arteries entered the FT at C5, and 21.3% of the right vertebral arteries at C7 [31]. Consistently, in the current study, most of the VA variations at both sides were seen at the foramen transversarium of C5, with rates of 73.1% on the right side (among variations) and 100% on the left side (because entry at C5 was detected only for the left vertebral arteries).

In our study, among all cases studied, 8.1% of the right vertebral arteries and 7.2% of the left vertebral arteries entered the FT at C5 level. Although our results were in line with the literature in terms of the most common entry level variation, we observed a very low rate for variations in VA entry level on the left side.

When we examined the relationship between variations in the origin of the vertebral artery and the levels of entry to the foramen transversarium, it was observed that only one (14.29%) of the left vertebral arteries emerging from the aortic arch entered the FT of the 6^{th} cervical vertebra and others (85.71%) entered at the 5^{th} cervical vertebra. In one study (2015), Vasan et al. reported that the left VA of aortic origin entered the FT at the 6^{th}

cervical vertebra; however, in Meila et al.'s study (2012), the left vertebral arteries were found to enter the FT at 4th or 5th cervical vertebra [18, 17]. Regarding the right side, there was only one vertebral artery originating from the truncus brachiocephalicus among all cases, which entered the foramen transversarium at 3rd cervical vertebra in our study. Of the remaining 248 vertebral arteries originating from the subclavian artery, 5 (2%) entered the FT at 4th cervical vertebra, 14 (5.65%) at the 5th cervical vertebra, and 229 (92.3%) at the 6th cervical vertebra. Uchino et al. (2013) found that the left vertebral arteries emerging from the aortic arch entered the foramen transversarium at C4, C5 or C7, the right vertebral arteries originating from the subclavian artery entered the FT at C5, C4 or C3, whereas an abnormal right VA entered at C7 [27]. A study examining the entry levels of the vertebral arteries to foramen transversarium on MDCT images reported that while the left VA entered the FT at C7 in only 2 cases, at C5 in 30 cases, at C4 in 7 cases, and at C6 in 421 cases, the right VA entered the FT at C5 in 15 cases, at C4 in 10 cases and at C6 in 434 cases [25].

There is still no clear consensus on the VA diameter to be defined as hypoplastic. Although a VA diameter of 2 mm or less was defined as hypoplastic in many studies and atretic in others, it was considered as a variation in some other studies [28, 4, 3]. In the literature, the reported frequency of hypoplastic VA which has been associated with pathologies such as migraine and stroke ranges from 2% to 6% [23, 3]. In clinical practice, it is important to distinguish between VA hypoplasia and its stenosis or occlusion [10]. In a study investigating the relationship between vertebral artery hypoplasia and ischemic stroke, the authors detected unilateral and bilateral VA hypoplasia in 26.5% and 1.6% of healthy individuals respectively. Among the patients with ischemic stroke, 19.3% had right VA hypoplasia, 12.5% had left VA hypoplasia and 3.4% had bilateral VA hypoplasia, and therefore, a significantly higher frequency of hypoplastic VA was reported in patients with ischemic stroke [23]. To identify the role of hypoplastic VA in stroke, Chuang et al. (2006) evaluated 191 patients with acute ischemic stroke using magnetic resonance angiography (MRA) within 72 hours of stroke onset, and reported a unilateral hypoplastic VA incidence of 11.51%. They stated that this rate was higher especially in patients with brainstem/cerebellar infarction [20, 34] . In a study (2004) examining vertebral artery hypoplasia and asymmetry, Jeng and Yip found right VA hypoplasia in 7.8% and left VA hypoplasia in 3.8% of the patients [10]. In the present study, 5.28% of the left vertebral arteries and 4.35% of the right vertebral arteries were hypoplastic. Thus, our findings are consistent with the literature.

Knowledge of the FT morphology is important in surgery to confirm whether screw fixation can be performed safely [20]. Because of many morphometric anatomic variations found in different ethnicities, it is our belief that such surgical procedures should be performed with utmost care without relying solely on information from previous studies.

Moreira and Herrero (2020) observed that the diameter of foramen transversarium was likely to be increased with advancing age [20, 34]. In another study, Zibis et al. (2016) found a strong correlation between the vertebral artery and the foramen transversarium and suggested that variations of vertebral artery may lead to variations in foramen transversarium [20, 34]. Similarly, we observed a moderate positive correlation between FT diameters and VA diameters bilaterally in this study using 644 CT images. However, only a weak positive correlation was found between age and left FT diameter in our study.

El-Dwairi et al. (2021) examined 329 CT scans of a Jordanian sample to generate a database of foramen transversarium dimensions, and reported mean FT diameters of 4.62 ± 0.52 mm on the right side and 4.76 ± 0.51 mm on the left side [8]. The authors also reported larger FT size in males than in females, and FT diameters were found to increase with increasing age. In our study, the mean right FT diameter was 6.39 ± 0.93 mm and the left FT diameter was 6.25 ± 0.91 mm. We consider that this difference may be related to the differences in the mean age or ethnicity of the samples studied. Our findings are in line with those of previous studies with respect to sex and age. We suggest that the increase in FT diameter with age may be attributed to morphological degeneration.

CONCLUSIONS

Extraforaminal variations are important considerations in planning cervical spine surgeries. An understanding of VA variations and FT morphometry is crucial for informed clinical practice. It is our belief that this will affect the success rates of physicians in the diagnosis and treatment of pathologies involving cervical region. We think that the presence of any VA variation in a patient should be investigated on CT or MRI images prior to surgery.

Conflict of interest: None declared

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Table 1. Distribution of MDCT images by age and sex

	Female	**Male**	**Total**
Group 1 (18 to 44 years)	71	44	**115**
Group 2 (45 to 64 years)	61	53	**114**
Group 3 (65 to 80 years)	35	54	**89**
Total	**171**	**151**	**322**

Table 2. Distribution of the origins of vertebral artery.

	Right VA		**Left VA**		**Total**
	Female	**Male**	**Female**	**Male**	
Subclavian artery	130	118	119	115	**482**

Aortic arch	-	-	5	2	**7**
Brachiocephalic trunk	-	1	-	-	**1**
Total	**130**	**119**	**124**	**117**	**490**

		C3	**C4**	**C5**	**C6**	**C7**
Right VA	Female	-	1	16	154	-
	Male	1	5	3	141	-
Left VA	Female	-	-	14	157	-
	Male	-	-	9	141	-
Total		**1**	**6**	**42**	**593**	-

Table 3. Distribution of the entry levels of the vertebral artery to foramen transversarium.

Table 4. Frequencies of VA hypoplasia and dominance.

	Right VA	**Left VA**	**Total**
VA hypoplasia, n (%)	14 (4.35%)	17 (5.28%)	31 (9.63%)
VA dominance, n (%)	42 (13%)	58 (18%)	100 (31%)

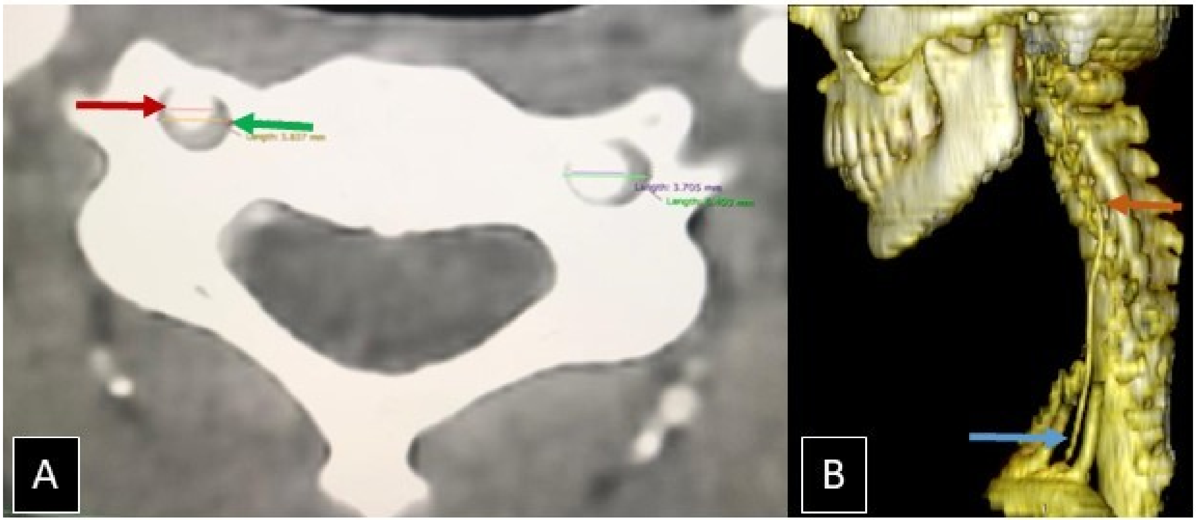

Figure 1. A: The green arrow shows the transverse diameter of the foramen transversarium, and the red arrow shows the transverse diameter of the vertebral artery. B: The blue arrow indicates the origin of the vertebral artery, the red arrow the level at which it enters the foramen vertebrae.

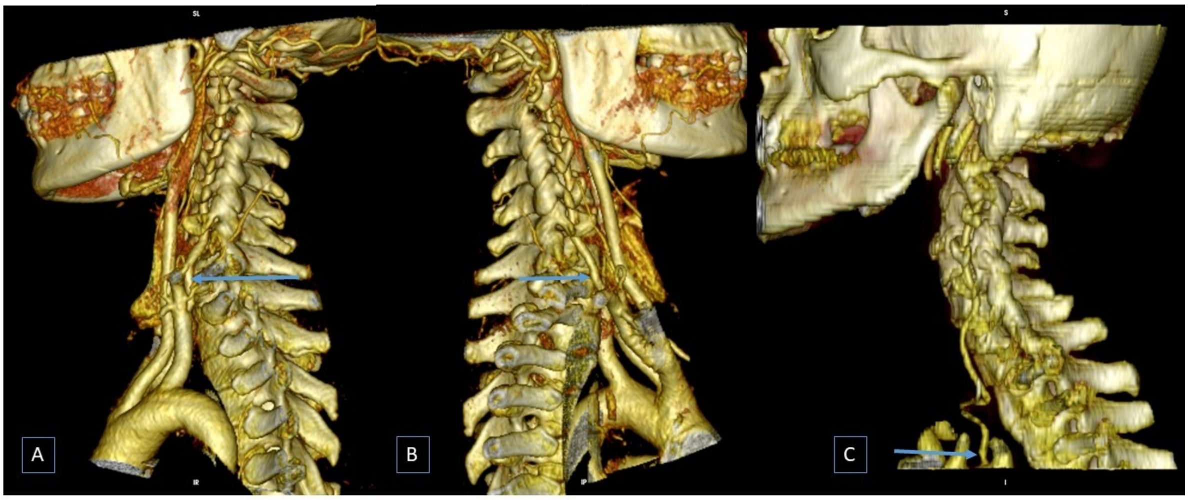

Figure 2. A: left VA originating from the left subclavian artery, B: right VA originating from the right subclavian artery, and C: right VA originating from the aortic arch are shown.

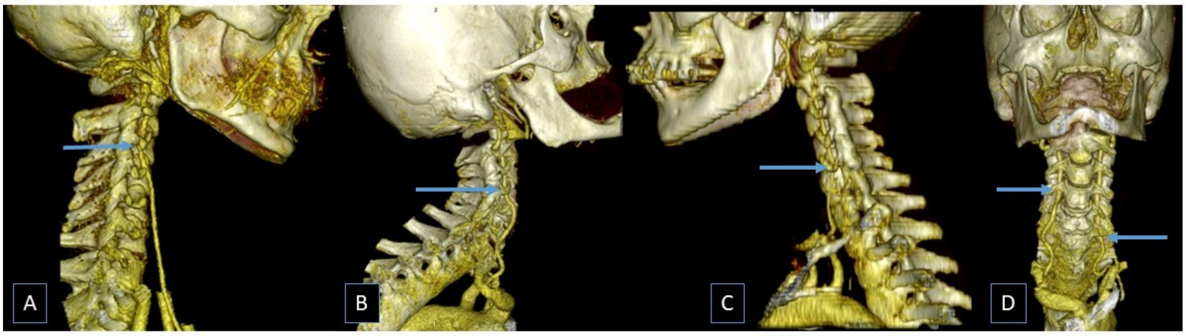

Figure 3. The entrances of A: the right VA through the foramen of the 3rd cervical vertebrae; B: the right VA through the foramen of the 4th cervical vertebra; C: the left VA through the foramen of the 5th cervical vertebra; and D: the right VA through the foramen of the 4th cervical vertebra, and the left VA through the 6th cervical vertebra are shown.

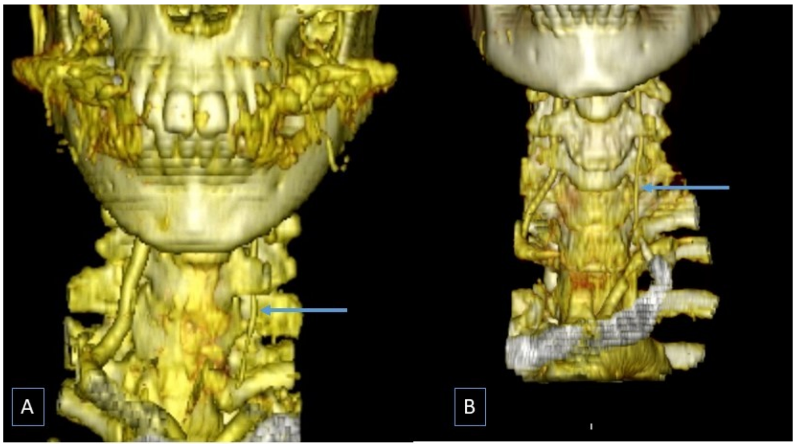

Figure 4. A and B: left-sided hypoplasic VA from different patients is shown.