Posterior inferior cerebellar artery with an extradural origin from the V₃ segment: higher incidence on the nondominant vertebral artery

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OBJECTIVE The posterior inferior cerebellar artery (PICA) and the vertebral artery (VA) often exhibit anatomical variations at the craniovertebral junction (CVJ). An example of this is the PICA originating extradurally from the V₃ segment of the VA. To date, some cadaveric investigations have been reported, but the incidence and relationship of this variation to the VA and the atlas as observed on clinical imaging have not been discussed. This study evaluated the prevalence of PICAs originating from the V₃ on CT scanning. Other variations of the atlas and VA were also analyzed.

METHODS CT images from a series of 153 patients who underwent 3D CT angiography (CTA) were analyzed, and variations of the PICA, VA, and atlas were investigated.

RESULTS A total of 142 patients (284 sides) were analyzed; 11 patients (7.2%) were excluded due to poor image quality. The most common VA variation was the PICA originating from V₃ (9.5% of 284 sides), which was more frequently observed on the nondominant VA than the dominant VA (22.5% vs 6.25%, $p = 0.0005$). A VA with a PICA end was identified in 4 sides (1.4%), which is the same incidence as observed in the persistent first intersegmental VA (1.4%). VA fenestration was only found in 1 side (0.35%). Regarding the atlas, ponticulus posticus was observed in 24 sides (8.5%). There was no relationship between the incidence of ponticulus posticus and the variations of the VA.

CONCLUSIONS A PICA originating from V₃ was the most common VA variation at the CVJ and was more common on the nondominant VA. Three-dimensional CTA is useful for the evaluation of this variance. Surgeons should be mindful of this variation during operations.

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KEY WORDS extradurally originating posterior inferior cerebellar artery; vertebral artery; craniovertebral junction; atlas; vascular disorders; cervical

THE posterior inferior cerebellar artery (PICA) is considered to be the first branch from the vertebral artery (VA). It perfuses important neural structures, including the lateral posterior area of the medulla oblongata, the inferior half of the anterior surface of the cerebellum, and the inferior half of the vermis. Occlusion of this vessel may cause serious ischemic conditions, such as Wallenberg syndrome, cerebellar infarction, and, in the worst cases, acute tonsillar herniation due to neural edema. It also results in serious sequelae, including difficulties in swallowing, saliva clearance, and articulation, as well

as hemiparesis. Great care should be paid to this artery in operations that involve the craniovertebral junction (CVJ).

The PICA is generally thought to originate from the intradural (V₄) segment of the VA; thus, surgeons pay careful attention to the artery after dural opening. However, among the cerebellar arteries, the course of the PICA shows the most variation.¹⁴ Rhoton reported on extradurally originating PICAs from the V₃ segment, which is the extradural portion from the transverse foramen of the atlas to its dural penetration close to the foramen magnum.²⁵ In this variation, the PICA branches off the extradural

ABBREVIATIONS CTA = CT angiography; CVJ = craniovertebral junction; DSA = digital subtraction angiography; FIA = first intersegmental artery; PICA = posterior inferior cerebellar artery; PP = ponticulus posticus; VA = vertebral artery.

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FIG. 1. An example of extradurally originating PICA. **Upper:** Three-dimensional reconstructed image. This variation is characterized by the origin of the PICA branching off the parent VA (V₃) into the extradural space between the occiput and the atlas (arrow). **Lower:** Axial CT angiogram of the atlantooccipital region, showing an extradurally originating PICA. On the axial section image, the PICA branches off the parent VA (V₃) (arrow) at 2 mm from the dura mater (arrowheads). The outer border of the dura mater is clearly visible with enhancement of the venous plexus. Note that its origin is located between the occiput and the atlas.

space between the occiput and the atlas. In such cases, the PICA may be damaged during extradural surgical dissection. Because of the abundant venous plexus covering the epidural space in this region, it is hard to visualize the extradural part of the PICA. It is important to understand the course of the PICA on imaging studies before surgery. Although some cadaveric investigations have reported extradural PICAs originating from V₃, the precise incidence and anatomical nature of this variation have not been studied on clinical images. It is essential to know if radiological examinations are applicable to the evaluation of PICAs originating from V₃.

In the present study, we focused on PICAs originating from V₃ as observed on CT. Enhanced CT images were reviewed to clarify their incidence, along with other VA variations and skeletal variations of the atlas. We then performed a statistical analysis to elucidate the relationship between VA variations, including PICAs originating from V₃, and atlas variations.

Methods

This clinical study was a retrospective analysis of 3D

FIG. 2. An example of a persistent FIA. CT angiogram showing the FIA at the atlantoaxial junction (arrow). It runs between the atlas and the axis.

CT angiography (CTA) data from a series of 153 consecutive patients who visited our department between January 2013 and March 2015 and underwent 3D CTA on a 64-slice CT system (SOMATOM Definition AS, Siemens AG) for the screening or evaluation of the intracranial arteries and/or the extracranial carotid and vertebral arteries. Nonionic iodinated contrast medium was injected into the antecubital vein using a bolus-tracking method with an automatic injector. The amount of contrast medium was properly adjusted to the patient's body weight and renal clearance. None of the patients had previously been diagnosed with atherosclerotic stenosis, traumatic dissection, or other pathologies of the VA. The imaging data of the patients was transferred in DICOM format to a workstation (Shade Quest version 1.22, Yokogawa Electric Corp.), and a reconstructed image of each patient was reviewed by the first and second authors (T.I. and M.Y.) to evaluate whether a PICA originating from the V₃ segment existed at the atlantooccipital junction (Fig. 1). At the same time, 4 other VA variations were investigated: laterality (asymmetry) of the VA caliber between the right and left sides (defined as a difference ≥ 2 mm), PICA end (VA ending at the PICA without anastomosis to the contralateral VA), persistent first intersegmental artery (FIA) at the atlantoaxial junction (Fig. 2), and VA fenestration (a circular arterial network around the posterior arch of the atlas) (Fig. 3). In addition, we investigated the frequency of the ponticulus posticus (PP) of the atlas. In the present study, PP was defined as a partial protrusion or a complete ring formation of bone at the dorsal surface of the atlas (Fig. 4).

We compared the incidence of PICAs originating from V₃ to that of the other analyzed variations, and we statistically analyzed the relationship between PICAs originating from V₃ and other variations. The chi-square test was used for the statistical analysis.

To clarify surgical significance, the PICAs from V₃ were evaluated and measured geometrically. The orifice of each PICA with an extradural origin from V₃ was locat-

FIG. 3. An example of fenestration of the PICA. CT angiogram showing the fenestration of the PICA (arrows). It is a duplication of the VA surrounding the posterior arch of the atlas.

ed and classified based on its relationship to the VA as follows: ventral, rostral, dorsal, or caudal surface of the VA. In addition, the length of the extradural segment of the PICA was measured, and the presence of any branch off this segment was evaluated. Finally, on the side with the PICA with the V_3 origin, placement of a condylar screw was simulated on the StealthStation S7 neuronavigation system (Medtronic) to determine if it could be placed safely.

This study is based on retrospective observations of CT images of the patients. No personal information (name and identification number) that could identify a patient was recorded. Therefore, special patient consent was not obtained in this study.

Results

We reviewed a series of 153 patients in the present study. None of these patients experienced any adverse effects due to the contrast medium. The image quality was not sufficient for analysis in 11 patients (7.2%), who were excluded from the evaluation. The reasons for poor image quality included metal fillings for dental treatment in 5 patients, newly diagnosed extradural VA dissection in 4 patients, history of surgery at the CVJ in 1 patient, and congenital systemic malformation in 1 patient. Therefore, the data from 142 patients were analyzed. The patients were between 6 and 82 years of age (mean 59.9 years). Seventy-six patients (54%) were men, and 66 patients (46%) were women.

VA variations, including caliber asymmetry, or variations of the atlas were recognized in 96 of 142 patients (67.6%) on 140 of 284 sides (49.3%). A PICA originating extradurally from the V_3 segment was observed in 27 patients (19% incidence; 9.5% of sides), although there were no cases with bilateral PICAs originating from V_3 .

VA caliber asymmetry (difference ≥ 2 mm) was observed in 80 patients (56.3%). A PICA end of the VA and FIA was found in 4 patients (2.8% of patients and 1.4% of sides). VA fenestration was only found in 1 patient (0.7%

FIG. 4. An example of a PP. CT angiogram shows PP of the atlas (arrow). It is a partial protrusion or a complete ring formation of bone connecting the dorsal surface of the lateral mass and the rostral surface of the posterior arch.

of patients and 0.35% of sides). None of these 3 variations were observed bilaterally in any patient. In the current study, we did not observe extradural PICA at the atlanto-axial junction (below the atlas at the V_2 segment) in any cases.

On evaluation of the atlas, a PP was recognized in 17 patients (12.0%); it was observed on both sides in 7 of these 17 patients, resulting in a prevalence of 8.5% (24 of 284 sides). Among these cases, an incomplete PP was recognized on 10 sides, and a complete PP was observed on 14 sides (Table 1). With regard to the other atlas variations, a transverse foramen defect was observed on 5 sides, and the C-1 posterior arch was partially defective in 2 patients.

In this study, the prevalence of PICAs from V_3 observed on the nondominant VAs, dominant VAs, and VAs without caliber asymmetry was 22.5% (18 patients), 6.25% (5 patients), and 3.2% (4 patients), respectively. PICAs from the V_3 segment were observed significantly more frequently on the nondominant VA than on the dominant VA (22.5% vs 6.25%, $p = 0.0005$). In contrast, no correlation was observed between the PP and all VA variations studied. These VA variations were present in 48.8% of 260 sides without a PP and in 54.2% of the 24 sides with a PP. The incidence did not differ to a statistically significant extent.

The orifice of a PICA with an extradural origin was located on the dorsal surface of the VA in 20 cases (74.1%),

TABLE 1. Variations of the VA and atlas

Variation	No. of Patients (%)	No. of Sides (%)
PICA from V_3	27 (19.0)	27 (9.5)
PICA end	4 (2.8)	4 (1.4)
FIA	4 (2.8)	4 (1.4)
VA fenestration	1 (0.7)	1 (0.35)
PP	17 (12.0)	24 (8.5)
PP on both sides	7 (4.9)	NA
Incomplete PP	9 (6.3)	10 (3.5)
Complete PP	10 (7.0)	14 (4.9)

NA = not applicable.

FIG. 5. Simulation of condylar screw placement on the Medtronic StealthStation S7 neuronavigation system. A 3D CTA image of the CVJ is reconstructed to simulate screw placement to the left occipital condyle. The track of the screw (arrow) crosses the extradural segment of the PICA (white arrowhead). The V₃ section of the VA (black arrowhead) is located caudal to the extradural PICA.

the rostral surface of the VA in 3 (11.1%), the caudal surface of the VA in 3 (11.1%), and the ventral surface of the VA in 1 (3.7%).

Among PICAs originating from V₃, the length of the extradural segment ranged from 1.5 mm to 15.7 mm (mean 4.3 mm, median 3.0 mm). No arterial branches off this segment were visible on the available CT images.

Under guidance of the StealthStation S7 neuronavigation system, the placement of a condylar screw was simulated on the side of the PICA with a V₃ origin. Among the 27 patients demonstrating a PICA arising from V₃, placement was regarded as safe on the simulation of 26 patients. However, in the remaining patient, the simulated screw coursed across the extradural PICA. This was the longest extradural PICA that we observed in our present study. This extradural PICA segment was rostral and parallel to the VA. Due to its course, surgical dissection and screw insertion seemed hazardous in this case (Fig. 5).

Discussion

The current radiological study of the CVJ revealed 2 important findings regarding the anatomy of PICA. First, of the 284 sides in 142 patients, PICAs originating from the V₃ segment, the most common anatomical variation of the VA at the CVJ, were seen in as many as 9.5% of all cases. Second, PICAs originating from V₃ were more frequently observed on the nondominant VAs than on the dominant VAs or the VAs with equal caliber. There seemed to be no relationship between variations of the atlas, such as a PP, and VA variations, including extradurally originating PICAs.

The prevalence of extradurally originating PICAs has been reported to range from 0.4% to 20.8%.^{6,19,21,32} However, most cases were identified at the atlantoaxial junction, rather than the atlantooccipital junction or V₃ segment. Some authors described the existence of PICAs originating from V₃ in case reports, and the incidence of these PICAs was estimated based on cadaveric inspection in Western countries.^{2,6,10,13,15,20,24,29–31} However, the clinical

utility of using enhanced CT scans as a diagnostic tool has not been evaluated. In the present study, we analyzed Japanese patients who underwent contrast CT examination. Most patients underwent examination to rule out atherosclerosis of the carotid artery, and we excluded patients with any lesion or a surgical history at the CVJ or VA. Among this study population, the rate of PICA with V₃ origin was 19% (9.5% of sides). This rate is comparable to that reported in a previous cadaveric study (5%–20%).^{10,13,15,20} The patients in our study can be considered to represent the general Japanese population, and the rate of the PICA arising from V₃ seems concordant with that reported in Western countries. Therefore, the results we obtained seem trustworthy and universal, underscoring the notion that the prevalence of this anatomical variation is much higher than imagined in daily clinical practice and that contrast CT studies are suitable for identifying it. Among other radiological modalities, digital subtraction angiography (DSA) and MR angiography can visualize the vasculature. Although DSA offers good spatial resolution, it requires invasive percutaneous catheterization into the target artery. MR angiography is a noninvasive examination that does not require a contrast medium, but its spatial resolution is not high enough for the evaluation of PICA variance. Furthermore, it is essential to recognize the geometric relationships among the VA, PICA, and dura mater, as well as the bone. Only enhanced CT can clearly visualize all of these structures, thereby making it better than DSA and MR angiography for this purpose.

In the present study, PICAs arising from the V₃ segment were more frequently observed on the nondominant VA. Our CT-based evaluation revealed that 22.5% of the nondominant VAs were accompanied by PICA from V₃. The prevalence was 3.6 times higher than that of the dominant VAs (6.25%). This difference was statistically significant ($p < 0.05$). In clinical practice, the nondominant VA is usually regarded as a less important vessel. Our results, however, serve as a reminder that the nondominant VA may contain a PICA with a variant extradural course, which can cause problems in certain situations. According to the published literature, there are 2 clinical risks associated with extradural origin of the PICA: injury during surgery and the formation of a dissecting aneurysm. The extradural segment of the PICA might be injured in surgeries at the CVJ or the upper cervical spine.^{6,10} When a surgical intervention such as a procedure performed with a transcondylar approach or foramen magnum decompression is scheduled for patients with this variation, surgeons should take care to avoid accidental damage to the artery during extradural dissection, which may result in a neurological catastrophe, such as Wallenberg syndrome or cerebellar infarction.

Our measurements on CT showed that the mean length of the extradural PICA was 4.3 mm, which is shorter than that reported in previous autopsy studies (range 6–12 mm).^{6,13,26} The extradural origin of the PICA is in the vicinity of the dura mater. In addition, we detected no branches on the extradural PICA segment on contrast CT, similar to the findings of a previous cadaveric study.⁶ These 2 facts imply that the extradural PICA can be preserved as long as surgical dissection is performed along

the periosteum away from the dura mater. But, at the same time, the orifice of the extradural PICA is generally on the rostral or dorsal surface of the VA, which is where surgical manipulation is often performed. Among the PICAs from V₃ in our present study, only 1 crossed the occipital condyle. In this case, dissection toward the condyle and condylar screw placement seem extremely hazardous, as shown in Fig. 5. Indeed, Nassr et al. reported a case of cerebral infarction due to injury of the extradural PICA during screw placement.¹⁸ In the surgical field, it might be difficult to identify an extradural PICA around the spinal canal in the CVJ because it is occupied by an abundant venous plexus, and its dissection may cause profuse bleeding from the fragile venous network. In addition, the extradural segment of the PICA in the vicinity of the VA may not be detected by ultrasonography. CTA should therefore be performed before surgery to analyze the structure of the PICA. Recently, multislice CT has become more common in clinical settings. Its spatial resolution is high enough to reveal the vascular architecture of the PICA.^{33,34} This technique is thought to be the most practical and useful for analysis of the PICA.

In other reports, PICA with an extradural origin is regarded as a risk factor for aneurysmal formation or occlusion.^{9,11,16,24,27,29} Some authors argue that extradural PICAs are vulnerable to dissection because they tend to be forcefully stretched by neck motions or chiropractic procedures.^{23,24,27} When encountering patients with subarachnoid hemorrhage in the posterior fossa with an unknown etiology, carefully consider involvement of an extradural PICA.

We could not determine why a higher rate of PICAs from V₃ was observed on the smaller VAs at the atlantooccipital junction; nevertheless, 1 embryological study suggested a possible theory. According to a human embryo study by Macchi et al., the genesis of VA and its branches starts with an arterial mesh around the hindbrain.¹⁴ The origin and course of the PICA are established at the end of the embryonic period. As the fetus matures, some of the tributaries in the arterial mesh form the initial VA. After the formation of the primary VA, the PICA also develops out of this anastomotic mesh structure. Finally, the remaining vasculature disappears. Throughout these steps, the formation of the PICA is thought to be highly influenced by the antecedent VA development. Therefore, one hypothesis is that when the VA is more poorly formed, the PICA origin might be formed more proximally, which allows it to maintain a sufficient blood supply to the neural tissue. This may lead to extradurally originating PICAs on the hypoplastic VA.

In our analysis, other VA variations were also observed at the CVJ. Asymmetry of the VA diameter (difference ≥ 2 mm) was observed in 32.1%–43.5% of the cases reported in the literature.^{8,22} The prevalence of a PICA end, FIA, and VA fenestration was 2.8%–12.3%, 0.01%–8.0%, and 0.01%–2.0%, respectively.^{1,8,19,28,33,34} In our study, the prevalence of these variations was similar to that of previous reports. Asymmetry of the VA diameter was observed in 56.3% of reported cases. The prevalence of a PICA end, FIA, and VA fenestration was 1.4%, 1.4%, and 0.35%, respectively. The similarity between the prevalence in our

study and previous studies implies that the anatomical characteristics of the current study population are close to those of other races and ethnicities and that the accuracy of our interpretation of the CT scans (such as the identification of PICAs from V₃ at the atlantooccipital junction) was sufficiently validated.

PP is a reasonably common bony variation of the atlas. According to previous studies, the prevalence of PP is 6.2%–26.2%.^{3–5,7,8,12,17,35} However, the relationship between PP and VA variations has not been studied thus far. In our current analysis, we evaluated the incidence of variations in the VA and PP. Although we expected some correlations between the VA variations and PP, the findings of the statistical analysis implied that VA variations are not associated with the presence of PP. For safe dissection and instrumentation in patients with a PP, we do not have to worry too much about vascular variation and can simply focus on osseous structures, as in the general population.

Conclusions

We studied 142 consecutive patients who underwent 3D CTA to investigate anatomical variations in the VA and atlas. PICAs from the V₃ segment of the VA in the atlantooccipital space were the most common and were found to be more common on the nondominant VA. Three-dimensional CTA is the diagnostic tool of choice for the evaluation of this variance. Surgeons should consider this fact when operating around the foramen magnum. We did not observe any correlation between PP and VA variations.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Isaji. Acquisition of data: Isaji, Kawaguchi, Aoyama, Niwa, Nakura, Matsuo. Analysis and interpretation of data: Aoyama. Drafting the article: Yasuda. Critically revising the article: Takayasu. Study supervision: Yasuda, Takayasu.

Supplemental Information

Previous Presentations

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