Anatomical Variations and Dimension of the Intracranial Vertebral Artery: Evaluation With Multidetector Computed Tomography Angiography

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Abstract

The intracranial segment of the vertebral artery (VA) is the unique part of the artery where the two VAs join to form a single vascular channel, viz. the basilar artery. In addition to this typical description, anatomical variations have been described; the presence of anatomical variation has been associated with some pathological processes, neurological complications, and the risk of vascular diseases in the posterior circulatory territory. We evaluated the typical anatomical features and variations of the VA4 component of the VA in a South African population to provide useful data on the prevalence of variation and morphometry of the distal VA. The study is an observational, retrospective chart review of 554 consecutive South African patients (Black, Indian, and White) who had been examined with multidetector computed tomography angiography (MDCTA) from January 2009 to September 2019. We observed various anatomical variations in the VA4 segment of the VA. We report the incidence of VA hypoplasia, hypoplastic terminal VA, and atresia. Fenestration and duplicate posterior inferior cerebellar artery (PICA) origin were also observed. The left intracranial VA was significantly larger than the right. Our study shows that anatomical variation of the intracranial VA is common in the population studied, with a total prevalence of 36.5%. Imaging of the entire course of the VA from the origin to the point of convergence to form the basilar artery may be necessary to decide a treatment strategy for interventions in the vicinity of the VA.

Introduction

The vertebral artery (VA) emanates from the superior-posterior part of the subclavian artery and proceeds through the foramen transversarium of the cervical vertebra. The left and right VA penetrates the dura mater to enter the intracranial space through the foramen magnum, where they converge to form the basilar trunk at the pontomedullary junction [1]. Anatomically, the VA is divided into four segments. The first three segments (VA1, VA2, VA3) are the extracranial segments, extending from the origin to where they penetrate the dura mater. The fourth segment of the VA (VA4) is intracranial, extending from the foramen magnum to the point where the left and right VA anastomose to form the basilar trunk [2]. The geometry of the basilar trunk depends on the pattern of the bilateral VAs. When there is an asymmetry of bilateral VAs or other morphological variations, the basilar trunk sometimes bends away from the midline [3]. Previously reported anatomical variations of the intracranial VAs include VA terminating as posterior inferior cerebellar artery (PICA), known as atresia, fenestration, asymmetry, and hypoplasia. Anatomical variations play a significant role in the clinical sequelae of an iatrogenic VA injury, which can vary widely [4]. For instance, damage to the dominant VA when the contralateral VA terminates as PICA can result in devastating complications since the dominant VA solely forms the basilar artery.

The presence of variation has been associated with some pathological processes, neurological complications, and the risk of vascular diseases in the posterior circulatory territory. For instance, atresia and hypoplasia have been associated with hypoperfusion of brain tissues and hemodynamic

insufficiency, which may predispose to transient ischaemic attacks or acute brainstem ischaemic stroke [5,6].

Reports on the prevalence of anatomical variations of the intracranial VA are scarce, with few previous reports in the Western population (Caucasians) [1], the Asian population [5], and the Turkish population [7]. Previous studies from the African continent used post mortem and cadaveric histological samples to report on average diameter and incidence of VA hypoplasia [8, 9,10]. Advances in modern imaging technology that led to the establishment of multidetector computed tomography angiography (MDCTA) have made endovascular procedures popular. These procedures require a detailed understanding of typical anatomy and the extent of anatomical variations of the VAs. Consequently, a report on the prevalence of possible variant anatomy will help in the interpretation of radiographs, prevention of iatrogenic injuries, and contribute to the advancement of non-invasive surgical intervention.

In the present study, we assessed the typical anatomical features and variations of the V4 segment of the VA using MDCTA. We aimed to determine the dimensional characteristics and prevalence of anatomical variations of the intracranial VA in a South African population. Due to the multiracial composition of the South African population, in addition to the overall incidence of variation, we also report variations based on three racial groups: Black, Indian, and White South African. It is necessary to have correct and detailed information about the typical anatomy and prevalence of anatomical variations. Such information is essential before neurosurgery, endovascular and non-invasive procedures. The detailed information from this study will be useful in neurosurgery, anatomy, endovascular, and non-invasive procedures.

Materials And Methods

Study population

This study is a retrospective observational review of 554 MDCTA images of South African patients. The patients underwent MDCTA for various reasons between January 2009 and September 2019. Images were obtained from the database of Lenmed Ethekwini Hospital and Heart Center, Durban, South Africa. The Biomedical Research Ethics Committee of the University of KwaZulu-Natal approved the study (Ethical No: BE 148/19) and waived the need for informed consent as this study utilized retrospective chart reviews. There was no patient contact, and no patient details were released from images. All methods were carried out in accordance with relevant guidelines and regulations. The angiographies were from 307 males (55.4%) and 247 females (44.6%). The average age of the patients is reported as median (IQR): 62 (23) (range: 10–99) years; 61 (23) for male patients and 62 (25) for female patients. The race was defined according to the guidelines outlined in the modern systems of racial classification in the Republic of South Africa [11]. The criteria used in the scheme of racial classification include skin colour and ancestry. The South African population is divided into four main racial groups: White, Black, Indian, and Coloured. Three population groups were included in the present study: Black 91 (16.4%), Indian 176 (31.8%), and White 287 (51.8%). According to the modern system of classification, a White individual was defined as a person of European descent. A Black individual was defined as a person having origins in

any of indigenous Africa or Native group. An Indian individual was defined as a person of Asian descent [11].

The MDCTA images were analyzed using picture archiving communication system (PACS) tools. The images were examined for vascular variations by a neurosurgeon, a neuroradiologist, and an anatomist using the coronal and sagittal view and the 3D reconstructed images. Exclusion criteria included CTA scans that showed no clarity of the VA's course, and scans with motion artefacts or poor-quality imaging.

CT Angiography Protocol and Imaging Reconstruction

The imaging examination was performed on a 64-detector row computed tomography (CT) scanner (Lightspeed CT, GE Healthcare Medical Systems, Milwaukee, WI, USA) with the scanning protocol as follows: 120 kVp, 697 mAs, beam collimation 64 × 0.625 mm, gantry rotation time 0.4 s, section thickness of 0.625 mm, pitch 0.969:1 and reconstruction interval of 0.625 mm. During the procedure, 80 mL of non-ionic iodinated contrast followed by 40 mL saline was infused via a double power injector (Medex flowSens, Geubert USA) into the patient’s antecubital vein (4 mL/s).

Postprocessing of three-dimensional images was performed using multiplanar reformation (MPR), maximum intensity projection (MIP), multiplanar reconstruction (MPR), and volume rendering (VR) algorithms. The volumetric MDCTA data sets were processed on Advanced Workstation 4.2 (GE Healthcare, Milwaukee, WI, USA).

Analysis of Morphological Variation and Dimensions of the V4 Segment

Each MDCTA image was examined for the presence of morphological variations. The following parameters were measured on a coronal view of the MDCTA (Fig. 1): 1) the diameters were measured along the course of the VA at a distance of 11 mm cranial to the entrance of the VA into the foramen magnum, 2) the length of the VAs was measured from the foramen magnum to the point of union with the contralateral VA, and 3) the angle between the bilateral VA at the vertebrobasilar junction. We were unable to appropriately quantify the frequency of the PICA and the spinal arteries because visualization of branches (such as the PICA and spinal arteries) is usually beyond the limits of the MDCTA. A diameter of ≤ 2 mm was described as hypoplasia; we classified the VA as dominant if the diameter was larger than that of the contralateral side by any size difference according to the method provided by Ergun and co-authors [12]. When the bilateral VAs had a similar diameter, we referred to them as “equal” or “codominant.” Results were analyzed separately for the left and right sides.

Statistical Analysis

All data were analyzed using SPSS version 27 (SPSS Inc., Chicago, IL, USA). Categorical variables were analyzed using the chi-square test. A Kolmogorov-Smirnov test was used to assess the normal distribution of continuous data. Because the distribution of the data was not normal, nonparametric tests

were used. The Kruskal-Wallis test followed by the Wilcoxon Signed-Rank test was used to detect significant differences in the obtained values. The interclass correlation coefficient was used to examine the reliability of measurements. All tests were performed at 95% confidence with a p-value of < 0.05.

Results

Continuous and categorical data are presented as the median and interquartile range (IQR) and percentage (N). The interclass correlation coefficient for intra-observer reliability testing was 92% for V4 length, 93% for diameter, and 96% for the angle at the VBJ. For inter-observer reliability testing, the intraclass correlation was 85% for V4 length and diameter; 87% for the angle at the VBJ.

Variation in Morphology

We observed the following variations of the intracranial segment: (1) The incidence of hypoplasia and hypoplastic terminal VA. (2) VA terminating as PICA (Atresia). (3) Fenestration (One was observed at the right intracranial VA, while the other was observed at the vertebrobasilar junction). (4) Duplicate origin of the PICA. The incidence of these variations is summarized in Table 1. The incidence of VA hypoplasia is significantly high in White, followed by Indian on the right (p = 0.01). There was no significant difference across the races on the left (p = 0.61). Also, there was no significant racial difference in the incidence of hypoplastic terminal VA (p = 0.26) and atresia (p = 0.54).

Morphometric Analysis of the intracranial Vertebral Arteries

Diameter

The average diameter of the left VA (3.17 (0.62) mm) was similar to that of the right VA (3.17 (0.7) mm). However, the Wilcoxon Signed-Rank test showed a significant difference (p < 0.001). This is because the Wilcoxon Signed-Rank test is a rank-sum test and not a median test. The sum of positive Ranks of the left VA was significantly greater than that of the right VA. We observed a left pattern of dominance in 45.3% (251/554) patients; the right side was dominant in 32.7% (181/554) patients. The left and right VAs was equal in diameter in 11.9% (66/554) patients. Concerning the racial groups, no significant differences were observed (Right VA, p = 0.567; Left VA, p = 0.180). The group diameters are summarized in Table 2. For gender, the diameters are summarized in Table 3. There were no significant gender differences in VA diameter (Right VA, p = 0.528; Left VA, p = 0.274).

Length

The length of the left (32.36 (7.18) mm) intracranial VA was significantly greater than the right (31.50 (7.22) mm). Within the racial groups, there were no significant differences (Right VA, p = 0.386; Left VA, p = 0.708). The average length and laterality of the VA across the racial groups are summarized in Table 2. There were no significant gender differences in the length of the VA (Right VA, p = 0.665; Left VA, p = 0.615). The results are summarized in Table 3.

The angle at the Vertebrobasilar Junction.

The angle at the vertebrobasilar junction was 46° (18°). Within the racial groups, the average angle in Black patients (51° (22°)) was significantly larger than in White (47° (18°) p = 0.037) and Indian (42° (16°) p = 0.000) patients. A significant difference was also observed between the White and Indian (p = 0.010) patients. There were no significant gender differences (p = 0.103).

Discussion

Our study shows that MDCTA made it possible to evaluate anatomical variations of the intracranial VA. We found that variation is common in the population studied, with a total prevalence of 36.5%. The most frequently observed is VA hypoplasia. The incidence of hypoplasia in the present study (8.3% on the right and 6.5% on the left) is similar to the report of Ergun et al. [12]. These authors defined VA hypoplasia using diameter criteria of ≤ 2 mm and reported an incidence of 7.1% on the right and 9.4% on the left among 254 patients in their angiographic series [12]. By contrast, Songur and co-authors in their autopsy study reported a relatively high incidence of 20.2% on the right, 14.4% on the left, and 4.3% bilaterally using a similar definition of VA hypoplasia [7]. Sometimes it is challenging to compare data from different populations and research groups due to the differences in study modalities, distribution of data, and average diameter. According to a recent report, an individual's VA diameter may depend on anthropometric parameters such as height [13]. All these factors may contribute to the wide range of differences reported in the literature. VA hypoplasia is a congenital anatomical variation that has been previously described with a cut-off diameter between 2.0 mm and 3.0 mm [14].

In addition to hypoplasia, we also noticed that the hypoplastic terminal portion of the unilateral intracranial VA is a common anatomical variant of the studied population (Fig. 2b). The VA seems to divide at a spot along its courses to a PICA branch and a tiny branch that joins the contralateral VA. Pekcevik and co-author proposed another terminology for this type of variation; vertebral artery continued as PICA [15]. In our own opinion, this suggested anatomical term can be confused with VA terminating as PICA or VA ending as PICA (atresia). We suggest that this variant anatomy can be simply described as hypoplastic terminal VA.

The reduced diameter of hypoplastic VA has been associated with an increased probability of spontaneous dissection [16] and ipsilateral PICA and lateral medullary infarctions due to suspected atherosclerosis as a result of abnormal hemodynamics [17]. Recently, VA hypoplasia has been associated with an aneurysm of the contralateral dominant VA, most especially at the site of PICA origin [18]. Knowledge of pathologies associated with VA hypoplasia can provide some clues and help diagnose pathological processes in the posterior circulatory territory.

In our series, the percentage of patients having VA atresia is 6.7% (Fig. 2a). Prevalence of VA atresia has previously been reported as up to 9% [5,19]. Our results were in accordance with the range of the reported prevalence but most similar to that reported by Liu et al. (6.3%) [5]. Clinically, VA atresia has been

previously linked to rotational vertebral artery syndrome (RVAS) [20] and bow hunter's syndrome [2,21], which may result from compression of this variant vessel.

Another important finding in the present study is the variant origin of atretic VA from the aortic arch (Fig. 2a). Some authors have previously reported this type of co-existing anatomical variation [19]. However, the true prevalence has not been established. Out of the 554 patients in our series, 38 left VA directly originated from the aorta arch, and 4 of the 38 VAs were atretic (11%). Knowledge of this variant anatomy is essential when planning for thoracic aortic surgery. Obstruction of this type of VA can increase the risk of posterior circulatory stroke [19]. In addition, VA atresia has been suspected to contribute to ischemic events in the vertebrobasilar system (Liu 2017).

We also observed fenestration at the right intracranial VA in one of the patients (Fig. 3b) and the proximal part of the basilar artery in another patient. Our observation is similar to the report of Dzierzanowski et al., which reported two fenestrations in the Caucasians [1]. Fenestration of the vertebrobasilar artery is a congenital anomaly that involves lumina division of an artery with a single origin into two separate channels that later reunite distally. Embryologically, the VA and the basilar artery develop from different primitive vessels. The VA is formed from the cervical intersegmental arteries, while the basilar artery develops from the longitudinal neural arteries. As a result of these, fenestration at the V4 segment of the VA is due to the absence of obliterations of two intersegmental vessels that fused [22]. Fenestration of the proximal basilar occurs due to partial failure or incomplete fusion of the longitudinal neural arteries and regression of the bridging arteries connecting the longitudinal arteries [23]. Fenestration may predispose to aneurysm around the fenestrated portion of the artery [7,15], and it has also been previously associated with unexplained subarachnoid hemorrhage [24]. In addition to the associated pathologies, knowledge of this variation is essential in clinical diagnosis as fenestration may be misinterpreted as an aneurysm or a dissection on magnetic resonance imaging [15].

In the present study, duplicate PICA origin was registered in one of the patients. It is important to note that duplicate PICA origin is different from the duplication of the PICA. In the duplicate origin, the PICA has two separate origins that later converge distally in the course of the artery (Fig. 3a). Whereas in duplication of the PICA, there is no distal arterial convergence [25]: each artery courses separately. Duplicate PICA origin is a rare congenital morphological variation of the PICA with a prevalence of roughly 1.45% previously reported in the Western population (White and Asian) [25]. Clinically, duplicate PICA origin has been previously reported to highly predispose to intracranial aneurysm formation with an associated incidence between 50% and 71% [25,26]. Embryologically, Lesley and co-authors hypothesized that duplicate PICA origin might be a manifestation of underlying deficient vascular developmental disorganization, which may upraise the tendency toward formation of an intracranial aneurysm [25]. Considering the unique embryogenesis, adequate perfusion of the regions supplied by the PICA may rely on flow from both origins [26]. Since duplicate PICA origin is an uncommon variation with few previous reports, it should not be overlooked when evaluating the diagnosis and surgical intervention images. Because visualization of branches of the intracranial VA (PICA and spinal arteries) is usually beyond the

limits of MDCTA, the frequency of PICA on the left, right, and bilateral PICA in the present study is low (15.7%, 13.9%, and 14.8%, respectively). We also observed bilateral and unilateral double PICA in 5 patients. Therefore, we cannot appropriately quantify the frequency of the PICA in all the VAs.

The average diameter and length of the VA in our result is consistent with the previous report on a South American population (Diameter Left- 3.12 ± 0.85 mm, Right- 2.94 ± 0.77 mm; Length Left- 33.86 ± 5.59 mm, Right- 32.47 ± 4.8 mm) [27] based on autopsy samples and another angiographic study of the Caucasians (Diameter Left- 3.16 ± 0.63 mm, Right- 2.78 ± 0.44 mm; Length Left- 31.51 ± 6.51 mm Right- 24.25 ± 6.76 mm) [1]. We observed a significantly larger diameter on the left compared to the right VA, which is comparable to the previous reports mentioned above. Interestingly, there was no significant difference across the racial groups and gender in our series. By contrast, a previous histological study of a South African population (Witwatersrand region) reported an average diameter (Left- 2.68 ± 0.86 mm, Right- 2.53 ± 0.75 mm) [9] that was lower than the present study. The differences in the study modalities (CTA vs. cadaveric) may be responsible for the contrariety noticed in the results. Tissue shrinkage associated with histological tissue processing may be the reason for the reduced diameter.

We described the pattern of dominance using the criterion of any size difference between the left and right VA; 45.3% showed left dominance, 32.7% showed right dominance, and 18.4% showed codominance. Using a similar criterion, Ozdemir et al. reported similar results of left dominance in 64% of patients and right dominance in 31% of patients [28]. In contrast, Ergun and co-authors reported right VA dominance in 49.5% and left dominance in 47.2% of patients using a similar criterion as described above [12]. Our result shows that most of the patients have left dominant VAs. Noticeably, we observed more VA hypoplasia and atresia on the right. Knowledge of the dominant VA is required for some endovascular procedures. It is also important to preserve the dominant VA since they are likely to predominates the basilar artery. This information is vital to reduce the risk of neurological symptoms that may results from iatrogenic injury.

The angle at the vertebrobasilar junction in the present study is comparable with the report of Songur et al. (52.2 ± 18.2°) [7]. On the contrary, other authors reported a larger mean angle (85.45 ± 10.76°) [1]. The disparity may have resulted from the confluence of the bilateral VA, which can either be a sharp or blunt edge depending on the pattern and frequency of asymmetry. It is essential to consider the geometry of the vertebrobasilar junction while planning for surgical interventions in this region. This region is of particular interest to neurosurgeons and radiologists due to various interventional neuroradiological procedures conduct in the area to treat vascular diseases such as arterial dissections, aneurysms, arteriovenous malformations, dural fistula, or repair of an occlusive disease [29]. In atresia, the VA did not fuse with the contralateral VA but terminated as PICA. The contralateral VA solely proceeds to form the basilar artery. In the case of hypoplastic terminal VA, the contralateral VA predominates the basilar artery with little contribution from the tapering end of the hypoplastic terminal VA. In addition to asymmetry, these two conditions can also cause the basilar artery to bend from the midline (Fig. 2b, also known as

bending basilar) [30]. Deviation and prominence of a vessel, such as bending basilar due to dominance of one of the VAs, may cause compression of cranial nerves [15].

Conclusion

Our study shows that anatomical variation of the intracranial VA is common in the population studied, with a total prevalence of 36.5%. Hypoplasia and hypoplastic terminal VA being the most frequent. Imaging of the entire course of the VA from the origin to the point of convergence to form the basilar artery may be necessary to select a treatment strategy for interventions in the vicinity of the VA. Understanding the patterns of anatomical variations of the VAs will contribute significantly to the interpretation of ischemic areas and diagnosis of various diseases in the posterior circulatory territory.

Declarations

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Competing interest: The authors declare no competing interests.

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Consent for publication: Not applicable

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Code availability: Not applicable

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Tables

Table 1: Incidence of Anatomical Variations at the intracranial segment of the VA diagnosed by CTA.

Type of Variation	Total number of patients (incidence%)	Left/Right/ Bilateral	Male/Female
Hypoplasia	89 (16.1)	36/46/7	56/33
Hypoplastic terminal VA	73 (13.2)	37/36	46/27
VA terminating as PICA (Atresia)	37 (6.7)	15/22	24/13
Fenestration	2 (0.4)	0/1	1/1
Duplicate PICA origin	1 (0.2)	0/1	0/1

Table 2: Diameter and length of the vertebral artery V4 segment grouped according to race and laterality in South African patients

	Black		Indian		White	
	Left	Right	Left	Right	Left	Right
V4 Diameter	3.17(0.7)	3.17(0.7)	3.17(0.69)	3.17(0.7)	3.17 (0.62)	3.17 (0.68)
V4 Length	32.74(9.13)	30.71(9.15)	32.20(7.74)	30.86(8.6)	32.38(6.87)	31.61(6.34)

Results are reported as median (IQR) mm

Table 3: Diameter and length of the vertebral artery V4 segment grouped according to gender and laterality in South African patients

	Male		Female	
	Left	Right	Left	Right
V4 Diameter	3.17 (0.62)	3.17 (0.7)	3.17 (0.62)	3.17 (0.62)
V4 Length	32.29 (7.34)	31.59 (6.92)	32.38 (6.68)	31.48 (7.69)

Results are reported as median (IQR) mm

Figures

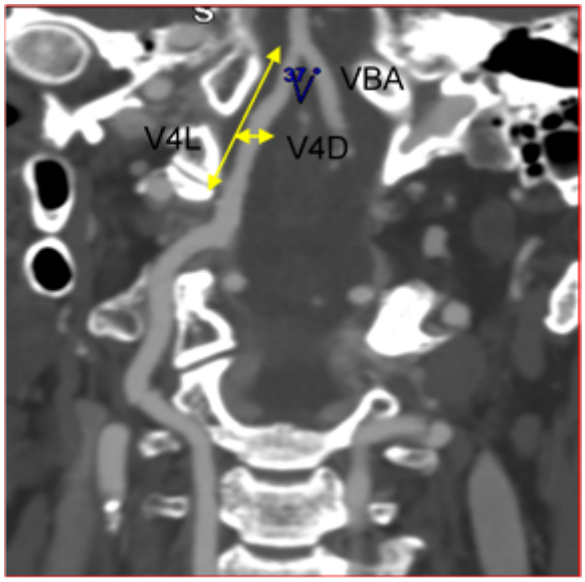

Figure 1

Coronal view of CTA image, showing the V3 and V4 segments of the VA. V4L – length of the V4 segment; V4D –Diameter of the V4 segment; VBA – angle at the vertebrobasilar junction

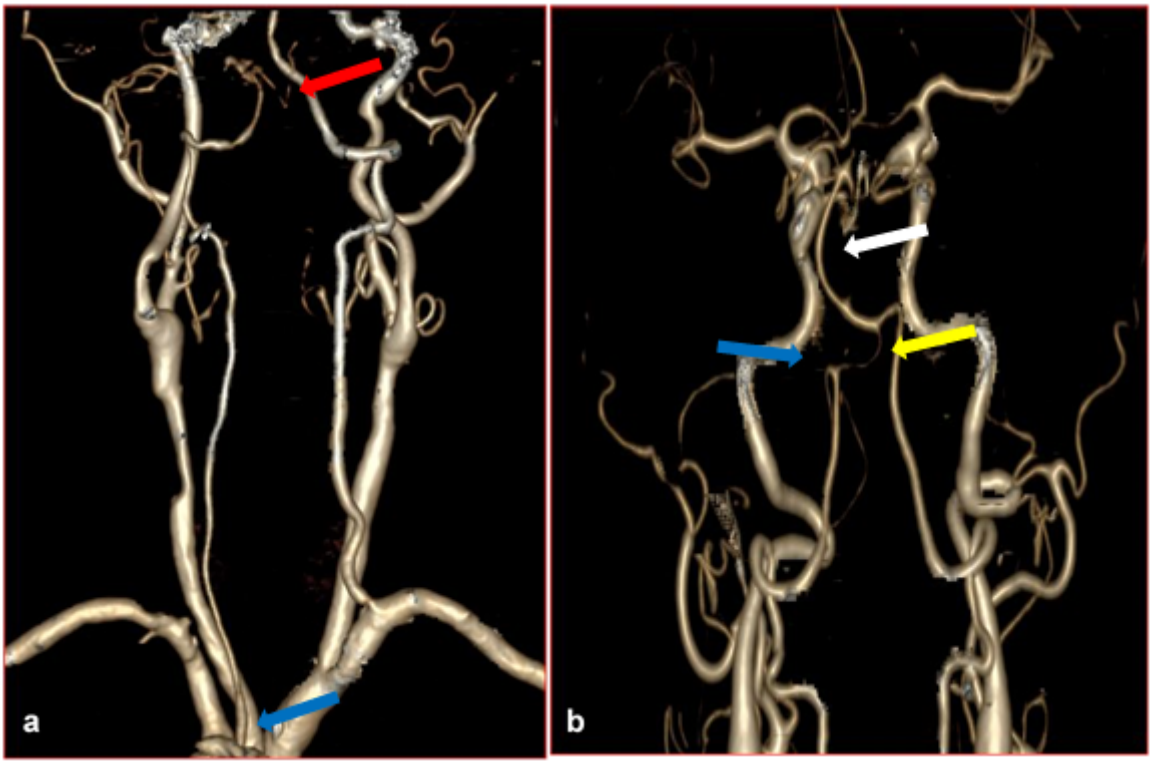

Figure 2

3D-CTA reconstructed images showing the vertebral, the subclavian and the carotid arteries. a) The blue arrow illustrated the origin of the left VA from the arch of the aorta and the red arrow shows the termination of ipsilateral VA as PICA. b) The blue arrow illustrated the point division into a PICA and a tiny

branch that joins the contralateral dominant VA. The yellow arrow shows hypoplastic terminal VA while the white arrow shows the bending basilar artery

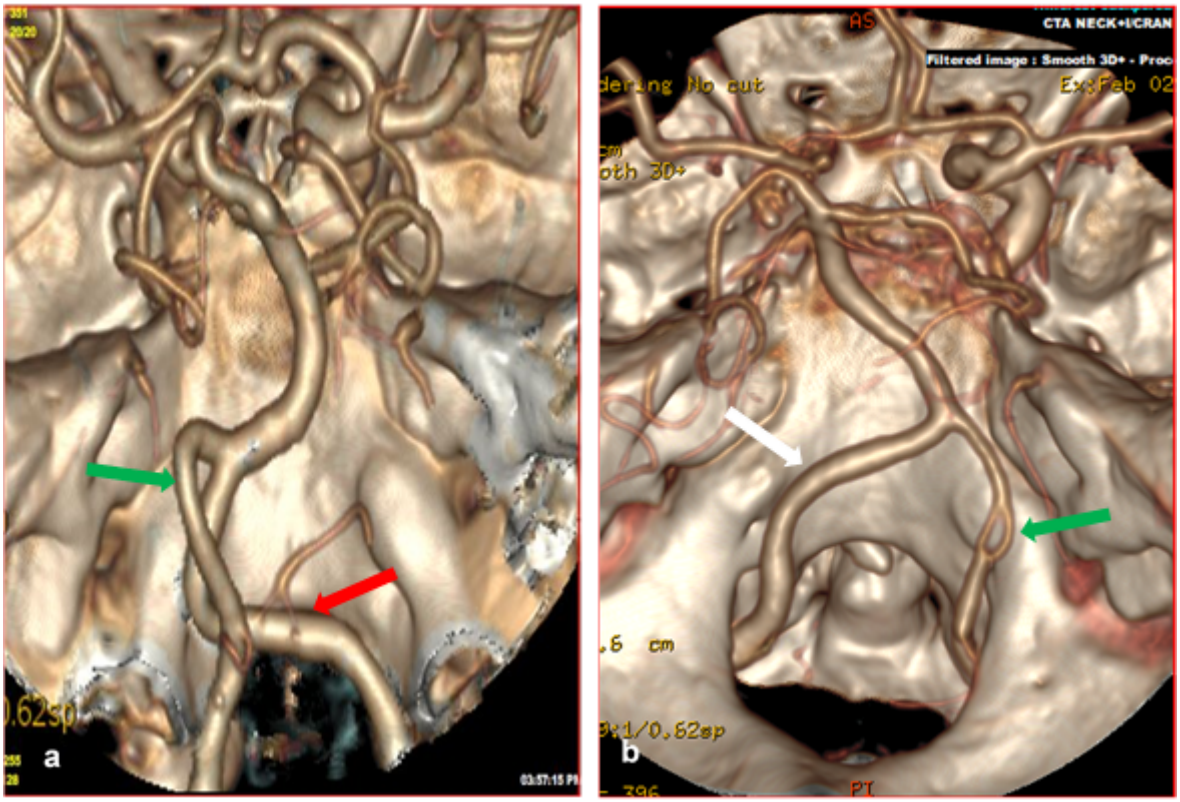

Figure 3

3D-CTA reconstructed images showing the vertebral, the basilar arteries, and the Circle of Willis. a) The red arrow illustrated duplicate PICA origin; while the green arrow shows the right VA. b) The green arrow shows fenestration of right intracranial VA while the white arrow shows the contralateral left VA