Developmental Anatomy of the Distal Vertebral Artery in Relationship to Variants of the Posterior and Lateral Spinal Arterial Systems

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BACKGROUND AND PURPOSE: A certain number of anatomic variants involving the distal vertebral artery (VA) are explained by variations in size and connection of the lateral spinal artery (LSA). This study examined the possible role of another branch of the VA, the posterior spinal artery (PSA), in the development of similar vascular variations.

MATERIALS AND METHODS: Four types of variations in the distal VA, including the C1 and C2 origins of the posterior inferior cerebellar artery (PICA), the duplication of the distal VA, and the aberrant course of the distal VA, are illustrated by 9 angiographic observations.

RESULTS: For each type of VA variant listed above, examples resulting from variations in size and connection of the LSA and PSA could be matched.

CONCLUSION: Variation in size and connection of the PSA is at the origin of a set of anatomic variations of the distal VA similar, but not identical, to the vascular variants linked to the LSA.

The formation of the distal vertebral artery (VA) and its principal branch, the posterior inferior cerebellar artery (PICA), involves the combination of several embryonic vascular segments. This complex developmental anatomy was well described by Congdon1 and Padget2,3 in human specimens and by Moffat4 in the rat. Among the embryonic precursors involved, particular attention needs to be given to the spinal branch of the proatlantal artery (ProA) (which corresponds, in fact, to the radicular artery of the first cervical nerve5), the primitive lateral basilovertebral anastomosis of Padget (PLBA), and the lateral longitudinal artery of Moffat.6

PSA system is matched with an equivalent variant derived from the LSA system.

Description of Case Histories
The case histories are arranged according to the type of anatomic variation described with, for each type, examples involving the PSA and LSA systems.

C1 Origin of the PICA
Case 1. A Wada test was performed in a 20-year-old woman as part of the presurgical work-up of a left frontal lobe neoplasm. Incidentally, cerebral digital subtraction angiography (DSA) documented a C1 origin of the right PICA. This variant is linked to the LSA (Fig 1A, B).

Case 2. A 15-year-old boy underwent preoperative embolization of a nasopharyngeal angiofibroma. Incidentally, a proximal origin of the right PICA from both C1 and C2 roots was documented. This variant is linked to the LSA (Fig 2A, B).

Case 3. A 47-year-old woman presented with acute left lower quadranopsia and left-sided paresthesia after head trauma. MR imaging of the brain revealed right cerebral peduncle and right occipital lobe strokes. Cerebral DSA showed a dissection of the proximal right posterior cerebral artery. Incidentally, a C1 origin of the left PICA was observed. This variant is linked to the PSA (Fig 3A, B).

C2 Origin of the PICA
Case 4. Cerebral DSA was obtained in a 44-year-old woman as part of an investigation for transient ischemic attacks. The results of the angiogram were unremarkable. Incidentally, a C2 origin of the right PICA was documented. This variant is linked to the PSA (Fig 4A, B).

Case 5. A 44-year-old woman was investigated for basal ganglia and subarachnoid hemorrhage. Results of cerebral DSA were unremarkable. Incidentally, a C2 origin of the PICA was noted on the left side. This variant is linked to the LSA (Fig 5A, B).

Duplication of the VA
Case 6. A 47-year-old woman presented with acute left dysmetria. Brain MR imaging showed an acute stroke in the left...
cerebellar hemisphere. Results of cerebral DSA were normal. Incidentally, a duplication of the distal right VA was observed. This variant is linked to the PSA (Fig 6A–B).

Case 7. A 52-year-old woman was investigated for left pulsatile tinnitus. The results of the angiogram were unremarkable. Incidentally, a duplication of the distal left VA was noted. This variant is linked to the LSA (Fig 7).

Aberrant Course of the Distal VA

Case 8. Brain MR imaging in a 64-year-old woman with systemic lupus erythematosus and progressive cognitive changes showed scattered foci of white matter T2-weighted hyperintensity, suggesting cerebral vasculitis. Results of cerebral DSA were normal. Incidentally, a superior convexity of the distal right VA was observed. This variant is linked to the PSA (Fig 8A–B).

Case 9. A 58-year-old woman presented with syncopal episodes suggesting vertebrobasilar insufficiency. Results of cerebral DSA were unremarkable. An intradural course of the right VA was noted (Fig 9).

Discussion

After a brief review of the normal and developmental anatomy of the cervical spinal arteries, several anatomic variants involving the distal VA and the PICA will be considered, and the embryologic mechanisms underlying their formation discussed. For each variation, 1 or more cases involving the PSA system will be matched with and compared with an example involving the LSA system.

Anatomy of the PICA and Upper Cervical Spinal Arteries

The blood supply of the spinal cord is derived from 3 longitudinal vascular axes: the anterior spinal artery (ASA) and the 2 unpaired PSAs.5 The ASA is formed by the junction of 2 small anterior spinal rami originating from the intracranial portion of each VA. These rami unite ventromedially to form a single descending channel that runs along the ventral sulcus of the spinal cord. In practice, there is often, if not always, an asymmetry in caliber of these 2 rami, and it is not unusual to see the ASA be the continuation of a single VA root.

The PSAs usually originate from the extracranial portion of the VA, generally near its point of dural penetration, or from the PICA itself7 (Fig 10A). From their origins, the unpaired PSA course caudally along the posterosilateral surface of the spinal cord, where they form 2 parallel anastomotic chains located dorsal to the attachment of the posterior nerve roots.

This basic vascular organization is supplemented, at the upper cervical level, by a lateral spinal longitudinal axis, which
was differentiated from the PSA by Kadyi in 1889, and later given the name of LSA. The LSA lies on the lateral aspect of the spinal cord, ventral to the posterior cervical nerve roots, and parallel to the spinal component of the eleventh cranial nerve. The LSA usually has several lateral segmental connections with the VA at C2, C3, and/or C4 (Fig 10D). Cranially, it ends into the intradural portion of the VA at C1 and/or joins the PICA. Caudally, at the level of C4 or C5, it turns dorsally to pass behind the spinal nerve roots and joins the ipsilateral PSA. The importance of the LSA for the understanding of several anatomic variants involving the distal VA and the PICA was recognized by Lasjaunias and coauthors.

The PICA originates most frequently from the intracranial portion of the VA, approximately 15 mm proximal to the verteobasilar junction, along the lateral aspect of the medulla. From its origin, the PICA courses laterally, along the roots of the hypoglossal nerve, forms a caudal loop over the dorsolateral aspect of the medulla, and turns upward to pass between the tonsil and the vermis, at which point it divides into its medial (vermian) and lateral (hemispheric) branches. The PICA is a late phylogenetic acquisition that appears fully developed only in humans. Common variants involving the PICA include low origins at C1, C2, or C3, usually explained by variations in size and configuration of the LSA, as well as the origin of the PSA from the PICA.

**Developmental Anatomy of the Upper Cervical Spinal Arteries**

The ProA is an embryonic vessel located between the most caudal presegmental artery (ie, the hypoglossal artery) and the first cervical intersegmental artery, which accompanies the second cervical nerve root (C2). Therefore, the ProA courses between the occipital bone and the atlas, along with the first cervical nerve root (C1). The ProA is one of the transient anastomoses that supply the basilar circulation before the development of the VAs. The ProA branching pattern follows the typical distribution of an embryonic segmental artery. In particular, it branches off a spinal artery (the radicular artery of C1) that divides into ventral and dorsal radicular branches. The ventral branch follows the anterior radix of C1 until it reaches the anterior-lateral aspect of the spinal cord, where it divides into ascending and descending rami. These rami later fuse with their contralateral counterparts to form the basilar and ASAs, respectively. Unlike the spinal branches at other cervical levels, the spinal branch of the ProA and its ventral radicular component remain prominent in the adult; in fact, they eventually form the distal segment of the definitive VA.

The dorsal radicular branch has a similar fate: it courses along the posterior radix of C1 until it reaches the posterolateral aspect of the spinal cord, where it divides into ascending and descending rami. The descending ramus anastomoses with the posterior spinal plexus of Moffat (the future PSA) and later becomes the trunk of origin of the PSA. The left and right PSAs do not fuse but remain separate vessels on each posterior-lateral aspect of the spinal cord. The ascending ramus of the dorsal radicular branch is smaller and establishes a connection with the PICA.

The definitive VA takes form through a series of longitudinal anastomoses linking the first 6 cervical intersegmental arteries. Eventually, the proximal connections of the intersegmental arteries to the dorsal aorta regress, with the exception of the sixth intersegmental artery, which remains prominent and becomes the adult subclavian artery. The longitudinal connection between the first intersegmental artery and the ProA establishes the continuity between the subclavian artery and the basilar artery. Although the proximal trunk of the ProA involutes, its dorsospinal branch becomes a portion of the adult VA (ie, the distal VA and its so-called C1 muscular branch). Through this assimilation of the distal ProA by the VA, the cranial origins of the ASA and PSAs, which originally correspond to the anterior and posterior radicular branches of C1, become distal branches of the adult VA. The correspondence between the anterior and posterior radicular branches of C1 in the embryo and the distal VA and the trunk of the PSA in the adult was recognized by Kadyi in 1889. The segmental nature of these vessels remains apparent through a close examination of the adult anatomy.

**Discussion of the Illustrative Cases**

**C1 Origin of the PICA.** A low PICA origin at the C1 level is a frequent variant, whose relationship with the LSA was identified by Lasjaunias and coauthors. Rostrally, the LSA and the PICA are connected by small anastomoses located at the level of the restiform body. It is believed that, during embryonic development, one of these anastomoses remains prominent and establishes a longitudinal continuity between the PICA and the LSA, the PICA eventually originating from the extradural VA through the LSA. Case 2, which shows a double origin of the PICA from the VA at the C1 and C2 levels, illustrates this concept (Fig 2). In this configuration, the proximal segment of the PICA corresponds to the LSA (Fig 10E).

On the other hand, in case 1, the PICA originates from the superior aspect of the distal VA, and adopts a “hairpin” course with a cranial loop before it passes posteriorly and ascends...
toward the cerebellum (Fig 1). This typical hairpin course of
the initial portion of the PICA strongly resembles the course of
the radicular arteries joining the posterior longitudinal spinal
axis. As mentioned above, the PSA corresponds embryologi-
cally to the descending ramus of the posterior radicular branch
of C1, whereas the ascending ramus establishes small connec-
tions with the PICA. Indeed, small anastomoses between the
PICA and the PSA have been described in the literature. For
instance, Sabatier,9 Maillot and Koritke,7 and Lazorthes and
colleagues10 explicitly mentioned an ascending branch of the
PSA that anastomoses with the PICA. By analogy with case 2,
these anastomoses may be preferentially recruited during de-
velopment to result in an apparent origin of the PICA from the
PSA system.

Case 3 shows another example of a low PICA origin at the
C1 level from the PSA. Figure 3 particularly illustrates how
well the distal segment of the VA corresponds to the anterior
radicular branch of C1 and how the proximal segment of the
expected course of the LSA, resulting in a more anterior posi-
tion at the foramen magnum.

Duplication of the VA
Arterial duplication refers to the division of an artery into 2 dis-
tinct vessels with different courses. Fenestrations, in which a sin-
gle arterial lumen divides into 2 parallel channels following the
same course, are frequently confounded with duplications. Du-
plications of the VA derived from the LSA system have been de-
scribed by Lasjaunias and coauthors.6 In this variation (Fig 10F),
the upper limb of the duplication corresponds to the VA per se,
whereas the lower limb is a prominent intradural LSA segment
(as in case 7). Case 6, which shows a VA dividing into 2 vessels
with separate courses, is also consistent with an arterial duplica-
tion. However, in this situation, the duplicated segment is more
distal, and the supernumerary limb is located above rather than
below the limb corresponding to the normal VA component (Fig
10C). The upper limb of the duplication forms an upward loop,
from which the PICA arises. In this variant, we believe that the
Fig 6. Duplication of the distal right VA (PSA type) in a 47-year-old woman.
A, DSA, right VA, anteroposterior view, showing a duplication of the distal VA consisting, in fact, of a double origin of the right PSA from the PSA (C1 origin, white arrow) and from the V4 segment of the VA (normal origin, white arrowhead). The LSA is indicated by black arrowheads.
B, DSA, right VA, lateral view, also showing a duplication of the distal VA consisting of a double origin of the right PCA from the PSA (C1 origin, white arrow) and from the V4 segment of the VA (normal origin, white arrowhead).

Fig 7. Duplication of the distal left VA (LSA type) in a 52-year-old woman.
A, DSA, left VA, anteroposterior view (flipped horizontally for comparison with Fig 6A), showing a dominant intradural segment (black arrowhead) corresponding to the LSA with a prominent C2 root (white arrow). The normal distal VA is slightly hypoplastic (white arrowheads).
B, DSA, right VA, unsubtracted lateral view. As with Fig 7A, this variant also shows a dominant intradural segment (black arrowhead) corresponding to the LSA with a prominent C2 root (white arrow).

Fig 8. An aberrant course of the distal right VA (PSA type) in a 64-year-old woman.
A, DSA, right VA, anteroposterior view. This variant is similar to the VA duplication shown in Fig 7, with a double origin of the PCA from the PSA (white arrow) and from the distal VA (white arrowhead). The difference between the 2 variants lies in the absence of a segment of the right VA between the 2 PCA origins, resulting in a seemingly “aberrant” course of the VA.
B, DSA, right VA, lateral view. As with Fig 8A, this variant is also similar to the VA duplication shown in Fig 7, with a double origin of the PCA from the PSA (white arrow) and from the distal VA (white arrowhead).
upper limb results from the simultaneous persistence of both the normal origin of the PICA and of a second origin derived from the PSA system (equivalent to a low PICA origin, as shown in case 1). Here again, the identification of a distinct LSA helps to differentiate the 2 types of variations (ie, derived for the LSA or PSA systems).

**Aberrant Course of the Distal VA**

Case 9 is an example of an intradural course of the distal VA. In this variant, the apparent distal VA corresponds, in fact, to a prominent LSA, whereas the VA may be diminutive (as in this case) or absent. It is similar to the VA duplication illustrated in case 7 and can be viewed as a VA duplication in which the LSA limb is markedly dominant (Fig 10F).

Case 8 shows a more distal type of “aberrant” course of the distal VA, where the vessel forms an upward loop that gives rise to the PICA. We propose that this aberrant course results from the simultaneous presence of 2 separate origins for the PICA, the normal one as well as a second origin derived from the PSA system. This situation is, in fact, similar to the distal VA duplication illustrated in case 6, the difference being that the normal distal VA is diminutive or absent in this aberrant course (Fig 10C).

Thus, it appears that a parallel can be drawn between a duplication and an aberrant course of the distal VA for variants derived from either the LSA and PSA systems. An aberrant course is an extreme form of duplication in which the limb corresponding to the normal VA is diminutive or absent, whereas the “supernumerary” limb has become a markedly dominant or unique vessel.

**Conclusion**

Anatomic variations commonly involve the distal segment of the VA. Lasjaunias and colleagues have simplified this complex anatomy by showing that a certain number of anatomic variants can be understood as segmental caliber variations of the distal VA and of one of its branches, the LSA. This report shows that a similar but not identical set of anatomic variants of the distal VA is linked to another of its branches, the PSA, as the result of comparable segmental alterations in caliber and connections.

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