The V₃ segment of the VA, as it exits the transverse foramen of the atlas, travels in a groove for the VA (sulcus arteria vertebralis) posterior to the lateral masses and on the posterior arch. Rarely, this groove may be converted into an osseous foramen (foramen arcuale) that then houses the VA, vertebral venous plexus, and suboccipital nerve (Fig. 1 upper). Since its early description, this structure has been given a myriad of names (Table 1).

Object. The neurosurgical literature is lacking information on the so-called foramen arcuale. When this foramen is present, the vertebral artery (VA) travels through it after exiting the transverse foramen of the atlas and prior to entering the cranium.

Methods. The authors performed a study in 60 cadavers to determine the incidence of the foramen arcuale and ascertain morphometric information on its anatomy. In specimens in which the foramen arcuale was observed, the authors studied the relationship between it and the VA.

The authors identified a foramen arcuale in 5% of specimens. The mean length and thickness of the osseous struts that converted the groove for the VA into the foramen arcuale were 7.0 and 2.0 mm, respectively. The mean area of the identified foramina was 14.2 mm². The mean area of the ipsilateral C-1 transverse foramina was 18 mm² in specimens with a foramen arcuale. The mean measurements of the proximal, intraforaminal (foramen arcuale), and distal diameter of the V₃ segment of the VA at the level of the foramen arcuale were 6, 4, and 5 mm, respectively. In all specimens the authors noted that the intraforaminal part of the V₃ segment was grossly compressed.

Conclusions. The authors found that the foramen arcuale may compress the V₃ segment of the VA. Based on their postmortem study, however, they cannot conclude that compression at this location results in symptomatic VA insufficiency. Based on their review of the literature, it seems that symptomatic compression of the VA at this location may be alleviated in some patients with decompressive procedures.

KEY WORDS • cervical spine • craniocervical junction • atlas • anatomical variation • vertebral artery • anatomical study

Abbreviation used in this paper: VA = vertebral artery.
strut were made with calipers. The cross-sectional area of these foramina was calculated using the formula for an ellipse: area = \( \pi \left( \frac{D_1}{2} \times \frac{D_2}{2} \right) \) where \( D_1 \) = horizontal length of the foramen arcuale and \( D_2 \) = vertical length of the foramen arcuale.\(^{29}\) The area of the ipsilateral transverse foramen of the atlas varied from 15 to 20 mm\(^2\) (mean 18 mm\(^2\)). In all specimens, the suboccipital nerve also accompanied the VA through the foramen arcuale when this variation was present. In these specimens, no gross atrophy of the suboccipital musculature was noted. The mean measurements of the proximal, intraforaminal (foramen arcuale), and distal diameter of the VA varied from 6, 4, and 5 mm, respectively. We found in some specimens that the intraforaminal part of the VA segment was grossly compressed (Fig. 1 lower). No cadaveric specimens exhibited gross evidence of disease in the region of the atlas or within the cranium. There was no statistically significant difference between the foramina arcualae of the left or right sides.

### Discussion

We identified a foramen arcuale in 5% of the cadavers. The reported incidence of this foramen has ranged widely, from 1.14 to 37%.\(^{4,5,9,11,14,16,20,21,24,25}\) Stubbs\(^{27}\) has found that a foramen arcuale was more common in males, but other authors have found a slightly greater incidence in females.\(^{22}\) We identified a foramen arcuale in two female and in one male specimen. Split and Sawrasewicz-Rybak\(^{26}\) found that this osseous variation was most common in individuals in their third and fourth decades of life. The foramen arcuale, however, has been documented in children as young as 2 years of age,\(^3\) and thus some authors have commented that this structure is simply a regressive and disappearing morphological phenomenon.\(^{15}\) Buna et al.\(^3\) have described the bridges in their series as typically 12 mm long and thicker than 1 mm.

In our study, all specimens in which a foramen arcuale was identified were found to have gross compression of the VA as it traveled through the foramen arcuale. Furthermore, the area of the foramen arcuale was found to be smaller than the area of the ipsilateral atlantal transverse foramen in all specimens. Interestingly, the authors of anatomical studies have shown that the left VA is often larger in 45% of the population.\(^4\)
Foramen arcuale

Some investigators have posited that these ponticles may be remnants of the proatlas, the so-called “occipital vertebra,”9,18,29 whereas others have suggested that they represent ossified primitive ligaments or parts of the posterior atlantooccipital ligament.20,23,32 Ossification of ligaments resulting in the formation of a foramen arcuale is unlikely because ossification centers have not been observed in these structures.20 Curiously, an additional osseous ring of the atlas for the VA is a common finding in other vertebrates.15 MacAlister19 has asserted that the formation of the foramen arcuale is a direct homologue of the superior oblique process in some mammals. Taitz and Nathan20 have stated that the foramen arcuale might be considered an accessory transverse foramen of C-1.

Clinically, Barre and Lieou described a syndrome involving symptoms of headache, retroorbital pain, vaso-motor disturbances of the face, and recurrent disturbances of vision, swallowing, and phonation, and they hypothesized that these symptoms were due to alternations of the blood flow within the VAs and their associated periarterial sympathetic plexus.18 Limousin18 has reported good results in patients with this syndrome and identified cases in which the foramen arcuale was surgically fractured and a periarterial sympathectomy of the VA, performed. Li and associates17 placed the presence of a foramen arcuale in the differential diagnosis for vertigo and reported satisfactory results in 11 patients who had undergone decompression of the VA when contained within such an osseous ring. Similarly, Sun28 has noted cessation of vertigo in 69 patients who underwent decompression and sympathectomy of the VA within a foramen arcuale. Cushing and colleagues8 found a foramen arcuale in eight of 11 patients with VA dissection and occlusion. The site of arterial injury was at the level of this anatomical variation in all cases. Because more than 50% of head rotation occurs at the atlantoaxial joint, the VA is vulnerable to compression and stretching at this level and thus additional compression/tethering by a foramen arcuale may compound its predisposition to injury. During neck flexion, the VA glides superiorly and anteriorly relative to the posterior arch, and this occurs more at the level of the lateral masses of the atlas than at more caudal sites in the neck.18 The presence of a foramen arcuale would inhibit this movement of the VA. It appears that the VA may be compressed during both ipsi- and contralateral rotation of the cervical spine, and rotational occlusion will induce symptoms only if flow in the contralateral VA is already compromised.23,31 Cellerier and Georget6 reported on a 35-year-old man with Wallenberg syndrome that developed following chiropractic manipulation of the cervical spine. Their patient was found to have dissecting aneurysms of the VAs and bilateral foramina arcuata. Posterior ponticuli (incomplete foramina arcuata) of the atlas were reported in one study to be associated with migraine and cervicogenic headaches.18 Tedeschi10 reported on a man who presented with verteobasilar insufficiency accompanied by fibrillations of the tongue and difficulty with phonation. Bilateral foramina arcuata were identified with unilateral agenesis of the VA and compression of the contralateral VA. Decompression of the compressed vessel resulted in signs of reinnervation of the tongue muscles. Finally, in a report of basal subarachnoid hemorrhages found at autopsy, Gross10 reported a foramen arcuale in seven of 13 cadavers and found that it was present bilaterally in two. In the three cadaveric specimens, we found compression of the VA as it traveled through the foramen arcuale (Fig. 1 lower); however, in no cadaver was there a known history of symptoms indicative of VA compression.

Surgical stabilization of the C1–2 joint is typically accomplished through reduction and fusion of the atlantoaxial complex in which internal fixation is conducted via a posterior cervical approach. Huang and Glaser12 have described a case of cervical instability in which a previously unidentified foramen arcuale precluded a C-1 lateral mass screw fixation procedure in a patient with rheumatoid arthritis. These authors stated that this anomaly “would place the VA in the path of any C1 lateral mass screw.”12 We disagree with this statement because the VA in the presence of a foramen arcuale maintains its normal course over the posterior arch of the atlas and simply lies deep within an anomalous strut of bone. As pointed out by Young and associates,34 however this variation may be mistaken for a widened posterolateral aspect of the atlantal posterior arch. Moreover, because placement of lateral mass screws into the C-1 vertebral body can be difficult, some surgeons have recommended beginning by inserting the screw into the superior aspect of the C-1 posterior arch, therefore predisposing a VA coursing through a foramen arcuale to injury if no such foramen is recognized.34 Although the suboccipital nerve also travels with the VA through the foramen arcuale (as seen in three of our cadaveric specimens), no reported cases of symptomatic entrapment of this nerve at this site have been reported. This may be due to the fact that this nerve primarily innervates the small muscles that form the suboccipital triangle and only rarely has a cutaneous branch.

Conclusions

Based on the findings in the present study, the foramen arcuale may compress the VS segment of the VA. Based on our postmortem study, however, we cannot conclude that compression at this location results in symptomatic VA insufficiency. Based on a review of the literature, it seems that symptomatic compression of the VA at this location may be alleviated in some patients with decompressive procedures. The foramen arcuale is an anatomical variation that the neurosurgeon should consider when undertaking surgery near or on the posterior atlas.

References


Manuscript received July 9, 2006.
Accepted in final form September 22, 2006.
Address reprint requests to: R. Shane Tubbs, M.S., P.A.-C., Ph.D., Pediatric Neurosurgery, Children’s Hospital, 1600 7th Avenue South ACC 400, Birmingham, Alabama 35233. email: rstubbs@uab.edu.