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# Radiological anatomy of the suboccipital segment of the vertebral artery in a select South African population

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## SUMMARY

Vertebral artery (VA) injuries remain one of the most encountered complications during surgical intervention at the craniovertebral junction (CVJ). Anatomically, the suboccipital segment is the most complicated segment of the VA. The artery undergoes a series of bends to form proximal and distal loops. In addition to this standard anatomical description, previously reported variant anatomies such as fenestration, persistent first intersegmental artery (FIA), hypoplasia, and extradural origin of the posterior inferior cerebellar artery (PICA) also contribute to the complexity of this segment. We evaluated the anatomical features of the V3 component of the VA in a South African population to provide useful data on the prevalence of variation and morphometry of the VA. The study is an observational, retrospective chart review of 554 consecutive South African patients (Black, Indian, and White) who had undergone computed tomography angiography (CTA) at Lenmed Ethekwini Hospital and Heart Centre, Durban, South Africa, from January 2009 to September 2019. Various morphological variations were registered in the course of the VA: (1) Hypoplasia; (2) Extradural (V3) origin of PICA; (3) persistent FIA; and (4) VA fenestration. Hypoplasia was observed in 5.6% of cases. The overall prevalence of the last three variations was 4.2% of the total patients. Codominance was observed in 42.6% of patients, left dominance in 34.3%, and right dominance in 23.1% of patients. Since failure to identify these morphological variations can result in inadvertent injury to the VA with serious neurological consequences, it is therefore imperative to recognize these variations preoperatively. Knowledge of these variations will also assist in the interpretation of radiographs.

**Key words:** Suboccipital segment of the vertebral artery – Vertebral artery hypoplasia – Fenestration – Vertebral artery dominance – Posterior inferior cerebellar artery – Persistent first intersegmental artery

## INTRODUCTION

Vertebral artery (VA) injuries remain the most common type of injury during cervical spine

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surgery (DeCarvalho et al., 2019). The risk of injury as a complication of surgery is a major problem, especially at the craniovertebral junction (CVJ) due to the variable course of the artery (Yamazaki et al., 2012). The VA is classically divided into four segments. The first segment (V1) extends from the origin at the subclavian artery to the C6 transverse process. The second segment (V2) extends from C6 to axis vertebra (C2) transverse processes. The third segment (V3) extends from the transverse foramen of the C2 to the point of penetration of the dura mater at the foramen magnum. The intracranial segment (V4) extends from the foramen magnum dura to the vertebrobasilar junction. The V3 part is the segment of the artery at the CVJ, also known as the suboccipital segment (Campero et al., 2011). The V3 is the most anatomically complicated segment of the VA. The artery undergoes a series of bends to form a proximal and a distal loop while passing through the transverse foramen of the axis and atlas vertebrae. Although arterial tortuosity is a morphological variation in the course of the VA frequently reported in the V1 and V2 segments, natural loop formation distinguishes the V3 from other segments of the artery.

The V3 segment of the VA is subdivided into three portions: the vertical part (V3v) ascends through the transverse foramen of C2 and atlas (C1); the horizontal part (V3h) extends from the transverse foramen of C1 and courses in the VA groove on the upper surface of the posterior arch of the atlas; and an oblique part (V3o) extends from the groove to the point of penetration of the posterior atlantooccipital membrane (George and Cornelius, 2001, Ulm et al., 2010). Apart from this standard anatomical description, anatomical variants such as fenestration, persistent first intersegmental artery (FIA), posterior inferior cerebellar artery (PICA) arising from the V3 segment, and hypoplasia have been reported at this segment (Uchino et al., 2012; Fortuniak et al., 2016). Failure to identify these morphological variations preoperatively may compromise collateral circulation resulting in brainstem infarction (Fortuniak et al., 2016). In FIA, the VA courses below the C1 arch to enter the spinal canal after leaving the transverse foramen of C2 without passing through the transverse foramen of C1. Fenestration was registered when the VA split into two vessels along the V3 segment, which rejoined distally before entering the dura mater. The origin of the PICA from the V3 segment was recognized as the extradural origin of PICA.

The prevalence of fenestration, persistent FIA, and PICA arising from the V3 segment have been observed in the normal population without CVJ anomalies. Most of the reports are from the Asian continent (Uchino et al., 2012; Wakao et al., 2014; Kim, 2016, Arslan et al., 2019), with few reports from Europe and the United States (O'Donnell et al., 2014; Fortuniak et al., 2016). Reports from the African continent are scarce. There is no report on the prevalence of morphological variation at the V3 segment in the South African population to the best of our knowledge. Genetic and environmental factors, including local hemodynamic influences, have been suggested to play a specific role in the endmost structure of the VA (Sikka and Jain, 2012). Therefore, racial differences in the Asian and Western populations could account for the disparity in the published reports (Arslan et al., 2019). As a result, it was considered crucial to describe the prevalence of these morphologic variations in a South African population. According to a textbook of complications in neurosurgery by DeCarvalho and co-authors, the incidence of anatomical variation increases the likelihood of injury, especially if it is not identified preoperatively (DeCarvalho et al., 2019). Therefore, the overall knowledge of the course of the V3 segment of the VA and prevalence of possible variation is essential to reduce the risk of catastrophic complications associated with vascular injury during a surgical intervention at the skull base (Hsu et al., 2017).

We evaluated the anatomical features of the V3 segment of the VA in a South African population using 3D computed tomography angiography (CTA) to provide valuable data on the prevalence of variation and morphometry of the VA. The reports from this study will also contribute to the knowledge of evidence-based anatomy in teaching anatomy and clinical practice.

## MATERIALS AND METHODS

### Patient Population

We reviewed the records of 554 South African patients who underwent multidetector CTA at Lenmed Ethekwini Hospital and Heart Centre, Durban, South Africa, from January 2009 to September 2019. The patient population represents the KwaZulu-Natal region. The design was approved by the Institutional Review Board/ Ethics Committee (Biomedical Research Ethics Committee of the University of KwaZulu-Natal with ethical No: BE 148/19). The angiographies were from 307 males (55.4%) and 247 females (44.6%). The average age of the patients is reported as median (interquartile range): 62 (23) (range: 10-99) years; 62 (25) for female patients and 61 (23) for male patients. Race was defined according to the guidelines outlined in the modern systems of racial classification in the Republic of South Africa (Khalfani and Zuberi, 2001). The South African population is divided into four main racial groups: White, Black, Indian, and Colored. Three population groups were included in the present study: Indian 176 (31.8%), White 287 (51.8%), and Black (16.4%). Images were analyzed using a Picture Archiving Communication System (PACS) Tools. The MDCTA images were examined for vascular variations by a neurosurgeon, a neuroradiologist, and an anatomist using the coronal and sagittal view. Patients with congenital abnormalities at the CVJ such as atlantoaxial dislocation, Down syndrome, Klippel-Feil syndrome, or osseous anomalies were excluded from the study to obtain data from the normal population.

### Imaging Technique

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 following scanning protocol: 120 kVp, 697 mAs, beam collimation 64 × 0.625 mm, gantry rotation time 0.4 s, section thickness 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, Guerbet USA) into the patient's antecubital vein (4 mL/s).

### Dimensions of the V3 Segment

The course of the V3 segment and tortuosity (proximal and distal loop) were analyzed. The diameters, lengths, and angles of arteries were measured with the Picture Archiving Communication System (PACS) Tools. The measurement of each part of the V3 was taken on the coronal view of the CTA images (Fig.1). The diameter of the vertical portion was measured before the VA entered the transverse foramen of the atlas vertebra, while the horizontal diameter was measured above the transverse foramen of the atlas. A diameter of ≤ 2.5 mm was described as hypoplasia according to the method provided by Chen and co- authors (Chen et al., 2010). We classified the VA as dominant if the diameter was larger than that of the contralateral side by a difference of ≥ 0.3 mm according to the method described by Zhang et al. (2014). When the bilateral VAs had a similar diameter or the difference between the VAs was less than 0.3 mm, we referred to them as being "equal" or "codominant." We measured the angles between the proximal and distal loops to evaluate the degree of tortuosity. The proximal loop of the V3 is formed as the VA bends to enter the transverse foramen of the C2 vertebra. The distal loop is present at the transition from the vertical to the horizontal portion at the transverse foramen of the C1 vertebra (Fig. 1).

### Statistical Analysis

Categorical and continuous variables were analyzed using SPSS version 27 (SPSS Inc., Chicago, IL, USA). Categorical variables were analyzed using the chi-square test. Because the continuous variables are not normally distributed, the Kruskal-Wallis test followed by the Wilcoxon Signed-Rank test was used to detect significant differences in the obtained values for continuous variables. All tests were performed at 95% confidence with a p-value of $< 0.05$.

## RESULTS

Continuous variables are presented as median, interquartile range (IQR), and Range. Categorical variables are presented by a number (N) and percentage. The interclass coefficient correlation for intra-observer reliability testing was 99 % for the V3v length; 97 % for V3v diameter; 99 % for V3h length and diameter; 99 % for V3o length, proximal and distal loop.

For inter-observer reliability testing, the intraclass correlation ranges between 72% to 96% for all the parameters.

### Vascular Variation

We registered four types of variation at the V3 segment: (1) hypoplasia; (2) extradural (V3) origin of PICA; (3) persistent FIA; and (4) VA fenestration. The most frequently observed variation was hypoplasia, found in 5.6% of cases (62/1108). Incidence of bilateral hypoplasia was registered in 0.9% (5/554) of patients. The prevalence of the last three, excluding hypoplasia, was diagnosed in 4.2% (23) of the total patients (23 cases/554). There was no significant racial or gender difference in the incidence of variation. The results are summarized in Table 1.

### Morphometric Analysis of the Vertebral Artery Diameter

We observed that the average diameter of the VA increases from the vertical (median (IQR)) (Left- 3.43 (0.61) mm; Right- 3.25 (0.70) mm) to the horizontal part (Left- 3.69 (0.89) mm; Right- 3.60 (0.71) mm) and oblique part (Left- 3.55 (0.79) mm; Right- 3.48 (0.83) mm). The average diameter is significantly larger on the left (vertical portion p=0.000, horizontal portion p=0.001, and oblique portion p=0.006) than on the right side. Most of the VAs had similar diameters (42.6%) with differences of ≤ 0.3 mm between the two sides. We observed a left pattern of dominance in 190 patients (34.3%) and right dominance in 128 patients (23.1%). Concerning the racial groups, the diameter of the left V3v was significantly different across the racial groups (p=0.002; specifically, between Black and Indian p=0.001; between White and Indian p=0.014). On the right V3v, there was no significant difference across the racial groups (p=0.368). The diameter of the left V3h showed a significant difference across the

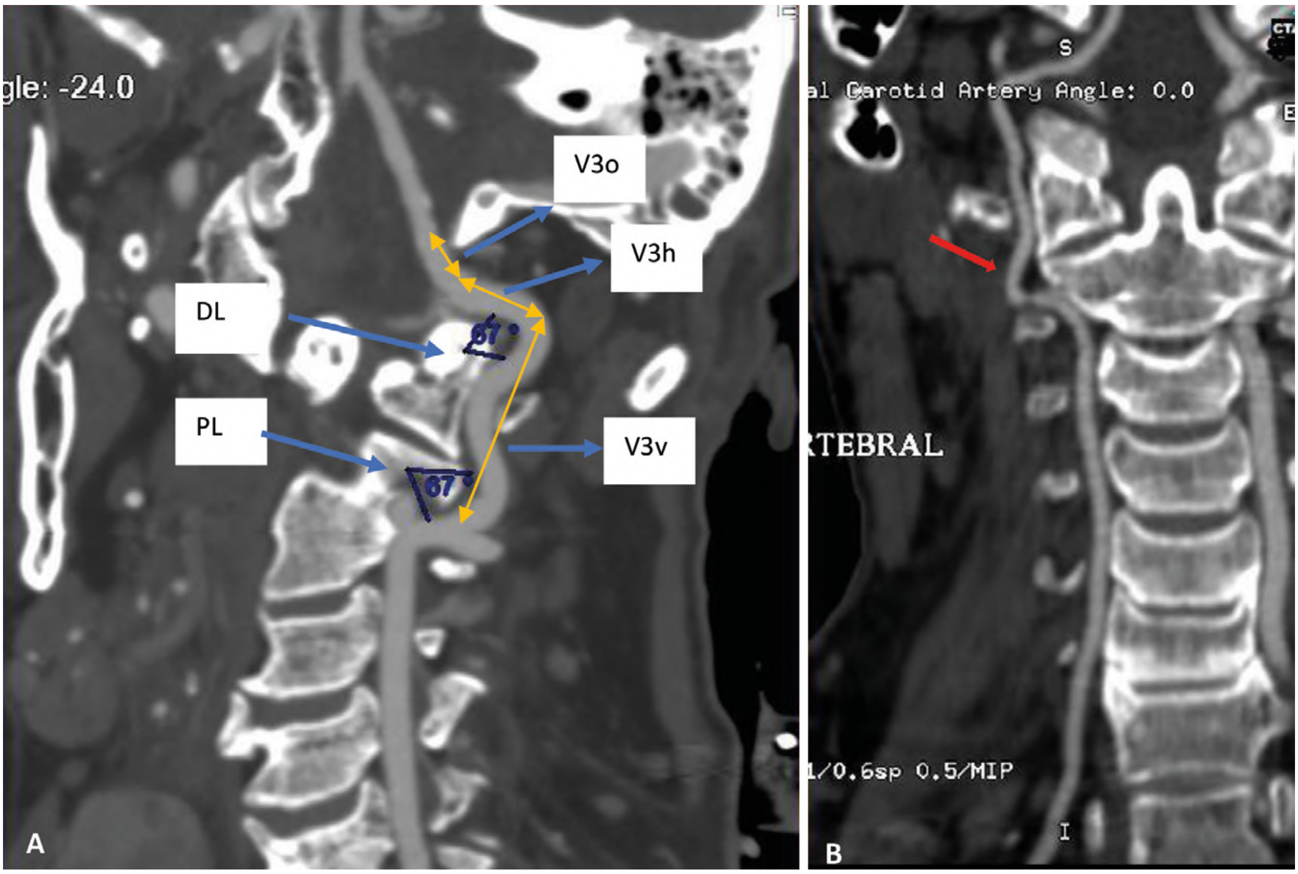


**Fig. 1.-** Oblique (**A**) and Coronal (**B**) view of CTA image. **A)** V3 segment of the left VA. V3v – vertical segment of the VA; V3h – horizontal segment of the VA; V3o oblique segment of the VA; PL – proximal loop of V3; DL – distal loop of V3. **B)** The red arrow illustrated right VA hypoplasia.

racial groups (p=0.002; specifically, between Black and White p=0.03; Black and Indian p=0.001). On the right V3h, there was no significant difference across the racial groups (p=0.286). The diameter of the left V3o also showed a significant difference across the racial groups (p=0.014; specifically, between White and Black p=0.005; Indian and Black p=0.01).

On the right V3o, there was no significant difference across the racial groups (p=0.315). The average diameter is summarized in Table 2. For gender, the average diameter of the V3o is significantly larger in females on the left (p=0.000). There were no significant gender differences on the right (p=0.063). The average diameter is summarized in Table 3.

**Table 1.** Incidence of Anatomical Variations at the suboccipital segment of the VA diagnosed by CTA FIA- Persistent first intersegmental artery, FEN- fenestration, PICA- posterior inferior cerebellar artery.

| Type of Variation | Total number of cases (incidence %) | Male/Female | Left/Right | Simultaneous Variation |
|---|---|---|---|---|
| **Hypoplasia** | 62 (5.6) | 36/21 | 25/37 | - |
| **Extradural PICA Origin** | 16 (1.44) | 11/5 | 8/8 | - |
| **Persistent FIA** | 5 (0.45) | 1/4 | 1/4 | - |
| **FEN** | 2 (0.18) | 0/2 | 1/1 | 2 with FIA |

**Table 2.** Diameter and length of the vertebral artery V3 segment grouped according to race and laterality in South African patients. Results are in mm. Median and (IQR). Range in mm.

| Racial Group | Parameters | V3v | | V3h | | V3o | |
|---|---|---|---|---|---|---|---|
| | | Left | Right | Left | Right | Left | Right |
| Black | Diameter | 3.25(0.77) (2.02-6.25) | 3.16(0.66) (1.93-5.28) | 3.52(0.64) (2.11-6.25) | 3.52(0.71) (1.94-5.63) | 3.69(1.14) (2.46-6.95) | 3.45(0.97) (2.33-6.42) |
| | Length | 24.89(10.3) (6.21-84.7) | 23.26(8.46) (10.6-48.3) | 7.17(3.22) (3.55-15.0) | 7.03(2.72) (3.21-13.5) | 4.32(1.9) (1.89-18.74) | 4.01(1.78) (1.86-6.39) |
| Indian | Diameter | 3.52(0.75) (2.11-7.04) | 3.44(0.79) (0.79-5.98) | 3.87(0.88) (2.11-7.92) | 3.60(0.71) (0.79-6.07) | 3.61(0.79) (2.02-6.42) | 3.52(0.79) (2.33-5.46) |
| | Length | 24.72(12.63) (11.8-48.7) | 23.10(9.44) (11.7-39.7) | 7.55(3.03) 3.69(0.82) | 7.26(2.8) (2.95-11.8) | 4.75(1.98) (2.47-8.25) | 4.42(1.94) (1.89-7.44) |
| White | Diameter | 3.43(0.53) (0.79-6.95) | 3.25(0.64) (1.85-5.72) | 3.69(0.82) (0.79-6.42) | 3.60(0.80) (1.85-5.54) | 3.52(0.8) (0.79-5.9) | 3.43(0.7) (0.79-5.72) |
| | Length | 21.94(11.82) (10.6-45.6) | 20.60(11.74) (8.71-46.6) | 6.19(2.88) (2.67-16.5) | 6.08(3.15) (2.6-13.9) | 3.50(1.85) (1.05-9.7) | 3.36(1.83) (1.32-7.56) |

**Table 3.** Diameter and length of the vertebral artery V3 segment grouped according to gender and laterality differences in South African patients. Results are in mm. Median and (IQR). Range in mm.

| | | V3v | | V3h | | V3o | |
|---|---|---|---|---|---|---|---|
| | | Left | Right | Left | Right | Left | Right |
| Male | Diameter | 3.43(0.53) (2.02-6.95) | 3.25(0.64) (0.79-5.98) | 3.69(0.97) (2.11-6.42) | 3.52(0.71) (0.79-5.54) | 3.45(0.79) (0.79-6.42) | 3.52(0.7) (0.79-5.72) |
| | Length | 24.40(11.76) (6.22-46.3) | 22.30(9.95) (10.6-43.6) | 6.95(2.98) (2.84-16.5) | 6.93(3.0) (2.60-13.5) | 4.08(1.89) (1.32-7.45) | 3.89(1.91) (1.89-8.25) |
| Female | Diameter | 3.43(0.70) (0.79-7.04) | 3.25(0.70) (1.85-5.72) | 3.69(0.88) (0.79-7.92) | 3.69(0.71) (1.85-6.07) | 3.77(0.72) (2.02-6.95) | 3.61(0.79) (2.2-6.42) |
| | Length | 22.10(11.16) (8.71-48.7) | 21.57(10.9) (10.6-48.3) | 6.45(3.22) (2.67-15.3) | 6.44(3.0) (2.95-13.9) | 3.96(0.88) (1.05-18.7) | 3.76(1.98) (1.87-7.56) |

### Length

The length of the V3 was significantly greater on the left than the right side in all parts of the artery (median (IQR)). V3v (23.19 (11.72) mm, 21.80 (10.34) mm) p=0.000; V3h (6.75 (3.17) mm, 6.67 (3.01) mm) p=0.000; V3o (4.03 (1.96) mm, 3.82 (1.93)) mm p=0.000. Within the racial groups, the length of the left and the right V3v showed a significant difference across the racial groups (Left p=0.011, but there was no specific difference between the racial groups; Right p=0.005; specifically, between White and Black p=0.035; White and Indian p=0.003). The average length of the horizontal portion (V3h) showed a significant difference across the racial groups (Left p=0.000; specifically, between White and Black p=0.008; White and Indian p=0.000; Right p=0.000; specifically, between White and Black p=0.011; White and Indian p=0.000). The average length of the oblique portion also showed a significant difference across the racial groups (Left p=0.000; between White and Black p=0.015; White and Indian p=0.000; Black and Indian p=0.025; Right p=0.000; specifically, between White and Black p=0.001; White and Indian p=0.000). The average length across the racial groups and laterality are summarized in Table 2. There were no significant gender differences in the VA length on both sides. The results are summarized in Table 3.

### Proximal and Distal Loop Angle

The average angle of the proximal loop was significantly larger on the left (median (IQR)) (67° (24°)) compared to the right (65.66° (25.33°)) side (p=0.001). There was no significant difference in the angle of the distal loop on the right and left sides (Right- 67° (14°), Left- 66° (15°)). We did not observe any significant differences across gender and racial groups. The results are summarized in Table 4.

## DISCUSSION

Iatrogenic injury to the VA during procedures around C1/2 constitutes a potentially catastrophic complication that may result in permanent neurological deficits or even death (Vergara et al., 2012; Akinduro et al., 2016). Studies have reported rates ranging from 1.7% - 9.0% (Vergara et al., 2012; Elliott et al., 2014; Liang et al., 2004). Adequate information about anatomical variation can influence the choice of surgical procedure at the CVJ. Apart from the risk of injury, morphological variation at the V3 segment of the VA may result in complications such as brainstem infarction if not recognized during preoperative planning (Fortuniak et al., 2016).

Hypoplasia of the VA has been previously described by different criteria in the literature. Using a measure of diameter ≤ 2.5mm according to the method provided by Chen et al. (2010), we observed a 5.6% (62 cases/1108 VAs) incidence of hypoplastic VA (Fig. 1B). Our results agreed with the findings of O'Donnell and co-authors (6.26%) in the US population, although hypoplasia was defined by different criteria (O'Donnell et al., 2014). By contrast, a similar study in the Asian population reported an incidence of 10% (Arslan et al., 2019), while another study in the European

**Table 4.** Characteristics of proximal and distal loops of the vertebral artery V3 segment grouped according to gender and racial group in South African patients. Results are in degrees. Median and (IQR). Range in degrees.

| | Proximal Loop | | Distal Loop | |
|---|---|---|---|---|
| | Left | Right | Left | Right |
| **Male** | 67.33(22.83)<br>(42.7-118.7) | 65.66(25.17)<br>(39-116.7) | 66.66(14.67)<br>(42.7-114.7) | 67(16)<br>(37.3-110.7) |
| **Female** | 68.16(25.17)<br>(36.3-120) | 65.33(26.17)<br>(36.3-111.7) | 66(16)<br>(41.7-115.3) | 66.66(14.16)<br>(43.4-97.3) |
| **Black** | 66(23)<br>(36.3-118.6) | 68(32)<br>(42-109.6) | 65.50(18.92)<br>(41.7-107.6) | 69.66(17.17)<br>(43-105.3) |
| **Indian** | 68.16(29.17)<br>(42.7-120) | 63.33(24.67)<br>(39.7-111.7) | 66(19)<br>(39.7-115.3) | 65.33(16.67)<br>(39.7-110.7) |
| **White** | 67.50(22.83)<br>(43.3-116.7) | 66(22.16)<br>(36.3-116.7) | 67.16(13.25)<br>(37.4-114.7) | 67.33(13.83)<br>(37.4-114.7) |

population reported an incidence of 20% (Fortuniak et al., 2016). In the studies mentioned above, a VA was considered hypoplastic if it was half or less than half of the diameter of its counterpart. We suggest that the disparity in the above studies and the present study may have resulted from the differences in the average diameter of the population studied. Going by the criteria described by Fortunaik et al. (2016) and O'Donnell et al. (2014), it may be practically impossible to report the occurrence of bilateral hypoplasia. Five (out of a total of 57) patients had bilateral hypoplasia in the present study. Because of the compromised blood flow in the VA with a reduced diameter (Chen et al., 2010), surgeons need to be aware of its possibility, which may require special attention during surgical intervention.

PICA is the principal branch of the VA, and it typically originates from the intracranial part of the vertebral artery (4th segment). However, due to numerous embryonic vessels forming the VA and its branches, PICA sometimes emerges from the V3 part. An abnormal course of the VA or its PICA branch below the C1 arch may predispose the arteries to iatrogenic injuries during drilling, tapping and insertion of lateral mass screws (Arslan et al., 2019). Previous studies have reported the incidence of extracranial origin of PICA between 0.4% to 2.9% (Table 5). The prevalence in the present study is similar to previous reports (Table 5). It is important to note that no perforating arteries emerge from the PICA of extradural origin. Instead, the perforators originate from the intracranial VAs (Mercier et al., 2008). The incidence of PICA arising from the V3 was observed at the oblique part in all the cases. This site of origin is also described as the C1 origin of the PICA. This information is clinically significant to prevent iatrogenic injury to PICA during surgical interventions at the upper cervical spine and posterior approaches to the lower brainstem (Miao et al., 2020).

The prevalence of FIA ranges between 0.01% to 3.2% (Table 5), similar to the prevalence in our series (0.45%; 5 cases/1108 VAs). We observed bilateral persistent FIAs in one of the patients (Fig. 2B). The simultaneous persistence of the FIA and the typical branch of the VA results in fenestration at the V3 segment (Uchino et al., 2012), as shown in Fig. 3. Both unilateral and bilateral persistent FIA can be easily overlooked (Uchino et al., 2012). An awareness of this variant anatomy and careful review of images will assist in proper identification to prevent VA injury.

Fenestration extended between the vertical and horizontal portion of the V3 segment in the two cases observed in the present study (Fig. 3). The two limbs of the fenestrated segment had a similar diameter. The prevalence of fenestration registered in the present study (0.18%; 2

**Table 5.** Prevalence of anatomical variations at the V3 segment of the VA in different population groups.

| Author (year) | Population | Type of study | Sample Size | Anatomical Variations (Patients %) | | | |
|---|---|---|---|---|---|---|---|
| | | | | Hypoplasia | Extradural PICA Origin | FEN | Persistent FIA |
| Uchino et al., 2012 | Japan | MRA | 2739 | 0 | 30(1.1) | 25(0.9) | 87(3.2) |
| O'Donnell et al., 2014 | US | CTA | 975 | 61(6.26) | 4(0.4) | 1(0.01) | 1(0.01) |
| Wakao et al., 2014 | Japan | CTA | 480 | 0 | 5(1.3) | 5(1.3) | 7(1.8) |
| Fortuniak et al., 2016 | Poland | CTA | 1800 | 360(20) | 11(0.61) | 3(0.16) | 0 |
| Kim et al., 2016 | South Korea | CTA | 546<br>314 | 0<br>0 | 11(2.0)<br>9(2.9) | 2(0.4)<br>2(0.6) | 7(1.3)<br>8(2.5) |
| Arslan et al., 2019 | Turkey | CTA | 200 | 10 | 2(1) | 0 | 1(0.5) |
| **Present study** | **South Africa** | **CTA** | **554** | **57(10.3)** | **16(2.9)** | **2(0.4)** | **5(1.0)** |

cases/1108 VA arteries) agrees with the reports from Western countries (Fortuniak et al., 2016), (O'Donnell et al., 2014), and is lesser than the report from a large series study of the Asian population (Uchino et al., 2012) (Table 5). There is a possibility of compromised blood flow at the proximal and distal end of the fenestrated segment of the VA, which may result in transient ischemic attacks (Omotoso et al., 2021). In addition, the passage of the catheter through the normal contralateral VA in patients with this unilateral vascular variation can expose the hindbrain to the risk of ischemia during neuroendovascular procedures (Fortuniak et al., 2016).

In the present study, most patients had equal VA diameters (codominance) (42.6%), the left side was dominant in 34.3%, and right-sided dominance was registered in 23.1%. Our study's pattern of dominance concurs with a previous report in the Asian population (49% equal dominance, 30% left dominance) (Arslan et al., 2019). It is imperative to identify and protect the dominant VA during a surgical intervention at the CVJ. Furthermore, the dominant VA must not be ligated when repairing VA injury, as it can result in permanent neurologic deficit (DeCarvalho et al., 2019).

The race, gender and side differences in the diameter and length of the V3 segment have been previously reported in the American, South African, and Asian populations (Alfaouri-Kornieieva and Al-Hadidi, 2014; Lang and Kessler, 1991; Mitchell, 2004). According to Mitchell's reports, there were no significant gender or laterality differences based on detailed histological analysis of South African adult cadavers (Witwatersrand region). The average diameter of the horizontal portion in our results is less than, but close to, the average value of the above histological reports (3.75±0.72 mm) (Mitchell, 2004) and MRA reports on the Asian population (3.8±0.51 mm) (Alfaouri-Kornieieva and Al-Hadidi, 2014). Noticeably, the average diameter of the vertical portion was smaller than that of the horizontal and oblique portion in our results. On the contrary, Alfaouri-Kornieieva and co-author (2014) reported a gradual decrease

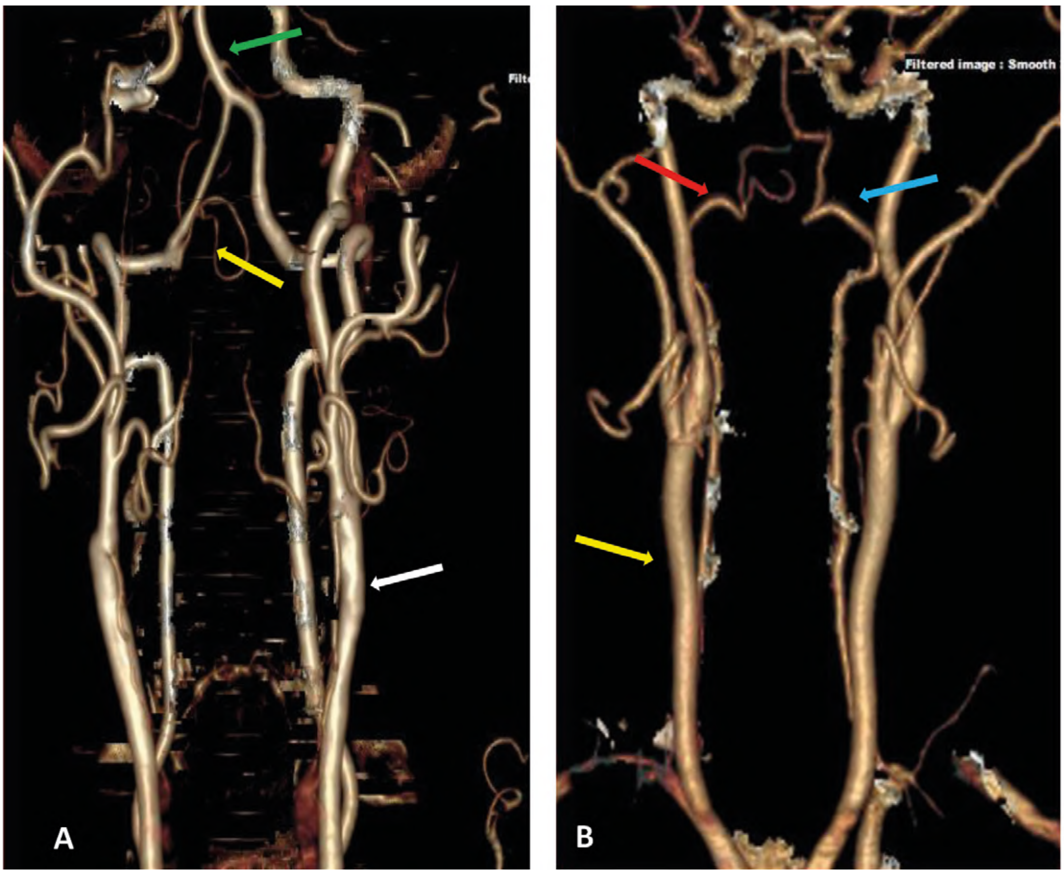


**Fig. 2.-** Anterior view of 3D-CTA reconstructed images showing the vertebral, basilar, and carotid arteries. **A)** PICA (yellow arrow) originates from the oblique part of V3 of the left VA. The green arrow illustrated the basilar artery. The white arrow illustrated the right common carotid artery **B)** The red and blue arrow illustrated bilateral persistent FIA. The yellow arrow illustrated the left common carotid artery.

from the vertical part to the oblique part in their MRA study. The entire length of the V2 and part of the V3 segment (excluding the horizontal and oblique part) of the VA is restricted within the transverse foramen of the cervical vertebrae, as shown in our CTA series (Fig. 1). We hypothesize that the artery could expand after its exits from the transverse foramen of the atlas (C1) vertebra, which may be a possible explanation for the differences. In agreement with the previous reports by Alfaouri-Kornieieva and co-author (2014) and Arslan et al. (2019), we registered a significantly larger left VA in all parts of the V3 segment (Alfaouri-Kornieieva and Al-Hadidi, 2014; Arslan et al., 2019). The total length of the vertical, the horizontal, and the oblique part in the present study agreed with a previous American study, which reported an average length of 38.91±5.53 (Lang and Kessler, 1991). In our study, the average length of the vertical part was similar, but the average length of the horizontal and the oblique part was shorter than in the Asian population (23.22±2.7 mm, 17.2±2.85 mm, and 12.31±1.8 mm, respectively) (Alfaouri-Kornieieva and Al-Hadidi, 2014). Generally, the disparity noted in the morphometry between the present study and the reports mentioned above may be due to differences in the modality of the studies. In the present study, we observed that the average length showed a significant difference across the racial groups. This dissimilarity may be due to some genetic factors. However, more studies may be required from other regions of South Africa to corroborate this theory.


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**Fig. 3.-** 3D-CTA reconstructed images showing the vertebral, basilar, and carotid arteries. Anteroposterior view, fenestration, and persistent FIA at the V3 segment of the left VA (yellow arrow). The white arrow illustrated the left internal carotid artery.

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