

Morphological expression of the anterior spinal artery and the intracranial segment of the vertebral artery: a direct anatomic study

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Abstract

Given its importance for clinical diagnosis and management, the purpose of this study was to determine the morphological expression of the intracranial segment of both vertebral and spinal arteries. Ninety-five fresh cadaveric specimens autopsied at the Instituto de Medicina Legal of Bucaramanga (Colombia) were perfused with polyester resins at the vertebrobasilar vascular bed, by canalizing the proximal segment of the internal carotids and vertebral arteries. The intracranial segment of the vertebral arteries (VA) had a length of 33.2 ± 5.2 mm and a caliber of 3.03 ± 0.81 mm. The left vertebral artery had a caliber of 3.12 ± 0.85 mm, this being greater than the caliber of the right artery in 59.6% of the cases. The VA junction was seen at the level of the ponto-medullary sulcus in 44.2%, above this level in 30.5%, and below it in 25.3%. The distance from the origin of the anterior spinal branches (ASBs) to the VA junction was 7.34 ± 2.71 mm, with a greater distance corresponding to the right ASBs, a difference that did not reach statistical significance ($p=0.32$). The anterior spinal arteries (ASA) had a bilateral origin in 65.3% of the cases, with the caliber being balanced in 37 (39%) and dominant at the right side in 15.8%. A right unilateral origin of the ASA was observed in 13.7% and a left unilateral origin in 9.5% of the specimens. There is disagreement in the literature as to the level of the junction of the two vertebral arteries. The unilateral origin of the spinal arteries is more frequent than most prior studies have indicated.

Keywords: vertebral artery, anterior spinal artery, basilar artery, intracranial segment of the vertebral artery.

Introduction

Several variations related to their origin, length, paths, and calibers have been added to the usual pattern of expression of the intracranial segment of the vertebral artery (V4) and of the anterior spinal arteries (ASA). Similarly, agenesis of some of these structures may occur. These anatomic features may determine obvious modifications of the brain blood flow. The right and left V4 segments usually join at the level of the ponto-medullary sulcus and form the basilar artery (AB), although this junction may occur above or even below this reference sulcus [1–5]. Similarly, the V4 segment is characterized by presenting a large variability in its caliber that may lead to hypoplastic expressions, reported with a wide range of frequency (3–25%) and that constitute in the anatomic substrate for ischemic disorders of the brainstem [6–9].

The anterior spinal branches (ASBs) originate from the medial aspect of the distal segment of V4, whence they cross the bulbar pyramids and then join each other to give origin to the ASA, which descends along the medial anterior cleft of the spinal cord [10, 11]. The bilateral origin of the ASA has been described with an incidence of 45–80%, whereas variant expressions such as the unilateral agenesis of the ASBs or the origin of the ASA from an intervertebral anastomosis have been reported in 20–40% of the cases [1, 2, 12–14].

The importance of being aware of the variability of the V4 segment and the ASA, beyond the academic field, also resides in its impact on hemodynamic procedures, on the etiology of brainstem infarctions resulting from

occlusive or hemorrhagic cerebrovascular disease, and on neurosurgical interventions [2, 14–16].

The morphological expression of AV and ASA has been studied using classical dissection techniques, injection of vascular beds, or imaging in some other population groups [4, 5, 13, 17–22]. With the purpose of accruing our own reference information, this study was conducted using fresh cadaveric materials obtained from Colombian subjects.

Materials and Methods

The ASA and V4 segment of 95 unclaimed corpses were investigated. These bodies were autopsied at the Instituto de Medicina Legal y Ciencias Forenses of Bucaramanga, Colombia. The specimens met the following inclusion criteria: Male subjects, with ages between 18–75 years, pertaining to the mixed racial group (Mestizo), with no evidence of having died because of direct head trauma or conditions involving the central nervous system. The Universidad Industrial de Santander Ethic Committee approved this investigation.

Each specimen was subjected to bilateral canalization of the proximal segments of the internal carotids and vertebral arteries; using these vessels, the brain was washed and pre-fixed with 3% formaldehyde, followed by the injection of 100 cc semi-synthetic resin (a mixture of Palatal E210[®] Basf 80 cc; Styrene 20 cc) impregnated with a red mineral dye. Once the polymerization of the resin was complete (30 minutes), the brain was removed from the cavity. Then, the specimen was fixated with 10% formaldehyde for 15 days.

Once the encephalic mass was appropriately fixed, blocks were obtained from the brainstems and cerebella and the leptomeninges were liberated with microdissection material, thus allowing for a full identification of each one of the structures composing the vertebrobasilar system. Then, the diverse morphological expressions of V4 concerning the level of its junction were recorded, taking as a reference the ponto-medullary sulcus; their lengths and calibers were measured at their ends. Similarly, the level of the origin of the anterior spinal branches with relation to the vertebrobasilar junction was determined, and their expression was typified according to the criteria of Rodríguez-Baeza *et al.* (1989). The distance of the origin of the ASBs with relation to the vertebrobasilar junction was measured. A digital calibrator (Mitotuyo®) was used for all morphometric assessments.

Digital pictures were taken from all of the studied specimens (Canon T2I camera) to support all recorded observations. The data obtained were digitized in Excel tables and the statistical analyses were performed using the STATA 8.0 program. Continuous variables were described with their means and standard deviations, nominal variables with their ratios. Statistical analyses

were made using chi-square (χ^2) test and Student *t*-test, accepting an alpha error of up to 5%.

Results

The ASAs and V4 segments were obtained from male cadaveric specimens with a mean age of 33.5 ± 10 years. The V4 segment had a length of 33.2 ± 5.2 mm, with the left side vessel being greater than in the right side vessel (33.86 ± 5.59 mm; 32.47 ± 4.8 mm) but the difference was non-significant ($p=0.446$). In 50 (52.6%) cases, the LVA was longer, greater in the RVA in 37 (39%) whereas in 8.4% the length of the two arteries was the same.

The VAs had a caliber of 3.03 ± 0.81 mm, corresponding to 3.12 ± 0.85 mm for the left vessel and 2.94 ± 0.77 mm for the right vessel ($p=0.47$). The left side artery had a greater caliber in 59.6% of the cases. Hypoplasia (≥ 2 mm) of the RVA was observed in 10 specimens (10.5%) (Figure 1) and of the LVA in eight (8.4%) but the difference did not reach statistical significance ($p=0.32$). LVA hypoplasia was more accentuated (1.75 ± 0.24 mm LVA; 1.9 ± 0.10 mm RVA). There was one (1.1%) case of RVA agenesis, with a LVA of the same caliber (4.2 mm) as the proximal segment of the BA (Figure 2).

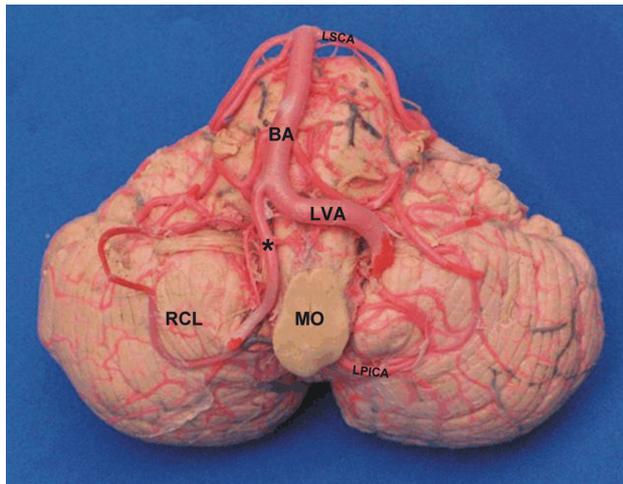


Figure 1 – Right vertebral artery hypoplasia. RCL – Right cerebellum lobe, MO – Medulla oblongata, LVA – Left vertebral artery, BA – Basilar artery, LSCA – Left superior cerebellar artery, LPICA – Left posterior inferior cerebellar artery. Asterisk – Hypoplastic right vertebral artery.

The vertebrobasilar junction was found at the level of the ponto-medullary sulcus in 42 (44.2%) specimens; above this level and at a distance of 4.1 ± 1.30 mm in 30.5% of the assessed specimens. Similarly, in 24 (25.3%) cases the VA junction was distal to the ponto-medullary sulcus, at a mean distance from this reference structure of 3.28 ± 1.44 mm (Figure 3). The difference between the distance from the proximal origin of the BA to the ponto-medullary sulcus with respect to the distal origin is not statistically significant ($p=0.34$). The number of cases where the vertebrobasilar junction is located proximally and distally to the ponto-medullary sulcus is significantly mayor ($p=0.001$) than the number of cases where it is located at the level of the reference sulcus.

The distance from the origin of the ASBs to the VA junction was 7.34 ± 2.71 mm, corresponding to a distance

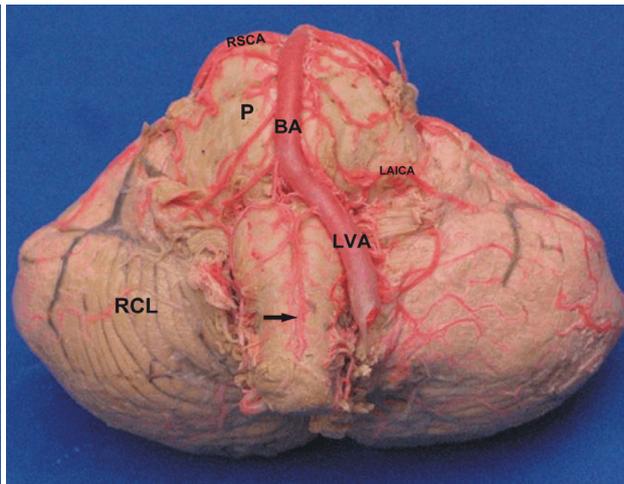


Figure 2 – Right vertebral artery agenesis. RCL – Right cerebellum lobe, P – Pons, LVA – Left vertebral artery, BA – Basilar artery, RSCA – Right superior cerebellar artery, LAICA – Left anterior inferior cerebellar artery. Arrow – Anterior spinal artery.

of 7.1 ± 2.56 mm for the right ASBs, whereas for the left it was 7.58 ± 2.87 mm, a difference that was not statistically significant ($p=0.32$).

With respect to the morphological expression of the ASBs, a bilateral origin descending from the medial, postero-medial or antero-medial surfaces of V4 was found in 62 specimens (65.3%) (Type I), in which 37 (39%) of the right and left branches had a similar caliber (subtype IA); in 15 (15.8%) the right ASBs had a greater caliber (subtype IB), whereas in 10 cases (10.5%) the left branch was dominant (subtype IC) (Figure 4).

The ASAs had a unilateral origin (Type II) in 22 (23.2%) specimens, emerging from the RVA in 13 (13.7%) cases and from the LVA in nine (9.5%) (Figure 5). The origin of the ASA from a transverse intervertebral anastomosis (Type III) was observed in 11 (11.5%)

specimens (Figure 6). In 37 (38.9%) cases, the emergence of an accessory ASA with a caliber smaller than the main vessel and with a path running parallel therewith was observed; this feature was found in 26 (41.9%)

Type I specimens, in seven (31.8%) of Type II specimens, and in four (36.4) of Type III specimens (Figures 2, 4B, and 5A).

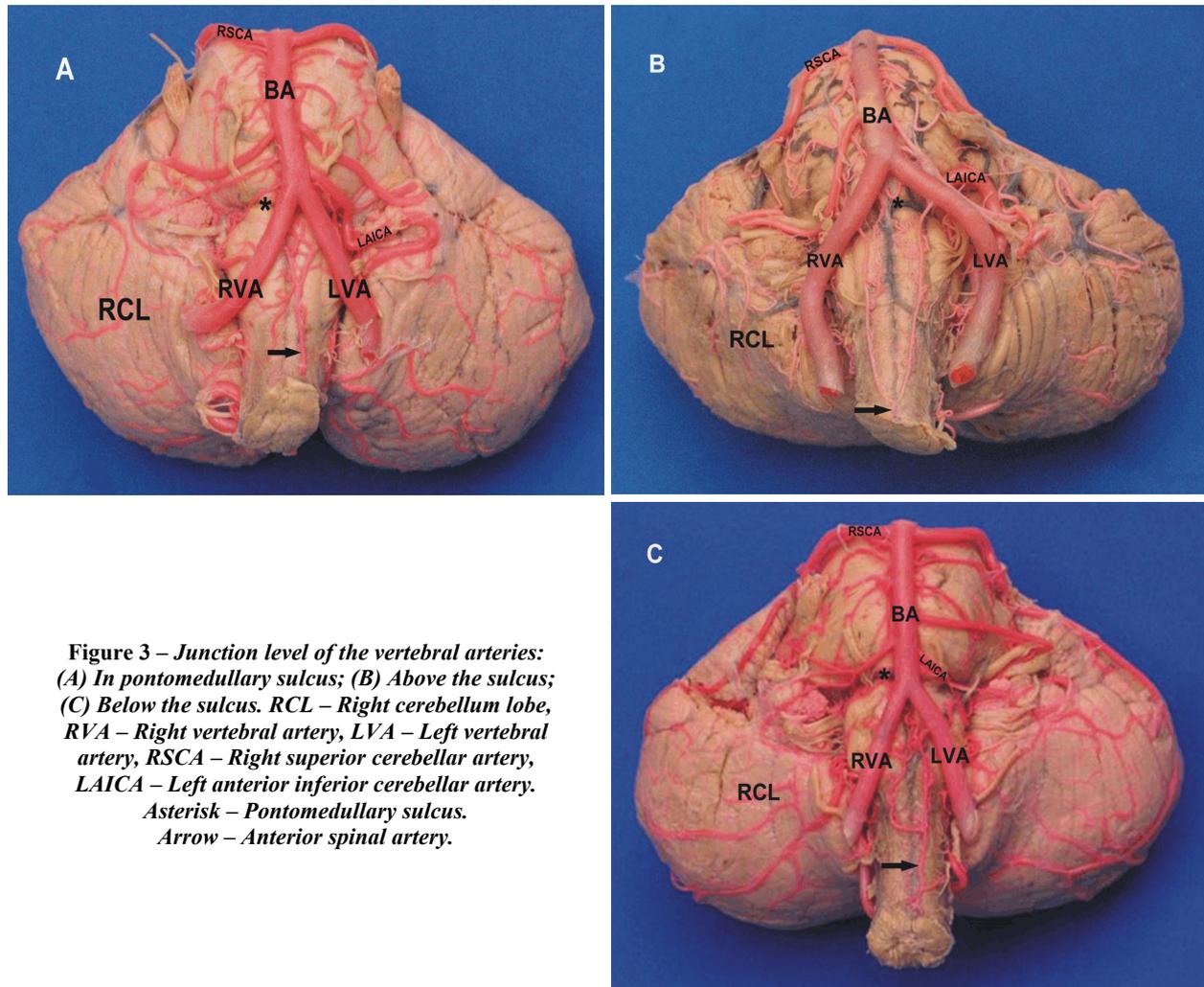


Figure 3 – Junction level of the vertebral arteries: (A) In pontomedullary sulcus; (B) Above the sulcus; (C) Below the sulcus. RCL – Right cerebellum lobe, RVA – Right vertebral artery, LVA – Left vertebral artery, RSCA – Right superior cerebellar artery, LAICA – Left anterior inferior cerebellar artery. Asterisk – Pontomedullary sulcus. Arrow – Anterior spinal artery.

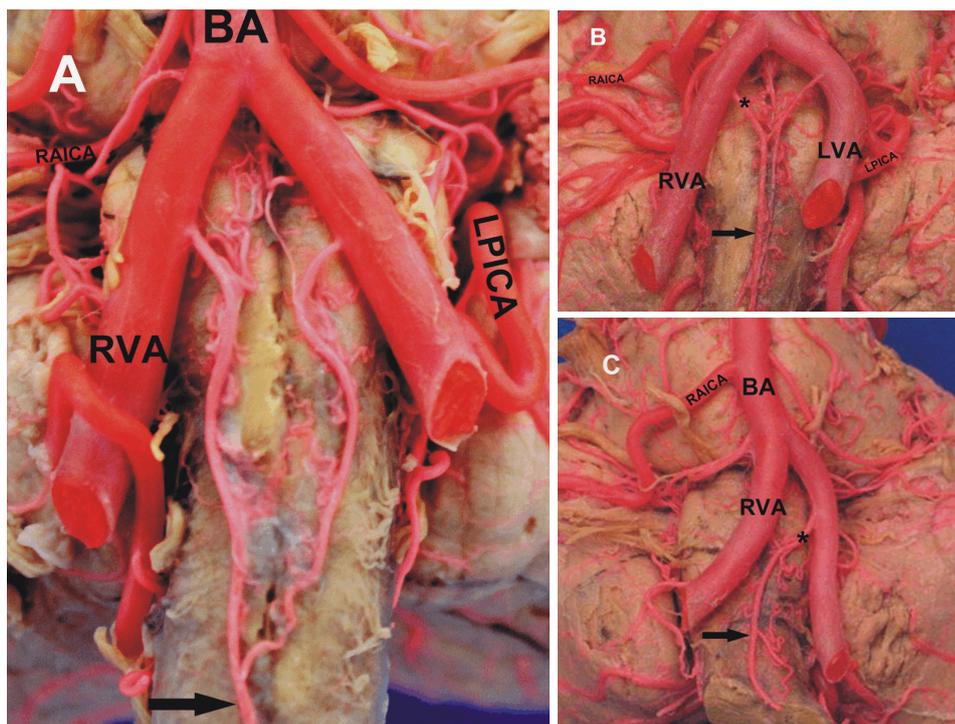


Figure 4 – Bilateral descending origin of the anterior spinal branches: (A) Similar calibers of the left and right branch; (B) Greater caliber of the right branch; (C) Greater caliber of the left branch. BA – Basilar artery, RVA – Right vertebral artery, LVA – Left vertebral artery branch, RAICA – Right anterior inferior cerebellar artery, LPICA – Left posterior inferior cerebellar artery. Asterisk – Greater caliber of the right anterior spinal artery. Asterisk – Left heavier gauge spinal branch. Arrow – Anterior spinal artery.

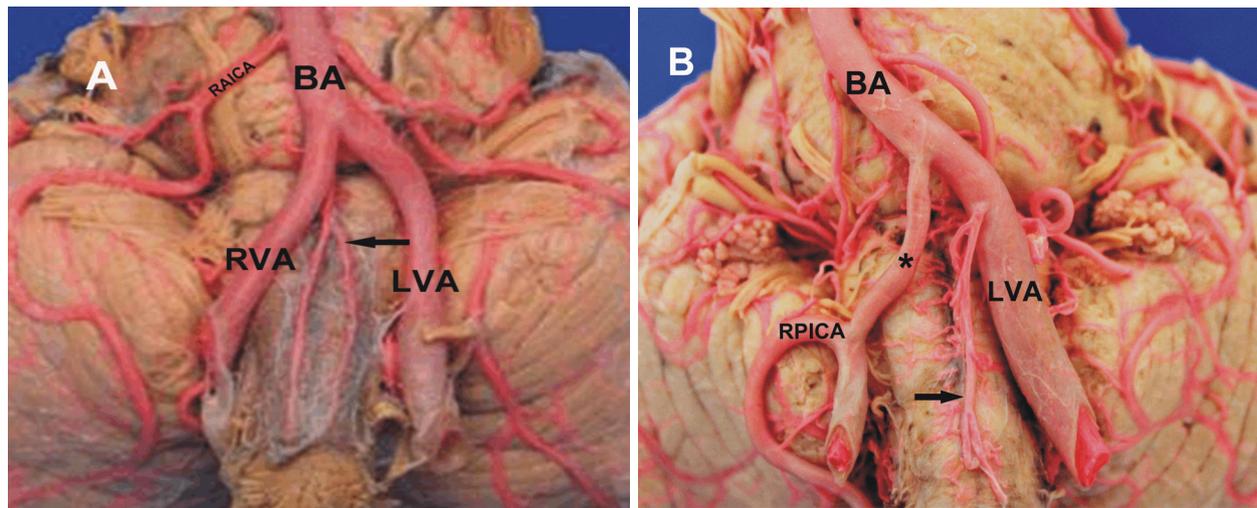


Figure 5 – Unilateral origin of the anterior spinal artery: (A) From the right vertebral artery; (B) From the left vertebral artery. BA – Basilar artery, RVA – Right vertebral artery, LVA – Left vertebral artery, LVA – Left vertebral artery, RAICA – Right anterior inferior cerebellar artery, RPICA – Right posterior inferior cerebellar artery. Asterisk – Hypoplastic right vertebral artery. Arrow – Anterior spinal artery.

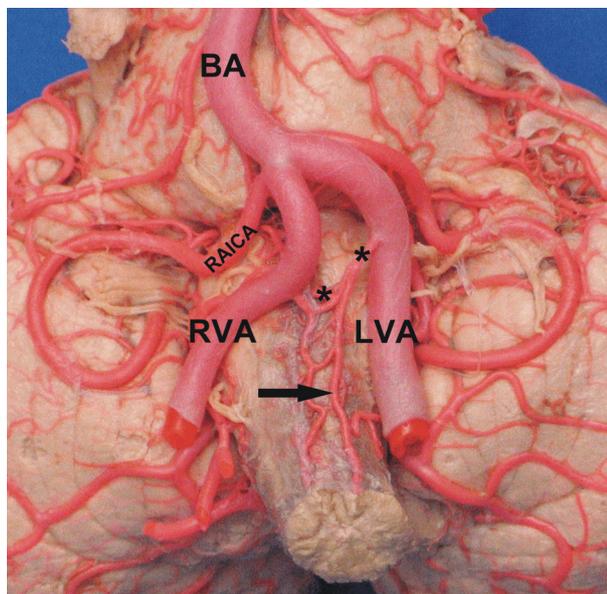


Figure 6 – Origin of the anterior spinal artery from a transverse intervertebral anastomosis. BA – Basilar artery, RVA – Right vertebral artery, LVA – Left vertebral artery, RAICA – Right anterior inferior cerebellar artery. Asterisk – Anterior spinal branches. Arrow – Anterior spinal artery.

Discussion

Classical Anatomy textbooks mention the ponto-medullary sulcus as the place where the left and right segments of V4 join giving origin to the BA [10, 11]. This description may be considered as general because diverse studies on these structures indicate that in less than one-half of the assessed specimens the vertebro-basilar junction occurs at the level of the ponto-medullary sulcus [1–5]. Our findings are consistent with the reports by Stopford JSB (1916) and Wójtowicz Z *et al.* (1989) (44–48%), whereas some other studies [1, 2] have reported incidences within a range of 27.5% to 36.4%. Of note is the work by Songur A *et al.* (2008), who report on this morphological trait with a low frequency (20.8%).

The BA being originated in the proximity of the ponto-medullary sulcus is described in the literature within a range of 12–53%, with a mean incidence of 30% corresponding to our series, whereas Stopford JSB (1916), Wójtowicz Z *et al.* (1989), Songur A *et al.* (2008) report this morphological expression with a low incidence (12.2–20%). Some other works have reported incidences of 37–53% [1, 2]. Similarly, with respect to the distal origin to the said sulcus, the present study found a frequency that is consistent with most reports within a range of 33–40% [2, 3, 5]. Of note is the low incidence (10.6%) reported by Akar ZC *et al.* (1994) and the very high incidence (67%) of Songur A *et al.* (2008). The divergence in the figures reported by the diverse authors is probably explained by multiple factors such the ancestral biological features that determine the variable expression of these structures in the populations evaluated, the size of the specimens, and the methodology used.

The mean distances from the origin of the BA proximal or distal to the ponto-medullary sulcus, observed in our series (4 mm; 3.26 mm) are similar to those reported by Pai BS *et al.* (2007) and Songur A *et al.* (2008). This information should be considered as a reference for the surgical management of aneurysms, tumors, and atheromatous lesions located in the posterior cranial fossa [2, 4, 20, 23, 24].

The asymmetry of the vertebral arteries, and more particularly the more severe pathology they are associated with, determines hypoplastic forms that together with the presence of the atheromatous plaques, also cause an alteration in the path of the AB, disorders in the blood flow of the brainstem that may lead to diverse neurological signs [7–9]. A low incidence of HAV, within a range of 2.4–13%, has been reported by several studies [6, 15, 17, 19, 25]; moderate frequencies such as those of our study, namely, within a range of 15–26.5%, have been reported by Park JH *et al.* (2007), Min JH and Lee YS (2007) and Peterson C *et al.* (2010). Songur A *et al.* (2008), in a study with necropsy material, reported hypoplasia of the AV in 39.2%. With respect to the size

of occurrence of VAH, our findings are consistent with prior studies indicating a significant predominance in the RVA [4, 8, 9, 17, 25]. Studies with subjects with signs of cerebral infarction or vestibular neuropathy, have reported the hypoplasia of one of the vertebral arteries within a range of 42–54.8% [16, 26]. The high incidence of hypoplastic AVs in patients with brainstem infarction, particularly at the level of the pons, demonstrates the correlation and significant predictive power of probable ischemic events in patients with this anatomic condition [16, 26].

The calibers reported in prior works [6, 18–20, 24] for the LVA (3.4–3.6 mm) and for the RVA (2.9–3.36 mm) are slightly greater than those found in our series are, but an agreement in the LVA being of a greater caliber has been found. Of note, Santos-Franco JA *et al.* (2006) in their study of 50 brainstems found a caliber of 2.6 mm for the LVA and 2.5 mm for the RVA, representing the smallest caliber for these vessels reported in the literature.

The length of the AV found in our work (33.2 mm) is similar to the length indicated in prior studies [1, 20, 27], agreeing with Duan S *et al.* (2010) in the LVA being longer, but with a non-significant difference with respect to the length of the RVA, whereas some other studies [1, 20] have reported a greater length for the RVA. The difference in length between the AVs is probably due to factors related to their development and more specifically to an asymmetry in calibers that leads to changes in the characteristics of the blood flow, which

at their turn determine undulating expressions of these vessels, with modifications in length in both the AVs and the BAs.

The distance of emergence of the ASBs with respect to the vertebrobasilar junction reported by the several investigators [1, 2, 13, 18, 20] within a range of 6–7.5 mm, is similar to what has been found in our study. In agreement with Akar ZC *et al.* (1994) a greater distance was observed at the left side, whereas Pai BS *et al.* (2007) reported equal distances for both sides. In some other studies [2, 13, 18] these distances have been reported in a global manner, with the information not being discriminated per side of presentation. This morphometric information should be borne in mind for those surgical approaches involving the vertebrobasilar system.

There is full agreement with the different studies [2, 5, 12–14] that indicate a predominant origin for the ASA from the fusion of the ASBs that emerge from V4, feature that is reported within a range of 45–80%. Similarly, among the bilateral origin type, cases in which ASBs are of similar caliber are thought to be more frequent. The unilateral origin of the ASA from the intracranial segment of the ipsilateral VA or from the transverse anastomoses between the ASBs has been reported by Stopford JSB (1916), Rodríguez-Baeza A *et al.* (1989), Gövsa F *et al.* (1996), and Marinković S *et al.* (2004) within a range of 9.7–18.2%. In our series, we found the unilateral origin of the ASA in 23.2 of the cases (Table 1).

Table 1 – Anterior spinal arteries origin (ASA) from the fusion of the anterior spinal branches (ASB) or the unilateral emergence from the intracranial segment of the vertebral artery (V4), presented in previous studies

	Stopford JSB n=150 [%]	Rodríguez-Baeza A <i>et al.</i> n=31 [%]	Gövsa F <i>et al.</i> n=80 [%]	Santos-Franco JA <i>et al.</i> n=50 [%]	Present study n=95 [%]
<i>Bilateral descending origin</i>	85	77.4	75	60	65.3
<i>Similar caliber</i>	–	22.6	42.5	–	39
<i>Greater right caliber</i>	–	32.2	17.5	–	15.8
<i>Greater left caliber</i>	–	22.6	15	–	10.5
<i>Unilateral origin</i>	12	9.7	11.3	38	23.2
<i>Right</i>	9	9.7	8.8	8	13.7
<i>Left</i>	3	–	2.5	30	9.5
<i>Transverse anastomosis origin</i>	–	12.9	13.8	–	11.6

The different expressions in the origin of the ASA, more particularly those related to their right or left unilateral origin, may become the anatomic substrate for such ischemic neurological conditions as involve the medulla oblongata, and at the same time explain the wide range of signs that characterize these clinical events.

In our series, a significant number of cases (39.8%) had an accessory ASA, a feature observed with a similar incidence in every type. This morphological trait has not been described in classical textbooks [10, 11] and some prior studies [2, 5, 12, 13] present it in a qualitative manner without a statistical representation as to its occurrence. The presence of an additional ASA could become a protective trait for potential ischemic events compromising both the medulla oblongata and the spinal cord.

☒ Conclusions

In agreement with the literature, we found that the

LVA is of a greater caliber. The disagreement between the diverse authors on the incidences related to the levels where the VAs are joined is evident, an issue that demands the performance of new studies with a significant number of specimens. Hypoplastic AVs found in 18.9% of our series is the anatomic substrate to be considered for the diagnosis and management of ischemic events of the brainstem. A greater frequency of unilateral origin of the spinal arteries was found as compared with prior studies. The knowledge of the variant expressions of the intracranial segment of the AV and of the ASAs allow for a better understanding of clinical events in which these vessels are involved.

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