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ORIGINAL ARTICLE

Foramen arcuale: a rare morphological variation located in atlas vertebrae

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Abstract
Objective To investigate the incidence of foramen arcuale in dry atlas vertebrae which may cause clinical problems.
Materials and methods Eighty-one dry human cervical vertebrae were examined. The evaluated parameters of two atlas vertebrae including foramen arcuale were as follows: maximum antero-posterior, transverse diameters and areas of the right and left superior articular facets and transverse foramina; maximum antero-posterior diameters, heights, areas and central sagittal thickness of bony arch forming roof of foramen arcuale, respectively. All parameters were measured with caliper in milimeters.
Results Thirteen of eighty-one cervical vertebrae specimens (13/81, 16.05%) were atlas and the two of thirteen atlas vertebrae (2/13, 15.38%) had macroscopically complete foramen arcuale. Each of the two atlas vertebrae was including one foramen arcuale (one on the left and one on the right side). There was a statistically significant difference ($p = 0.04$) between the mean antero-posterior diameter of superior articular facet located on each side of atlas vertebrae, whereas not ($p = 0.51$) between mean antero-posterior diameter of transverse foramina. There was not any significant difference between the mean transverse diameters and areas of superior articular facets and transverse foramina located on each side of atlas vertebrae, respectively. Each of the areas of transverse foramina located on the same sides with foramen arcuale in two atlas vertebrae was less than the mean areas of transverse foramina located ipsilateral side with each foramen arcuale in thirteen atlas vertebrae.
Conclusion The present study provides additional information about the incidence and topography of the atlas vertebrae including foramen arcuale.

Keywords Foramen arcuale · Atlas vertebrae · Transverse foramen

Introduction

Atlas, the first cervical vertebra, consisting of anterior and posterior arches including two superior articular facets (SAF) along with transverse processes, is a ring-like structure. Two lateral masses hold kidney-shaped superior articular facets articulating with occipital condyles to form atlanto-occipital joint [65].

In the atlas, there is a groove just behind each superior articular process called as sulcus arteriae vertebralis which is transmitting the vertebral artery (VA), the first spinal nerve (suboccipital nerve), venous plexus and the peri-arterial sympathetic plexus [6, 64].

A small bony prominence called as foramen arcuale (FA) arising from posterior portion of the SAF or from posterolateral portion of superior margin of the posterior arch partially or completely bridges over the sulcus [22, 44, 49].

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The mechanism of this bony ring formation is not definitely understood, there are a number of proposed theories as follows: ossification of the connective tissue surrounding the VA; late ossification of lower edge of the atlantooccipital membrane [1]. The posterior bridging of the atlas is accepted as a nonmetrical trait of the infracranial skeleton [18].

There are many alternate names used for this foramen in the literature: Kimmerle's anomaly/variant/deformity, ponticulus posterior (ponticulus posticus) of atlas, posterior osseous bridges, pons posticus, foramen atlantoideum posterius/vertebrale, canalis arteriae vertebralis, foramen sagitale, retroarticular VA ring, foramen retroarticular superior, retrocondylar bony foramen, posterior atlantoid foramen, atlas bridging, posterior glenoid process and spiculum [70].

The incidence of this trait is reported as 10–14% [4, 34, 35]. Formation of the complete foramen may disturb normal function of the VA [5, 68]. The more than 50% of head rotation occurs at the atlantoaxial joint, and the VA is vulnerable to compression and stretching at this level, thus additional compression caused by the FA may predispose VA to injury [70]. The FA embracing the VA and the root of the suboccipital nerve may cause vertigo, vertebrobasilar insufficiency, neck pain, shoulder pain, and cervicogenic headache [10, 29, 70].

The objective of this present study is to investigate the incidence of FA in dry atlas vertebrae among Western Anatolian Population.

Materials and methods

Eighty-one dry human cervical vertebrae of unknown age and sex were examined from the bone collections in Laboratory of the Anatomy Department of Dokuz Eylul University Medical School. Official permission was obtained from Dokuz Eylul University Medical School. Thirteen of eighty-one (16.05%, 13/81) were determined as atlas evaluated for the presence of the FA and photographed with Canon 400B (55 mm objective). The study parameters measured with caliper in milimeters were established as follows: minimum, maximum and mean antero-posterior, transverse diameters and areas of the right and left SAF and transverse foramina (TF) in thirteen atlas vertebrae; maximum antero-posterior, transverse diameters and areas of the right and left SAF and transverse foramina (TF) in two atlas vertebrae including FA; maximum antero-posterior diameters, heights, areas and central sagittal thickness of bony arch forming roof of FA, respectively (Tables 1, 2, 3). The areas of SAF, TF and FA were calculated using the formula for an elipse area: π.[D1/2.D2/2] (D1: maximum transverse diameter, D2: maximum vertical diameter) [44].

The mean antero-posterior and transverse diameters and areas of SAFs and TF located on each side (right and left) of thirteen atlas vertebrae were compared with each other, respectively. Statistical analysis was performed with SPSS-16.0 (SPSS Inc., Chicago, IL, USA).

Results

We determined that thirteen of eighty-one cervical vertebrae (13/81, 16.05%) were atlas and the two of thirteen atlas vertebrae (2/13, 15.38%) had macroscopically complete FA. Each of the two atlas vertebrae was including one FA (one on the left and one on the right side), (Fig. 1). The bilateral bridging was not observed.

We found that there was a statistically significant difference ($p = 0.04$) between the mean antero-posterior diameter of SAF located on each side of atlas vertebrae, whereas not ($p = 0.51$) between mean antero-posterior diameter of TF. We did not observe any significant differences between the mean transverse diameters and areas of SAFs and TF located on each side of atlas vertebrae, respectively

Table 1 The study parameters evaluated in thirteen atlas vertebrae

	Superior articular facet, right side	Superior articular facet, left side	*p*	Transverse foramen, right side	Transverse foramen, left side	*p*
Antero-posterior diameter, minimum (mm)	20.00	19.00		6.40	6.70	
Antero-posterior diameter, maximum (mm)	27.50	24.00		8.80	9.20	
Antero-posterior diameter, mean (mm)	23.40	22.16	0.04*	7.63	7.79	0.51
Transverse diameter, minimum (mm)	9.20	9.00		5.70	5.00	
Transverse diameter, maximum (mm)	13.20	15.00		11.00	11.00	
Transverse diameter, mean (mm)	10.76	11.65	0.08	6.99	7.03	0.84
Area, minimum (mm^2)	170.30	157.00		32.90	30,20	
Area, maximum (mm^2)	224.50	245.50		72.50	79.40	
Area, mean (mm^2)	196.73	202.92	0.41	42.08	42.83	0.63

* $p < 0.05$ accepted as statistically significant

Table 2 The study parameters evaluated in two atlas vertebrae inluding FA

	No. 1: Atlas vertebra including FA located on the right side		No. 2: Atlas vertebra including FA located on the left side	
	Right side	Left side	Right side	Left side
SAF, maximum antero-posterior diameter, (mm)	22.00	23.00	21.00	19.00
SAF, maximum transverse diameter, (mm)	11.00	9.00	11.60	15.00
SAF, area, (mm^2)	189.90	162.40	191.20	223.70
Transverse foramen, maximum antero-posterior diameter, (mm)	7.40	7.30	7.00	7.40
Transverse foramen, maximum transverse diameter, (mm)	6.50	6.60	6.00	7.00
TF, area, (mm^2)	37.70	37.80	32.90	40.60

Table 3 The maximum antero-posterior diameters, heights, areas and central sagittal thicknesses of bone arch forming roof of each of two FA

No	Foramen arcuale			
	Maximum antero-posterior diameter (mm)	Maximum heigth (mm)	Maximum area (mm^2)	Maximum central sagittal thickness of bone arch forming roof of FA (mm)
No. 1: Atlas vertebra including FA located on the right side	6.40	5.00	25.10	2.40
No. 2: Atlas vertebra including FA located on the left side	7.00	6.20	34.06	1.20

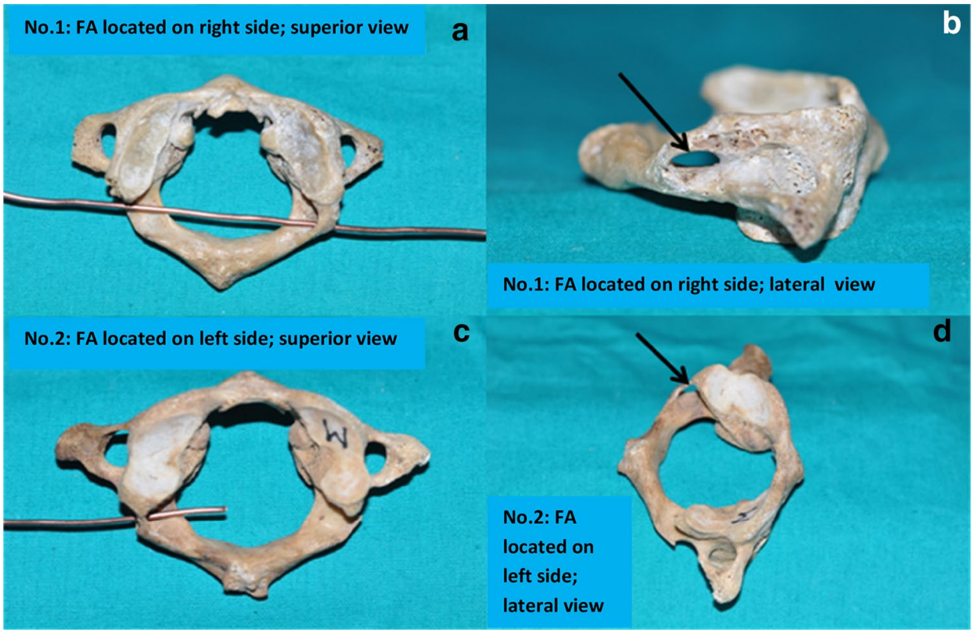

Fig. 1 The images of two atlas vertebrae (No. 1 and No. 2) including foramen arcuale (FA)

(Table 1). Each of the areas of TF located on the same sides with FA in two atlas vertebrae were less than the mean areas of TF located ipsilateral side with each FA in thirteen atlas vertebrae (Tables 2, 3).

The maximum antero-posterior diameters, heights, areas and central sagittal thicknesses of bone arch forming roof of the two FA (first FA right side of one atlas and the second FA left side of other atlas vertebra) were determined as 6.40 mm, 5.00 mm, 25.10 mm^2, 2.40 mm and 7.00 mm, 6.20 mm, 34.00 mm^2 and 1.20 mm, respectively (Table 3).

Discussion

The atlas vertebra articulating cranially with the skull and caudally with axis forms the atlanto-occipital and atlanto-axial joint, respectively. These two joints provide wide range of flexion, extension, lateral movements and rotation of the neck [54]. The incidence of FA, familial rather than age related, varied among ethnic groups [17, 59].

According to the geographic regions, ponticulus posticus has the lowest frequency in India [61] and South Korea [30], and the highest prevalence in North American populations [7, 59].

Ossenfort found the rate of FA of the atlas vertebra as 12% among white Americans and 12% among black Americans [1]. Taitz et al. [68] found this rate as 25.9% with partially bridging and as 7.9% with complete ring in their study. With respect to complete posterior bridging and formation of foramen, it was found, in descending order, higher among blacks (16.4%), Middle East (7.4%) and then Egyptian population (2.63%) [2]. On the contrary, in our study, incidence of FA was found as higher (15.38%) than Middle East and Egyptian populations although they were geographically adjacent to our country. This difference may be due to numerous migrations into our geographic region (Anatolia) over centuries. When the frequency of FA among sexes was considered, inconsist results were reported in two studies. Stubbs found that FA was more common in males, whereas another study showed that incidence of FA was slightly greater in females [53, 66]. Travan et al. summarized the prevalence of FA from published studies in the literature (Table 4) [69].

Although the ossification is a possible gradual process, congenital alterations in grades of ossification of the atlas may lead to occurrence of FA; this concept may be supported by the findings of the cartilaginous FA in fetuses and children in one study [34].

FA may not be considered as a degenerative variation related to aging, because the rate of this variation has been found more common in individuals who bear greater external stress on the craniovertebral junction [24, 26]. Paraskevas et al. [49] also found that incidence of complete canal for the passage of VA was higher among the laborers than the non-laborers. The difficult physical act of working may affect the formation of this variant [33].

Cushing et al. [12] found an association between the presence of FA and tethering of the VA and between the dissection of the VA and repetitive traumas caused by neck motions. The left-tilted head posture is more common among right-handed persons as they have the stronger right sternocleidomastoid muscle; therefore, it was hypothesized that the unequal weight-bearing and/or asymmetric use of the cervical spine might cause left–right asymmetry of SAF [15, 46, 50, 72]. Dhall et al. observed that SAF located on the side of FA had larger anteroposterior and transverse diameters and elliptical area [15, 22]. The results of the present study support these findings that the SAF located on the side of FA had larger transverse diameter and elliptical area comparing to the opposite side, whereas anteroposterior diameters of the SAF which were located on the same side with FA were shorter than the SAF which were located on the opposite side in the present study (Fig. 1).

A positive correlation has been found between the sizes of the TF and vertebral artery and between diameter of TF and blood volume in vertebral arteries [31, 32, 67]. Travan et al. found that the mean area of the FA (24.5 mm^2) was smaller than TF (28.5 mm^2) in C1 [69].

The area of the TF on the atlas vertebrae including FA were smaller than the mean area; furthermore, the differential ratio of SAF area in the patients with unilateral and partial or complete FA was significantly larger than that in the patients without FA [8]. In their cadaveric study, Tubbs et al. determined that FA exposed too much compression to the third segment of vertebral artery in all cases [70]. Bone abnormalities as well as arterial abnormalities, or combination of both, may cause a reduction in cerebral blood flow [69]. In the present study, area of SAF which was located on the same side (left) with FA was larger than the mean area of SAF which were located on the same side (left) of thirteen vertebrae and vice versa.

The metrical alterations in the articulating surfaces of atlanto occipital joint may lead to asymmetric movements in motion of the intervertebral segment, and these asymmetric movements may lead to alterations in ergonomics of atlanto occipital joint and so may constitute one of the possible mechanisms of migraine, neck strain, or tension-type headache [8]. During the rotational and bending movements of the neck, the VA may be physiologically stretched and compressed by posterior bony bridge of the atlas, and it may lead to impairment in VA flow causing vertebrobasilar insufficiency syndrome or VA tethering and dissection [10, 12, 26, 34].

Lateral mass (LM) screw fixation of the atlas has performed for the treatment of atlanto-axial instability, whereas precise identification of this anomaly on preoperative lateral radiographs should alert surgeons to avoid using FA as a starting point for this surgical procedure [54].

The broad dorsal arch of the atlas is accepted as the best indication for this modified screw trajectory. The FA through which VA passes may be incorrectly accepted as the broad dorsal arch and the surgeon may mistakenly insert the screw into the FA and so may injure VA. This iatrogenic injury leads to stroke or even death from

Table 4 Prevalence of FA (foramen arcuale) in published studies

First author (year) (Ref. no.)	Country	Material	No of CI specimens	Prevalence (%)
Varaglia (1885) [73]	Italy	Bone	172	8.1
Fusari (1889) [19]	Italy	Bone	60	11.6
Macalister (1893) [40]	England	Bone	100	7.5
Pitzorno (1899) [51]	France	Bone	100	18
Poirier (1892) [52]	–	Bone	500	17.6
Dubreuil-Chambardel (1921) [16]	–	Bone	342	19.5
Le Double (1912) [36]	–	Bone	500	7.8
Ossenfort (1926) [48]	USA	Bone	183	12
Hayek (1927) [23]	Germany	Bone	–	10.4
Selby (1955) [59]	USA	Radiographic images	306	12.1
Kendrick (1963) [28]	–	Radiographic images	353	5.1
Lamberty (1973) [34]	England	Bone	60	15
Lamberty (1973) [34]	England	Radiographic images	990	7.5
Zaborowski (1975) [77]	Poland	Radiographic images	4046	8.5
Sato (1978) [56]	Japan	Bone	97	5.2
Sato (1978) [56]	Japan	Radiographic images	1,428	5.5
Saunders (1978) [57]	Canada	Radiographic images	592	9.3
Farman (1979) [17]	South Africa	Radiographic images	222	8.1
Malhotra (1979) [41]	India	Bone	–	5.1
Miki (1979) [43]	Japan	Radiographic images	307	4.9
Taitz (1986) (archeological sample) [68]	Middle Eastern	Bone	187	7.4
Taitz (1986) (archeological sample) [68]	India	Bone	139	2.2
Taitz (1986) (archeological sample) [68]	USA	Bone	326	11.4
Stubbs (1992) [66]	–	Radiographic images	1,000	13.5
Mitchell (1998) [44]	South Africa	Bone	1354	9.8
Nagar (1999) (archeological sample) [47]	Israel	Bone	110	6.3
Cederberg (2000) [7]	USA	Radiographic images	255	11.4
Hasan (2001) [22]	India	Bone	350	3.4
Manjunath (2001) [42]	–	Bone	60	11.7
Wysocki (2003) (archeological sample) [75]	Polland	Bone	100	13.8
Kavakli (2004) [27]	Turkey	Bone	86	12.8
Unur (2004) [71]	Turkey	Radiographic images	351	5.1
Le Minor (2004) [37]	France	Bone	500	14.2
Cakmak (2005) [6]	Turkey	Bone	60	11.7
Cakmak (2005) [6]	Turkey	Radiographic images	416	7.2
Paraskevas (2005) [49]	Greece	Bone	176	10.2
Young (2005) [76]	USA	Bone	20	10
Senoglu (2006) [60]	Turkey	Bone	166	10.8
Senoglu (2006) [60]	Turkey	Radiographic images	172	5.2
Krishnamurthy (2007) [33]	India	Bone	1,044	8.3
Tubbs (2007) [70]	USA	Bone	60	5
Kim (2007) [30]	Korea	Radiographic images	537	4
Chinnappan (2008) [9]	India	Bone	102	8.8
Hong (2008) [24]	Korea	Radiographic images	1,013	6.5
Ilie (2008) [25]	Romania	Bone	75	8
Gupta (2008) [21]	India	Bone	55	5.4
Simsek (2008) [63]	Turkey	Bone	158	3.8
Awadalla (2009) [2]	Egypt	Bone	76	2.6
Cho (2009) [11]	Korea	Radiographic images	200	11.5

Table 4 (continued)

First author (year) (Ref. no.)	Country	Material	No of CI specimens	Prevalence (%)
Dahiphale (2009) [13]	India	Bone	50	2
Karau (2010) [26]	Kenya	Bone	102	14.2
Schilling (2010) [58]	Chile	Radiographic images	436	9.2
Sharma V (2010) [61]	India	Radiographic images	858	4.3
Baeesa (2012) [3]	Saudi Arabia	Radiographic images	453	16.1
de Carvalho (2012) [14]	Brazil	Bone	30	16.6
Shinde (2012) [62]	India	Bone	67	2.9
Vijayalakshmi (2012) [74]	–	Bone	75	5.3
Gopal (2013) [20]	–	Bone	300	8
Munjal (2013) [45]	–	Bone	90	22.2
Munjal (2013) [45]	–	Radiographic images	620	21
Rekha (2013) [55]	–	Bone	200	3
Travan (2015) [69]	Italy	Bone	136	7.3
Cirpan (present study)	Turkey	Bone	13	15.38

thrombosis, embolism or dissection of VA [76]. Surgical posterior approaches to the cranio-vertebral junction and especially lateral dissection and decompressive C-1 laminectomy may cause the VA injury [54]. The decompression procedures may relieve complaints in some patients with symptomatic compression of VA in FA [70].

In eleven patients complaining of vertigo, Li et al. [38] reported that VA were injured while passing through the osseous ring and the satisfactory outcomes were obtained after the VA decompression surgery; therefore, they proposed the presence of FA in the differential diagnosis of vertigo. Even if the suboccipital nerve travels along with the VA through the FA, there are no cases of symptomatic suboccipital nerve entrapment that have been reported in the literature. It may be because suboccipital nerve primarily innervates the small muscles forming the suboccipital triangle and also rarely give off a cutaneous branch [70].

Unur et al. [71] studied the dimensions of the FA and mentioned that the mean height and length were 5.7 mm (3.7–8.5 mm) and 8.1 mm (5.7–10.0 mm), respectively. Cakmak et al. [6] calculated the mean area of FA in dry atlas vertebrae 34.6mm^2 on the right and 34.3 mm^2 on the left sides. In our study, the mean height and length of the FA were 5.6 and 6.7 mm ,respectively .We found the area of FA in dry atlas vertebrae 25.10 mm^2 on the right and 34.06 mm^2 on the left side.

FA can only be evaluated two dimensionally by lateral cervical spine or cephalometric radiographs, whereas vertebral column can be evaluated three dimensionally with the cone-beam computed tomography (CBCT) providing additional benefits of lower radiation exposure and higher spatial resolution compared with conventional CT [39].

Conclusion

Consequently, the clinicians must be aware of possibility of the presence of this mentioned foramen for patients complaining headache, vertigo, vertebrobasilar insufficiency and unexplained shoulder pains; therefore, we conclude that the present study provides additional information about topography of the atlas vertebra including FA and guide the investigators dealing with the neurosurgery, orthopedics, physical medicine and rehabilitation and radiology in their practice.

Compliance with ethical standards

Conflict of interest There is no conflict of interest among the authors and any financial support.

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