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Surgical Microanatomy

Microsurgical considerations of the anterior spinal and the anterior-ventral spinal arteries

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Summary

Background. There are few data describing the microanatomy of the anterior-ventral spinal (AVSA) and anterior spinal arteries (ASA) and discussing their clinical and surgical implications. We describe the anatomical features of this arterial complex, and highlight their use when planning and performing surgical approaches to lesions involving the ventral aspect of the medulla and the foramen magnum.

Method. The microsurgical anatomy and branching pattern of the AVSA and the ASA from fifty human cadaver brain stems is described using a surgical microscope.

Results. We found one anterior-ventral spinal artery at each side in 30 of the brain stems (60%). The ASA was a direct branch emerging from the left vertebral artery (VA) in 15 (30%), from the right VA in 4 (8%), and from the basilar artery (BA) in one brain stem (2%). The previously described as "typical pattern" of the junction of the AVS arteries from both sides, was observed only in 9 brain stems (18%). The anterior communicating spinal artery (ACoSA) was observed in 15 brain stems (30%). Also multiple ACoS arteries were described in one brain stem. Both, the AVSA and the ASA were observed to send long circumferential branches that supplied irrigation to the olive in 42 (84%) brain stems.

Conclusions. This anatomical study gives important information for a better understanding of the clinical picture of ischemic lesions of the brain stem, such as the medial medullary syndrome, and highlights the remarkable role of the AVSA and ASA as anatomical landmarks during the surgical approaches to lesions involving the ventral aspect of the medulla and the foramen magnum.

Keywords: Microanatomy; anterior spinal artery; foramen magnum; cervico-medullary junction; vertebro-basilar junction.

Introduction

The anterior spinal artery (ASA) is typically described as the result of the confluence of both anterior-ventral spinal arteries (AVSA), which are branches emerging from the vertebral arteries (VA) on each side [7, 8, 30, 32, 47, 48]. The ASA runs along the ventral aspect of the medulla supplying the pyramids and their decussation, the medial lemniscus, the interollivary bundles, the posterior longitudinal fasciculus and the hypoglossal nuclei [7, 8, 34].

There are only a few papers describing the microanatomy of the AVSA and ASA and their clinical and surgical relevance. In this study, we describe in detail the anatomy of the AVSA and ASA, with particular interest in their morphology and branching pattern. We found this description to provide remarkable information for planning and performing surgical approaches to lesions involving the anterior rim of the foramen magnum and the ventral aspect of the medulla oblongata, and to increase our understanding of ischemic insults of this region such as the medial medullary syndrome.

Methods and materials

We studied 50 adult human cadaver brain stems, obtained from patients who died from a non-neurological cause. The specimens were previously flushed with saline solution, injected with red colored silicone latex particles and fixed with 10% formalin solution. The ventral aspect of the medulla, limited rostrally by the ponto-medullary sulcus and caudally by the origin of the first cervical root, was observed under microscopic magnification provided by an OPMI I (Carl Zeiss Inc., Germany) and a M900 (DF Vasconcellos, Brazil) surgical microscopes. Images at different magnification levels were obtained by a MVC-FD83 digital camera (Sony Inc., Japan). A detailed anatomical description of the vertebral arteries (VA), basilar artery (BA), AVSA and ASA is given. Information such as diameter, origin, branching pattern and the presence of the anterior communicating spinal artery (ACoSA) was recorded. Each AVSA–ASA complex was drawn in order to describe the morphological pattern. The branching pattern was obtained by locating the distal branches of AVSA and ASA and the exact place where they pierced the brain stem surface.

Results

The average outer diameters of the left and right VA were 2.6 mm (range 1–4.6) and 2.5 mm (range 0.7–4), respectively. In one case (2%) we noticed atresia of the right vertebral artery (Fig. 1). There was no side dominance, described by the authors as a >1 mm difference in the outer diameters, between both VA in 36 brain stems (72%). This predominance was recorded in 8 brain stems (16%) for the left VA, and in 6 (12%) for the right VA. The average outer diameter of the BA was 3.75 mm (range 2.3–7.6). A basilar artery fenestrated in its distal third was recorded (Fig. 2).

We could not determine the vertebro-basilar junction (VBJ) in two specimens, one with right VA atresia and the other with a saccular vertebrobasilar aneurysm (Fig. 3). The VBJ was rostral to the ponto-medullary sulcus in 18 brain stems (37.5%), caudal in 17 (35.4%) and at the same level in 13 (27%). The VBJ was located to the right of the midline in 11 brain stems (22.9%), at an average distance of 2.4 mm from the midline. In 9 brain stems (18.8%) the VBJ was located to the left, at an average distance of 2.1 mm from the midline.

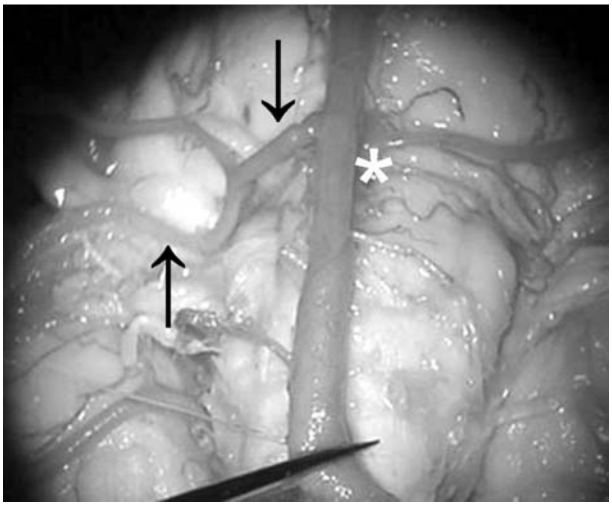

Fig. 1. Atresia of the right vertebral artery. The white star points out the inferior foramen cecum. The posterior inferior cerebellar artery arises from a common trunk along with the anterior inferior cerebellar artery (arrows)

Fig. 2. Fenestration of the proximal third of the basilar artery (arrow)

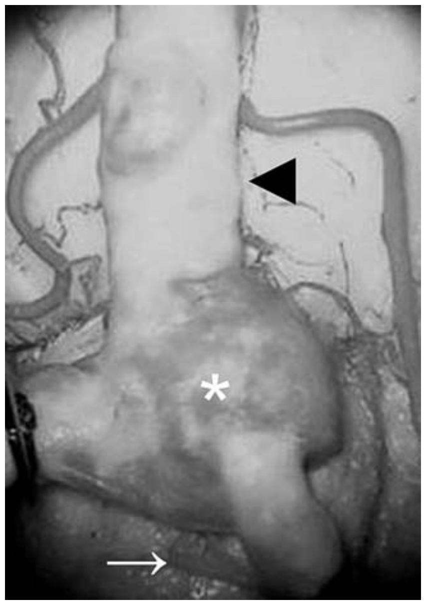

Fig. 3. Aneurysm at the vertebro-basilar junction (star). Atherosclerotic changes of the basilar artery are noticed (arrowhead). The anterior spinal artery emerges from the left vertebral artery (arrow)

Table 1. *Origin of the anterior-ventral spinal and anterior spinal arteries*

	Origin	No. of BS (%)	Total
AVSA	VA	30 (60%)	60
ASA as a direct branch	left VA	15 (30%)	15
	right VA	4 (8%)	4
	BA	1 (2%)	1

AVSA Anterior ventral spinal artery, *ASA* anterior spinal artery, *VA* vertebral artery, *BA* basilar artery, *BS* brain stems.

We found one AVSA arising from each contralateral VA in 30 brain stems (60%), while, in 19 brain stems (38%) the ASA was a direct branch from the ipsilateral VA (Table 1). In these cases, 15 brain stems (30%) showed that each ASA originated from the left VA, while in 4 brain stems (8%) it originated from the right VA (Fig. 4). In only one brain stem did the ASA originate from the BA (Fig. 5). In all these cases, the ASA was found sending paramedian and short circumferential branches to the contralateral pyramid (Fig. 4).

The average distance between the VBJ and the origin of the AVSA or the ASA was 7.5 mm (range 0.2–15 mm). The arteries originating from the left side had an average outer diameter of 0.8 mm (range 0.3–1.9), while those originating from the right side had an average outer diameter of 0.65 (0.2–2.1). The outer diameter of the ASA originating from the BA measured 0.9 mm. The AVSA or ASA arose from the medial wall of the vertebral arteries in 36 brain stems (43.8%), from the posteromedial wall in 19 (23.8%), and from the posterior wall in 15 (18.5%).

In 30 brain stems (60%) we found one AVSA running along each side of the midline. In 15 (30%) brain stems

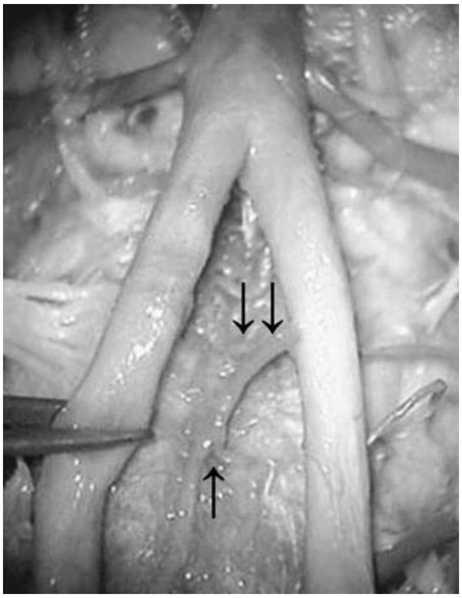

Fig. 4. The anterior spinal artery emerges as a direct branch of the left vertebral artery (double arrow). The branches of the anterior spinal artery supply both pyramids (single arrow)

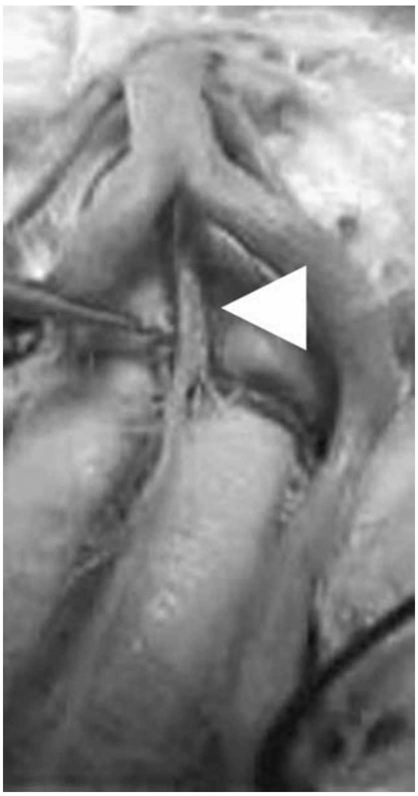

Fig. 5. An anterior spinal artery emerging from the basilar artery (arrowhead)

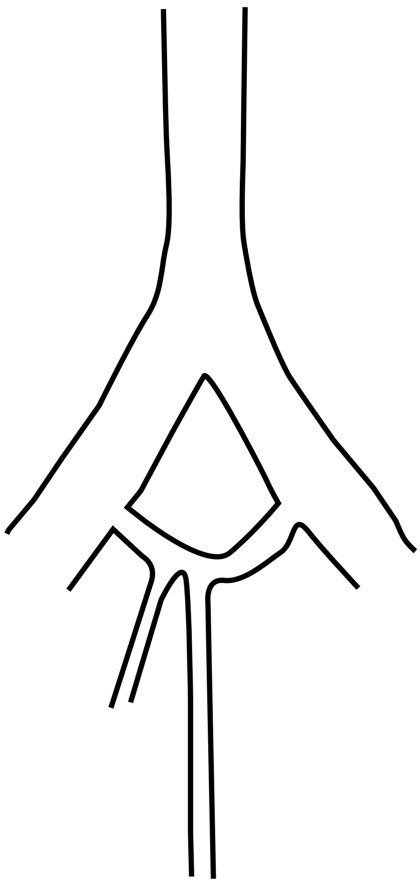

Fig. 6. Diagram of an arch-like junction between the anterior ventral spinal arteries, the anterior spinal artery and its accessory branch

we found the ASA formed from the confluence of both AVSA. In three of them we described an arch-like junction that sent one or two perforating branches running parallel to the ASA, following a distal trajectory. We named these perforating arteries as accessory ASA (Fig. 6).

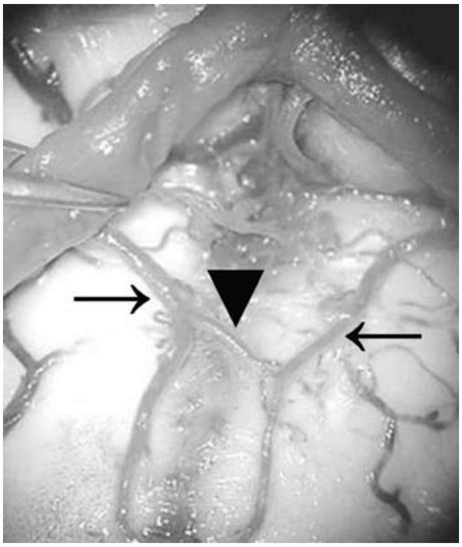

Fig. 7. A single anterior communicating artery (arrowhead) joining the anterior ventral spinal arteries (arrows)

Table 2. *Anterior spinal communicating artery pattern*

ACoSA	No. of BS	%
1, Single	11	22
2, Double	3	6
3, Triple	1	2

ACoSA Anterior communicating spinal artery.

Different ACoSA were described in 15 specimens (30%) (Figs. 7 and 12b). One ACoSA was observed in 11 brain stems (22%), two in three specimens (6%), and three ACoSA in 1 brain stem (2%) (Table 2).

We defined the terminal branches as follows. The paramedian branches (PM) were those straight vessels that entered through the ventral aspect of the medulla and supplied the medial portion of the pyramids. The short circumferential branches (SC) were those that supplied the rostral aspect of the pyramids and olive without passing beyond the anterolateral (pre-olivary) sulcus. The long circumferential branches (LC) were defined as those that run beyond the anterolateral sulcus. We found PM branches in all the brain stems. We counted 750 PM branches in total, with an average of 14.7 per brain stem (range 8–40).We also found SC branches in all the brain stems, a total of 477 SC branches were counted, with average of 9.4 per brain stem (range 6–32). The LC branches were described in 84% of the specimens, a total of 132 LC branches with an average number of 3.5 per brain stem (range 1–8) (Fig. 8a, b, Table 3).

A total of 64 branches piercing the foramen of Vicq d'Azyr (inferior foramen cecum) were described in 56% of the specimens, with an average of 2 per brain stem (range 1–10) (Table 3). We also described 32 anastomotic branches to the contralateral AVSA or ASA in 19 (38%) brain stems, and 18 branches of the ipsilateral vertebral artery in 18 (36%) brain stems (Fig. 9, Table 4).

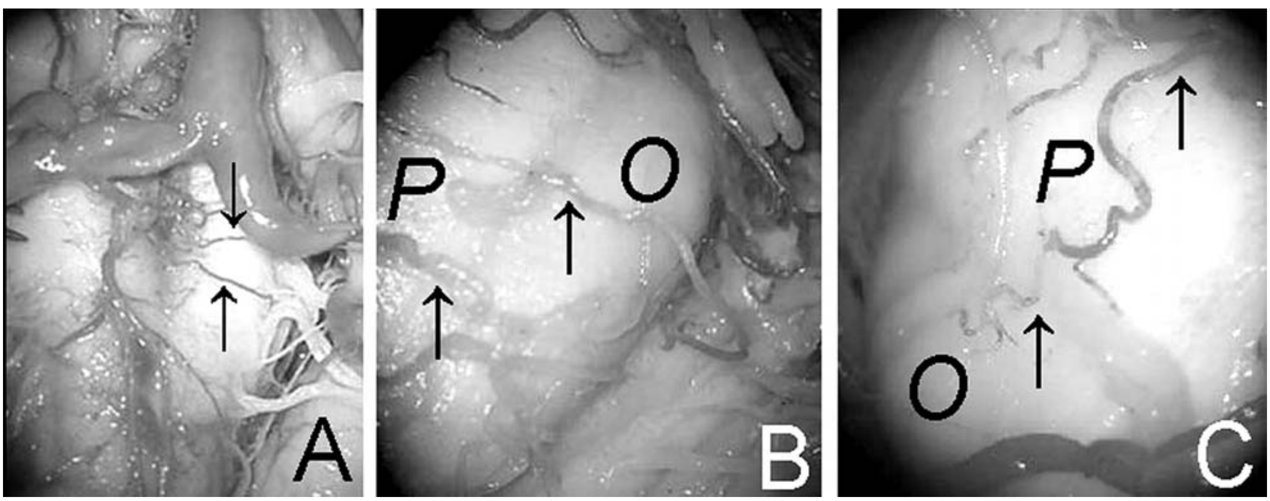

Fig. 8. (A–C) Long circumferential branches of the anterior spinal arteries (arrows), crossing over the pre-ollivary sulcus. (*O* Olive, *P* Pyramid). The vertebral arteries are separated by dissecting forceps. The hypoglossal rootlets were excised

Table 3. *Branching pattern*

Branches	Total	No. of BS (%)	Average	Range
PM	750	50 (100%)	14.7	8–40
SC	477	50 (100%)	9.4	6–32
LC	132	42 (84%)	3.5	1–18
F. VDA	64	27 (56%)	2	1–10

BS Brain stems, *PM* paramedian branches, *SC* short circumpherential branches, *LC* long circumpherential branches, *F. VDA* branches to the foramen of Vicq d'Azyr.

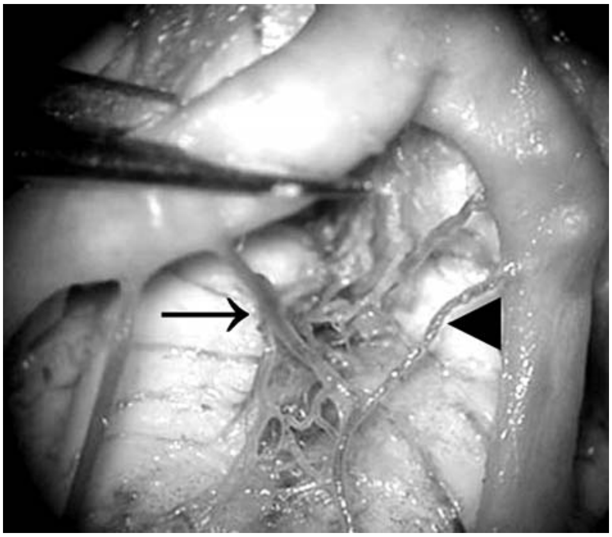

Fig. 9. Anastomotic branch between the left anterior ventral spinal artery (arrowhead) and the contralateral vertebral artery (arrow)

Table 4. *Anastomotic branches*

Branches	No.	No. of BS	%
To the ipsilateral VA	18	18	36
To the contralateral AVSA	32	19	38

BS Brain stems, *VA* vertebral artery, *AVSA* anterior ventral spinal artery.

Discussion

The anterior-ventral spinal arteries are typically described as branches of the vertebral artery. They emerge from near to the vertebro-basilar junction [7, 8, 36]. These branches run caudally and medially over the ventral aspect of the rostral part of medulla oblongata as far as the spot where they reach the contralateral one, usually at the level of the foramen magnum. They join to form the ASA, which follows a caudal trajectory [7, 8, 24, 36, 47]. In some cases the AVSA do not reach the contralateral one and both run separately, communicated in some cases by the anterior spinal communicating artery, as described by Akar *et al.* [1].

At the level of the medulla, the AVSA and/or ASA supply the pyramids and their decussation, the medial lemniscus, the interolivary bundles, the posterior longitudinal fasciculus and part of the hypoglossal nuclei. These arteries also supply the medial accessory olive nuclei, the most caudal portions of the solitary fasciculus and nuclei, and the dorsal motor nuclei of the vagus nerve. In the upper part of the medulla the blood supply from the AVSA and/or ASA becomes gradually less important and is replaced by branches of vertebral and basilar arteries. At the lowest segment of the medulla and the upper part of the cervical cord the ASA receives anastomotic branches from the anterior radicullary arteries [7, 8, 29, 32, 36].

Morphology of the AVSA–ASA complex

No side dominance of the vertebral artery was found in 36 (72%) brain stems. Left and right dominance were described in 8 (16%) and 6 (12%) brain stems respectively. This information differs from the 39.9% dominance of the left vertebral artery and 21.45% of the right vertebral artery reported in Grant's study [12], and the 18.2% left-vertebral dominance and the 45.6% right-vertebral dominance reported by Akar [1]. We found hypoplasia of the vertebral artery in 6 brain stems (12%) (Fig. 10a, b, c), 4 (8%) in the left VA and 2 in the right one (4%), similar to what was reported by Blackburn, who described 9% and 5%, respectively [3, 24].

The so-called typical morphology of the AVSA–ASA complex described in 76.7% of the specimens studied by Brunner [24] and in 85% of the Stopford's study was only observed in 27.27% of Akar *et al.* study [1] and in 18% of our study.

We found 60 AVSA in 30 brain stems (60%), this largely differs from previous reports by Stopford [47] and Mahmood [28] who reported the presence of this vessel in 85 and 100% of the brain stems analyzed, respectively. We reported the ASA as a direct branch of the left vertebral artery in 30% of all specimens (Figs. 3 and 4), whereas 8% was described arising from he right VA. Again these numbers differ from previous studies by Stopford and Akar who described a smaller number of vessels emerging either from the left or right VA, 3% and 9%, 18% and 9.09%, respectively [1, 15]. In one specimen, the ASA originated from the basilar artery. To our knowledge, this pattern has not been previously described (Table 1, Fig. 5). In our study the presence or absence of a hypoplastic VA did not have

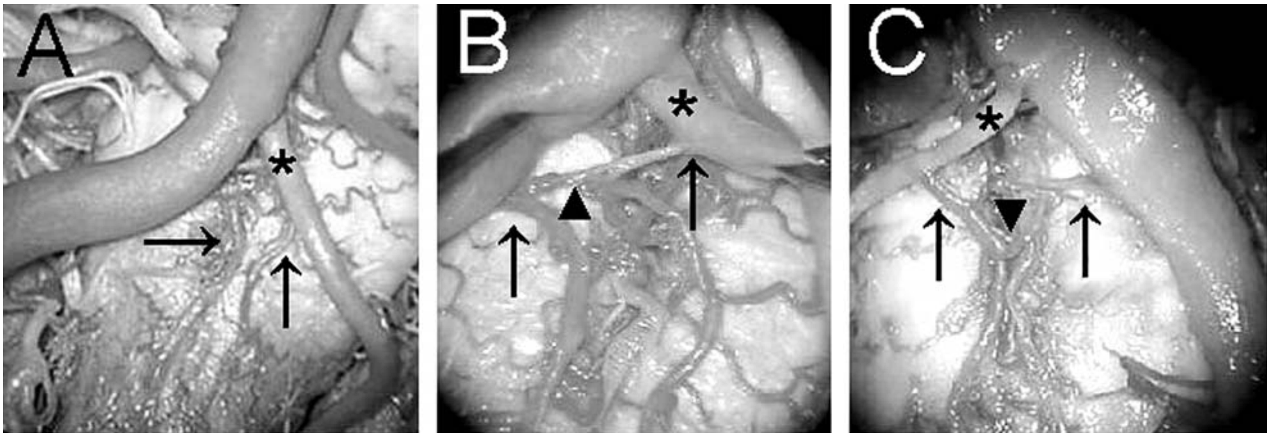

Fig. 10. (A–C) Hypoplastic vertebral arteries (star) from which the anterior ventral spinal arteries arise (arrows). The arrowhead points at the anterior communicating artery

Table 5. *Morphological patterns*

Type	No. of BS	%
I	12	24
Ia	3	6
II	3	6
IIa	12	24
III	15	30
IIIa	4	8
IV	1	2

BS Brain stems.

any influence on the origin of the AVSA, actually all the hypoplastic VA gave rise to one AVSA (Fig. 10a, b, c).

Previous reports by Akar *et al.* defined the anterior spinal communicating artery (ACoSA) as a branch connecting both AVSAs (Figs. 7 and 12b) [1]. We noticed the existence of this artery in 15 specimens (30%): single in 11 brain stems (22%), double in 3 (6%), and triple in 1 specimen (2%) (Table 2).

We distinguished four different morphological patterns in this study. Each pattern was defined by the presence or absence of the AVSA, the AVSA junction, and the presence or absence of the ACoSA (Table 5, Fig. 11). The morphological pattern type I is the one where the ASA is formed by the confluence of two contralateral AVSAs. This type is the one classically described by previous reports. We included three specimens with a type I pattern with an arch-like junction of both contralateral AVSA (Fig. 6). We propose to define a subtype Ia when an ACoSA is noted. We describe 12 specimens Type I (24%) and 3 Ia (6%) in this study. The pattern type II was defined as the presence of two AVSA that do not join together to form the ASA, instead they run separately over the ventral aspect of the pyramids and the medullo-cervical junction. They were also considered as a subtype IIa when an ACoSA was observed connecting them. We found 3 brain stems (6%) with a pattern type II, and 12 (24%) with a subtype IIa. Type III pattern was considered when the ASA originated from the VA as a direct branch. We found 19 brain stems (38%) with this pattern, 15 of them (30%) with the ASA arising from the left vertebral artery, and 4 (8%) from the right vertebral artery. We decided to name them as Type III when the ASA arose from the left VA and Type IIIa when it arose from the rigth vertebral artery. In one brain stem we did not find any AVSA or ASA arising from any of the vertebral arteries, in this specimen the ASA arose from the basilar artery. We defined this pattern as Type IV.

Branching pattern

We found an average of 9.4 SC and 14.7 PM branches per brain stem. They supplied the anteromedial and ventral aspect of the medulla oblongata (Table 3). This observation is contradictory to the report by Marinkovic *et al.* [29], who counted between 1 and 4 perforators from the ASA and AVSA. The difference might rely on the fact that we counted terminal branches but not main trunks as they did.

It is important to highlight the presence of branches that supplied the ventral aspect of the olive in 42 (84%) specimens, with an average of 3.5 per brain stem (Table 3 and Fig. 8a, b, c). This information supports the data reported by Akar *et al.* about the microvasculature of the ventral portion of the medulla and the olive [1]. It is, however, contradictory to the previous concept that the ASA and the AVSA were involved in the arterial supply

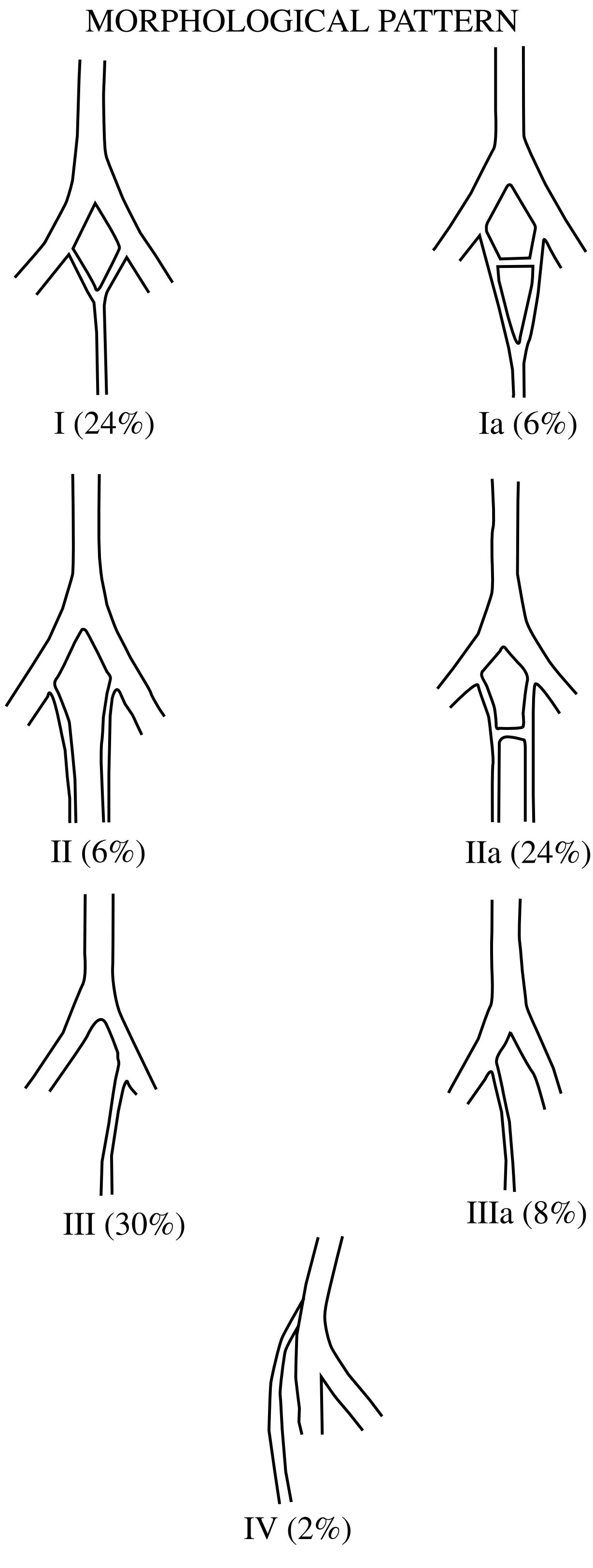

Fig. 11. Morphological patterns of the anterior ventral spinal and anterior spinal arteries

only of the ventromedial aspect of the medulla oblongata [7, 24, 29, 36, 48].

The distribution of perforating branches from VA, BA and ASA to the foramen of Vicq d'Azyr had been well described by others [1, 12, 28, 29, 31], nevertheless it is important to highlight that 56% of specimens in this study sent branches to the foramen of Vicq d'Azyr with an average of 2 per brain stem. We observed anastomotic branches of the AVSA and/or the ASA to the VA and to the contralateral AVSA in 74% of the brain stems (Table 3). This architectonic organization might represent a protective vascular network during ischemic insults of the ventral medulla and ponto-medullary junction.

Akar *et al.* had described the ACoSA in 5 of 11 brain stems [1], in this study we observed them in 15 specimens (30%). Interestingly, we report the presence not only of a single ACoSA, but the existence of double and triple ACoSAs (Table 2).

An important finding of this study is the presence of a branch of the left VA in 10% of the specimens, which reach the foramen cecum and the most rostral aspect of both pyramids. This vessel may correspond to the artery mentioned by Brunner as the accessory anterior spinal artery [24]. We differ with this definition because this vessel does not replace the absence of the ASA, and it is not exclusively related to the ASA. Considering its vascular distribution to the foramen of Vicq d' Azyr and the rostral pyramids, we have decided to named this branch as the *foraminopiramidal artery* (Fig. 12a, b), while the small perforating branch that emerged from the AVSA and displays a similar orientation and distribution as the ASA was defined as the *accessory anterior spinal artery.* We described this vessel in 3 brain stems (6%) (Fig. 6). Mahmood *et al.* previously described three branching patterns of perforating vessels arising from the vertebral arteries and heading to the foramen cecum [28]: Pattern A consists of a trunk arising with ASA, pattern B of a trunk arising separately from the ASA, and pattern C consists of trunks, arising with or without the ASA. Following this notion, the *foraminopiramidal artery*, which sends branches to the foramen of Vicq d'Azyr and to the pyramids, should be considered as a variant of pattern B or even as a new pattern D.

Clinical and surgical considerations

Dejerine described the classical medial medullary syndrome as contralateral hemiparesis, contralateral

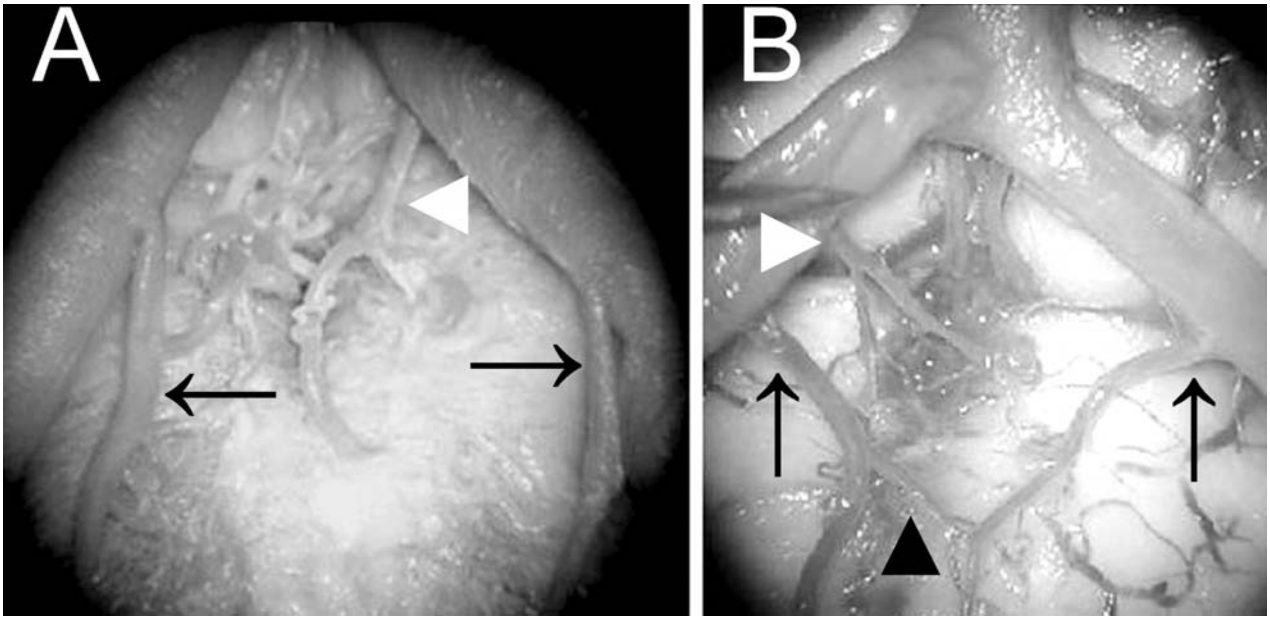

Fig. 12. (A, B) The foraminopiramidal artery (white arrowhead) as a branch of the vertebral artery that ends at the foramen of Vicq d'Azyr and the pyramids. The anterior ventral spinal artery (arrow) and the anterior communicating artery (black arrowhead) are also described

deep sensation disturbance and ipsilateral hypoglossal palsy [4, 5, 18–20, 33]. Variations of this classical description can be seen frequently displaying dysarthria, dysphagia, central facial paresis, bilateral motor impairment, respiratory weakness, thermoalgesic sensation disturbance, and even also associated with lateral medullary syndrome [2, 4, 9, 10, 13–16, 21, 25, 38, 42, 43]. The impairment solely of the paramedian medulla is infrequent but the number of cases reported is increasingly higher since the introduction of the MRI [14, 18, 23, 25]. The etiology varies from atherosclerotic infarction (0.5% of all cases of cerebrovascular diseases) [4, 20, 27], vertebral artery dissection [11, 27], inflammatory and infectious diseases [18], tumors of the foramen magnum [18], intramedullary arteriovenous malformations [34], Chiari malformation [21], neurovascular compression mainly due to vertebral artery dolicho-ectasia [22, 35, 45], and vertebral artery aneurysm [17, 23] among other less common causes. The conspicuously little frequency of the classical Dejerine's syndrome and its highly variable presentation can be explained by the existence of anastomotic branches from the contralateral VA, AVSA or ACoSA. The presence of morphological patterns of the AVSA–ASA complex such as types II and IIa, could act as protective nourishing pathways guarding against ischemia.

Lesions involving the foramen magnum, the lower third of the clivus, and the cervicomedullary junction are traditionally reached through a suboccipital, retrosigmoid or far lateral approach [7, 37, 39–41, 46]. The variations we described in this study should be considered when planning and performing these approaches. In our study, the pattern type III was highly prevalent, it was present in 30% of the brain stems, and all the branches from these AVSA–ASA complexes were responsible for the blood supply of both sides of the ventral aspect of the medulla oblongata, particularly through paramedian and short circumpherential arteries. In order to preserve the AVSA–ASA complex and protect the blood supply to the medial medulla we suggest that, if possible, any selected approach should be chosen to be performed from the right side. This is particularly advisable in cases of lesions centered over the medial and ventral aspect of the medulla. The fact that the hypoplasia of any of the VA is not related to the absence of the AVSA or ASA should be taken into account as well.

Conclusion

This study highlights the highly variable morphology of the AVSA–ASA complex. It is specially focused on the detailed description of the anterior-ventral spinal artery. The clinical relevance of this information relies on a better understanding of the indistinctive features and the underscored frequency of the medial medullary syndrome. The different morphological types and branching patterns of this arterial complex can be considered as protective nourishing pathways against ischemia. The knowledge of this anatomical description should be of use when planning challenging surgical approaches to the foramen magnum, the ventral aspect of the medulla and the cervicomedullary junction in neoplastic as well as vascular diseases.

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Comment

The authors investigated the micro-anatomical situation of the vasculature of the lower brain stem, medulla oblongata and the adjacent part of the spinal cord. The variants of the arterial supply of this region are well described and extensively discussed. Useful proposals for nomenclature are made. The differences of findings to other investigators are precisely described and evaluated.

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