Original Articles

Prevalence and Morphologic Characteristics of Ponticulus Posticus: Analysis Using Cone-Beam Computed Tomography

Ahmet Ercan Sekerci DDS, PhD^{a,*}, Emrah Soylu DDS, PhD^b,
Mehtap Payveren Arikan DDS^c, Gozde Ozcan DDS^d,
Mehmet Amuk DDS^d, Fatma Kocoglu DDS^d

^a Assistant Professor, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Erciyes University, Kayseri, Turkey

^b Assistant Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Gaziosmanpasa University, Tokat, Turkey

^c Physicist, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Erciyes University, Kayseri, Turkey

^d Research Assistant, Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Erciyes University, Kayseri, Turkey

Received 17 July 2014; received in revised form 28 May 2015; accepted 5 June 2015

Key indexing terms:

Cervical atlas;
Tomography;
Spine

Abstract

Objective: This study evaluated the prevalence and morphologic characteristics of ponticulus posticus (PP) by using cervical 3-dimensional (3-D) cone-beam computed tomography (CBCT) scan images.

Methods: This was a retrospective study conducted by selecting cervical 3-D CBCT images of 698 patients, which were examined for the presence and types of PP.

Results: In 257 patients, 438 PPs, complete or partial, bilateral or unilateral, were identified on the 698 cervical 3-D CBCT scans; therefore, the prevalence was 36.8%. Bilateral complete PP and partial PP were observed in 6.3% and 16.2% of subjects, respectively. There was a significant difference in the prevalence between males and females ($P = .001$) and between the right and left sides between males and females, but not between age groups.

Conclusion: Ponticulus posticus is a relatively common anomaly in this Turkish sample, which may have implications for those who perform clinical procedures on the upper cervical spine.

© 2015 National University of Health Sciences.

Introduction

The normal atlas is a ringlike structure consisting of 2 lateral masses connected by a short anterior arch and a longer posterior arch. It is the widest cervical vertebra,

* Corresponding author. Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Erciyes University, Kayseri, Turkey. Tel.: +90 352 2076666 29227; fax: +90 352 438 06 57.

E-mail address: aercansekerici@hotmail.com (A. E. Sekerci).

with its anterior arch being approximately half as long as the posterior arch.¹ The ponticulus posticus (PP), speculated to be congenital or to result from degeneration, is a bony bridge arising from the posterior portion of the superior articular process and the posterolateral portion of the superior margin of the posterior arch of the atlas that completely or partially encircles the vertebral artery.^{2,3}

The PP had not been a subject of concern for spine surgeons until its surgical significance in the insertion of screws into the lateral mass of the atlas was recently reported.⁴ There has been a steady increase in the number of patients undergoing the C1 lateral mass screw (C1LMS) procedure through the posterior arch. Although skeletal maturation evaluation⁵ using the cervical vertebrae and its modified version are now commonly used to interpret the growth potential of young patients, inadequate attention is paid to the radiological anatomy of this region with a view to identifying pathology.⁶ Knowledge of this anomaly is critical to surgeons performing posterior atlantoaxial fusions.⁷ Since the treatment of atlantoaxial instability was revolutionized by the introduction of the C1LMS insertion,⁸ many alterations to the method have been described and used successfully.^{9–11} Young et al⁴ reported that mistaking the PP for just a broad posterior arch of the atlas during C1LMS placement could cause injury to the vertebral artery.

The prevalence of PP has been reported to be between 1.3 % and 45.9.^{5,12} We, however, could find only a few studies^{13–15} on its prevalence or morphological characteristics in an Asian population. This information on the posterior neural arch of C1 when performing lateral mass screw insertion is very important to avoid vertebral artery injury. Paraskevas et al¹⁶ believed that the prevalence of the PP is related to age.

Exact characterization of the PP is only possible by three-dimensional (3-D) study, as illustrated by a computed tomography scan. Cone-beam computed tomography (CBCT), which can definitively measure the length of the anatomical structures of the craniofacial region, was introduced as a new and alternative modality. This recently designed technology has become an important tool for the diagnostic imaging of oral and maxillofacial osseous structures, providing professionals with access to excellent image quality and greater diagnostic accuracy and sensitivity. Therefore, we investigated the prevalence and morphological features of the PP in a Turkish population comprising patients reporting to our department who were all healthy and free of any systemic or musculoskeletal problems. The purpose of the present study was to

determine the frequency of the anomaly and to identify its anatomical features in relation to surgical approaches to the posterior aspect of the atlas in a Turkish population by using CBCT.

Methods

The study protocol was approved by the Ethics Committee of the Medical Faculty of Erciyes University. We designed a retrospective study composed of the CBCT (Newtom 5G;QR, Verona, Italy) images of patients who presented to the Dentomaxillofacial Radiology service at Erciyes University's Dentistry Faculty. All the patients had been referred for diagnosis and treatment planning for different problems involving the maxillofacial region.

The CBCT scans were retrieved from the archives of the department and examined for cervical spine anomalies, in particular PP. Exclusion criteria included inadequate picture quality (artifacts caused by metallic implants or osteosynthesis plates, low resolution, and patient movement during imaging). Patients presenting with congenital anomalies such as cleft lip and palate were not included. In addition, patients with other syndromic conditions involving the craniofacial region were excluded. The CBCT images of 313 males and 385 females were examined.

The examination of the PP was made by the consensus of 2 experts (AES and ES) with 5 years of experience in assessing CBCT volumetric data. Selecting and moving the cursor on 1 image to change the center of the view altered the reconstructed slices in 3 orthogonal planes. Tomography sections of 0.25-mm thickness in the axial, coronal, and sagittal planes were created. Axial and cross-sectional images (coronal and sagittal image) were transmitted to a personal computer in digital imaging and communications in medicine format and reconstructed into multiplanar reconstruction images using the digital imaging and communications in medicine viewer ExaVision SX Ver.1.13 (Ziosoft, Inc, Tokyo, Japan). These views were used to examine the PP. The CBCT images were analyzed with the inbuilt software (NNT) in a Dell Precision T5400 workstation (Dell, Round Rock, TX) using a 32-in Dell LCD screen with a resolution of 1280 × 1024 pixels. These images were reconstructed into 3-D images and carefully inspected for the presence of a PP and whether it was complete or partial. *Complete type* was defined as a clear bony bridge between the superior articular process and the posterior arch of the atlas in

3-D CBCT images. We did not include a bony protrusion due to noticeable impression for vertebral arteries as partial type. Partial type was considered as partial posterior ponticulus which was noted as a distinct bony spicule extending from the superior articular facet overhanging the dorsal arch. During the initial examination, all the images were studied by the authors. To eliminate any error, 140 randomly selected images were reexamined separately by the same 2 authors 1 month after initial examination. There was complete agreement between the 2 authors and the 2 examinations. The prevalence according to sex was calculated.

Statistical analysis was conducted with χ^2 test using SPSS 16.0 for Windows (SPSS, Chicago, IL). The level of significance was set at $P < .05$.

Results

The study group comprised 313 (44.9%) males and 385 (55.1%) females with a mean age of 24.8 ± 12.38 years (range, 8-72). The age ranged from 8 to 68 years in male patients and from 11 to 72 years in female patients.

Two hundred and fifty-seven patients with PP were identified on the 698 cervical 3-D CBCT scans; therefore, the prevalence was 36.8%. The PPs identified consisted of bilateral complete in 44 (6.3%), bilateral partial in 113 (16.2%), unilateral complete in 44 (6.3%), and unilateral partial in 32 (4.6%) (Table 1; Figs 1a-d and 2a-d). The analysis of the right side of the PP revealed that 10.5% and 19.6% of the 698 patients had complete and partial PPs, respectively. The analysis of the left side of the PP revealed that 11.7% and 21 % of the 698 patients had complete and partial PPs, respectively. The frequency between the right and

left sides was statistically significant between males and females (Table 2). The data indicate that the distribution of the presence of the bony bridge in the first cervical vertebra is higher in males (41.2% [129 of 313]) than in females (33.2% [128 of 385]). There was significant difference in the prevalence between males and females ($P = .001$). Table 3 shows the distribution by age group of PP. There was no significant difference in the prevalence of PP between age groups.

Discussion

Many terms have been used in the literature to describe this anomaly, including sagittal foramen and atlantal posterior foramen, arcuate foramen, a variant of Kimmerle's anomaly, upper retroarticular foramen, canalis vertebralis, retroarticular vertebral artery ring, arcuate foramen, retroarticular canal, and retrocondilar vertebral artery ring. However, its most commonly accepted name is PP (Latin for little posterior bridge).⁴

The citation lists made from the references that were included have subsequently been examined in an attempt to identify additional reports^{3,4,12-47} (Table 4).

Elliott and Tanweer⁷ provided a great service to surgeons by systematically reviewing and analyzing radiographic, cadaveric, and surgical data and reporting on the prevalence of PP. In 44 reports describing the presence of "PP" in online databases, 21,789 cases (15,542 patients and 6247 bony/cadaver specimens) were included in this series. The overall prevalence of "PP" was 16.7%, 16.6% on radiographic studies, 17.2% on CT study, and 18.8% in cadaver specimens. The anomaly comprised a complete foramen in 9.3% of the cases and incomplete in 8.7%. It was noted

Table 1 Morphologic Analysis of Patients Examined for Ponticulus Posticus

	Male		Female		Total	
	n	%	n	%	n	%
Bilateral absent	184	58.8	257	66.8	441	63.2
Right absent–left complete	21	6.7	7	1.8	28	4
Right absent–left partial	7	2.2	12	3.1	19	2.7
Right complete–left absent	11	3.5	5	1.3	16	2.3
Bilateral complete	26	8.3	18	4.7	44	6.3
Right complete–left partial	7	2.2	6	1.6	13	1.9
Right partial–left absent	3	1.0	10	2.6	13	1.9
Right partial–left complete	2	0.6	9	2.3	11	1.6
Bilateral partial	52	16.6	61	15.8	113	16.2
Total	313	100.0	385	100.0	698	100

$P = .001$.

n, number of subjects.

Fig 1. Various morphologic types of PP seen on posterior view of 3-D CBCT images (a-c). Bilateral complete (a); complete on the left side and partial on the right (b); bilateral partial (c). Coronally reconstructed CBCT images showing partial PP on the left side and complete PP on the right side. (*Color version of figure appears online.*)

bilaterally in 5.4% of the cases and unilaterally in 7.6%. In their study, there was no difference between males and females. They concluded that careful assessment via preoperative multiplanar CT imaging should be performed prior to consideration of C1LMS implantation. Sharma et al⁶ studied the lateral cephalometric radiographs of 858 Indian orthodontic patients aged 8 to 22 years for the presence of PP of the first cervical vertebra. In their study, complete PP was found in 4.3% of the subjects studied, with a male (5.33%; 16 of 300) predominance over female in the population (3.76%; 21 of 558). Kendrick and Biggs¹⁹ studied the lateral cephalometric radiographs of 353 young Caucasian orthodontic patients aged 6 to 17 years for the presence of the same entity. Of the subjects, 15.8% showed “some degree” of PP, with no apparent sex predilection (14.6% males and 16.9% females). The youngest female with PP was aged 6 years 7 months, and the youngest male was aged 6 years 4 months. This proves again that higher age is not a criterion for the formation of ponticulus. The present study is the first report to

evaluate the presence of PP in a Turkish population using CBCT images. Therefore, we examined the 3-D CBCT scan images of a Turkish population. We were astonished that as much as 36.8% of the patient population had PP because we had not noticed through our daily practice that its prevalence was so high. Therefore, the presence of this anomaly should be carefully checked before screw placement in the lateral mass of the atlas in order to avoid vertebral artery injury.

Recognition of PP in the atlas is important because it has been implicated in the development of otherwise unexplainable neck pain and headaches, visual disturbances, problems with speech and swallowing, vertigo, and vascular problems.¹⁶ Considering the growing clinical importance of PP, we need to understand the morphological features and the prevalence of this anomaly. The PP, which seems to be the consequence of the complete or incomplete ossification of the posterior atlantooccipital membrane over the vertebral artery groove,²¹ has become a significant abnormality

Fig 2. Isolate atlas. Posterior superior view of 3-D CBCT image of atlas (normal) (a). Oblique (posterosuperior and right) view of various morphologic types of PP. These perspectives allow a better structural definition of the bilateral complete (c), bilateral partial (b), and unilateral partial on the left side. (*Color version of figure appears online.*)

of the atlas in the management of atlantoaxial instability, which has gained popularity.^{10,48} Therefore, developmental anomalies of the atlas are of interest not only to anatomists but also to clinicians, radiologists, surgeons, and chiropractors, who should be aware of their distinct morphological manifestations as well as correlated clinical expressions.^{49–51}

The PP is generally regarded as a simple anatomical variant. However, the compression of the nervous and vascular structures passing through the foramen (vertebral artery, periarterial plexus, and suboccipital nerve) may result in a combination of symptoms such

as cervical migraine⁴⁹; neurosensory-type hearing loss⁵²; neck pain; vertigo; shoulder-arm pain; and, in some instances, even loss of postural muscle tone, consciousness, and vertebrobasilar insufficiency syndrome.¹⁷ Severe headache is present in 56% to 90% of subjects.⁵³ Headache, neck, and shoulder/arm pain as well as vertigo have been found with significantly greater frequency in patients with complete PP compared with partial PP.⁵⁰ Takaaki et al⁵¹ observed in a radiological survey that in patients with at least 1 narrow disk space, the possible occurrence of PP was higher. No correlation was found with other cervical

Table 2 Prevalence of Ponticulus Posticus in 3-D CT Images of 698 Patients

	Right						Left					
	Male		Female		Total		Male		Female		Total	
	n	%	n	%	n	%	n	%	n	%	n	%
Valid												
Absent	229	73.2	259	67.3	488	69.9	221	70.6	249	64.7	470	67.3
Complete	27	8.6	46	12	73	10.5	31	9.9	51	13.2	82	11.7
Partial	57	18.2	80	20.7	137	19.6	61	19.5	85	22.1	146	21
Total	313	100	385	100	698	100	313	100	385	100	698	100

n, number of subjects.

Table 3 Distribution by Age Group of Ponticulus Posticus

			Age Group (y)			
			8-20	21-40	41-72	Total
PP	Absent	Side	578	195	185	958
		%	68	67.2	72.3	68.7
	Partial	Side	91	38	26	283
		%	10.7	13.1	10.2	20.2
	Complete	Side	181	57	45	155
		%	21.3	19.7	17.6	11.1

PP, Ponticulus Posticus.

anomalies such as block vertebrae. This feature was not looked into in the present study and needs further investigation before commenting on.

C1 lateral mass screw insertion is a difficult procedure, as the region contains the epidural venous plexus and the greater occipital nerve. Because putting a C1LMS in the classical entry point at the junction of the posterior arch and the lateral mass^{10,54} causes significant bleeding from the epidural plexus and can possibly cause irritation to the C2 nerve root resulting in occipital neuralgia, some surgeons recommend placing the screw higher, starting in the posterior aspect of the posterior arch.⁵⁵ The purported benefits include longer bony purchase, increased rigidity, less C2 ganglion manipulation and postoperative neuralgia, and less intraoperative blood loss due to less disruption of the perineural venous plexus.^{9,11,56} The broad posterior arch of the atlas is the best location for this modified screw placement. Although this may be reasonable for most patients, in patients with a PP, the anomaly has the possibility of being misidentified as the broad posterior arch. It can be mistaken for a broad dorsal arch, and the surgeon may insert the screw into the PP.⁴ This can result in an injury to the vertebral artery which is trapped in the arcuate foramen and lead to stroke or even death by thrombosis, embolism, or arterial dissection.⁴ Vertebral artery injury may not cause any symptoms if the patient and the surgeon are lucky; however, it can lead to stroke or even death by thrombosis, embolism, or arterial dissection.⁵⁷

Most previous studies have been based on lateral radiographs; therefore, it is not usually suitable to determine if the PP is bilateral or unilateral. In the study of Young et al,⁴ PP was almost equally detected in both the left and right sides. This was not clearly identified in previous plain radiographic studies because plain film studies fail to differentiate between the right and left. In previous cadaveric studies, there was no difference between the 2 sides.^{14,38} Young et al⁴ stated that most of these patients underwent a CT scan because of cervical spine problems. Therefore, these

patients did not necessarily represent the whole population. Additionally, since these patients require screw fixation at other levels of the cervical spine or the occiput, 3-D CT scans will also be helpful in planning these screws. Further studies, including lateral cephalometric head radiographs, which are taken at the department of dentistry for evaluation of dental conditions, regardless of any cervical symptoms, are needed to investigate the exact prevalence of PP.⁴²

The clinical significance of the PP is far from clear. It has also been associated with Barré-Lieou syndrome and photophobia. However, little epidemiologic evidence for this exists.^{31,55} A link between PP and head pain was observed by Wight et al³¹ who noted a significant overrepresentation of the ring in chiropractic patients presenting with head pain without aura (ie, visual or auditory disturbances). Surgical excision of the PP appears to alleviate the symptoms of headache, vertigo, and basilar insufficiency.^{58,59} In addition, spinal manipulative therapy involving craniovertebral articulation seems to alleviate the symptoms of vertigo, headache, and nausea.^{31,60} Chiropractic treatments have been found to treat migraine with significant improvement rates. Therefore, in addition, the surgeons' findings of our study may also be relevant to manual therapists, such as chiropractors, physical therapists, manual therapists, or other health care providers who need to be aware of these findings. If any such anomaly is detected or suspected, it must be documented in the patient's health record and specialist consultation must be sought.

Clinical Relevance for Surgical Cases

Because PP has a wide and varied spectrum of shape and size that cannot be determined using other studies, the presence of this anomaly should be carefully ruled out on lateral radiographs before C1LMS to avoid vertebral artery injury. If PP is suspected or confirmed on radiographs, because its size and shape have wide variation, 3-D CBCT scanning should be considered before lateral mass screw placement into the posterior arch.

Study Limitations

A limitation of our study is that the present study attempted to explore the characteristics of PP on CBCT images. Symptoms of PP anomaly may include several symptoms. Further tomographic evaluation of subjects with the clinical findings of patients with PP is strongly recommended to assess the association between PP and its symptoms. This study was also limited in that only 1

Table 4 Prevalence of Ponticulus Posticus in the Literature

Author	Reference	Year	Review Source	Sample	Population	Mean Age or Age Ranges	PP (%)	Male (%)	Female (%)
Selby et al	¹⁷	1955	LR	306	North America	NA	27.1	41.83	58.17
Pyo and Lowman	¹⁸	1959	LR	300	Northeast America	49.2	12.7	43.33	56.67
Kendrick and Biggs	¹⁹	1963	LR	353	North America	6-17	15.9	46.46	53.54
Romanus and Tovi	²⁰	1964	C	105	Sweden	40.4	14.3	51.43	48.57
Lamberty and Zivanovic	²¹	1973	C	60	England	NA	36.7	NA	NA
Lamberty and Zivanovic	²¹	1973	LR	990	England	NA	13.6	NA	NA
Saunders and Popovich	²²	1978	LR	592	Canada	38.8	29.2	50.00	50
Farman et al	²³	1979	LR	220	South Africa	8-25	26.8	NA	NA
Dugdale	²⁴	1981	LR	316	—	NA	15.5	NA	NA
Taitz and Nathan	²⁵	1986	C	672	Various continents	NA	33.8	NA	NA
Ruprecht et al	²⁶	1988	LR	419	Saudi Arabia	NA	32.9	43.68	56.32
Hoenig and Sehoener	²⁷	1992	LR	60	Germany	22.8	21.7	56.67	43.33
Stubbs	²⁸	1992	LR	1000	North America	36.9	18.7	46.60	53.4
Presch	²⁹	1997	C	200	Germany	NA	11.0	NA	NA
Mitchell	³⁰	1998	C	1354	South Africa	20-80	10.2	71.86	28.14
Wight et al	³¹	1999	LR	895	Scotland	44.0	18.0	46.93	53.07
Hasan et al	¹⁴	2001	C	350	Northern India	NA	6.6	NA	NA
Manjunalh	³²	2001	C	60	Southern India	S.A.	11.7	NA	NA
Wysodci et al	³³	2003	C	95	Poland	NA	31.6	NA	NA
Kavaklı et al	¹³	2004	C	86	Turkey	NA	22.1	NA	NA
Le Minor and Trost	³⁵	2004	C	500	France	NA	14.2	NA	NA
Çakmak et al	³⁵	2005	LR	416	Turkey	49.5	13.5	31.73	68.27
Young et al	⁴	2005	LR	464	North America	NA	15.5	NA	NA
Çakmak et al	³⁵	2005	C	60	Turkey	NA	15.0	NA	NA
Paraskevas et al	¹⁶	2005	C	176	Northern Greece	NA	34.7	51.14	48.86
Young et al	⁴	2005	C	20	North America	NA	15.0	NA	NA
Lee et al	³⁶	2006	C	709	North America	NA	26.9	64.46	35.54
Krishnamurthy et al	³	2007	C	1044	India	NA	13.8	NA	NA
Tubbs et al	³⁷	2007	C	60	North America	73	5.0	65.00	35
Kim et al	³⁸	2007	LR	312	Korea	28	14.1	37.50	62.5
Kim et al	³⁸	2007	CT	225	Korea	45	25.8	64.89	35.11
Gupta	³⁹	2008	C	55	India	16-60	10.9	NA	NA
Kobayashi et al	⁴⁰	2008	C	50	Japan	62	10.0	76.09	23.91
Simsek et al	¹⁵	2008	C	158	Turkey	NA	9.5	NA	NA
Hong et al	⁴¹	2008	CT	1013	Korea	55.7	15.6	44.03	55.97
Cho	⁴²	2009	CT	200	Korea	45	15.5	50.00	50
Karau et al	⁴³	2010	C	102	Kenya	25-75	52.9	48.04	51.96
Kuhla et al	⁴⁴	2010	LR	246	North America	NA	45.5	NA	NA
Sharma et al	⁶	2010	LR	858	India	15.0	4.3	34.97	65.03
Yeom et al	⁴⁵	2012	CT	52	Korea	44.0	17.3	36.54	63.46
Chilroda et al	⁴⁶	2013	LC	500	India population	5-70	68.4	53.00	47
Bayrakdar et al	⁴⁷	2014	CBCT	730	Turkey	8-81	17.4	37.90	62.1
Geist et al	¹²	2014	CBCT	576	America	<17	26.2	47.10	52.9

C, cadaver; CBCT, cone beam computed tomography; CT, computed tomography; LC, lateral cephalography; LR, lateral radiography; NA, not available; PP, Ponticulus Posticus.

population was assessed. Future studies should include additional populations.

posticus was a common anomaly in our group of Turkish population study group, although its prevalence in other groups remains to be investigated.

Conclusion

Our results suggest that the prevalence of PP is higher than has been previously believed. Ponticulus

Funding Sources and Conflicts of Interest

No funding sources or conflicts of interest were reported for this study.

References

- Ghanayem AJ, Paxinos O. Functional anatomy of joints, ligaments and disc. In: Clark CR, editor. *The cervical spine*. 4th ed. Philadelphia: Lippincott Williams and Wilkins; 2005. p. 46–54.
- Hong JT, Lee SW, Son BC, et al. Analysis of anatomical variations of bone and vascular structures around the posterior atlantal arch using three dimensional computed tomography angiography. *J Neurosurg Spine* 2008;8:230–6.
- Krishnamurthy A, Nayak SR, Khan S, et al. Arcuate foramen of atlas: incidence, phylogenetic and clinical significance. *Rom J Morphol Embryol* 2007;48:263–6.
- Young JP, Young PH, Ackermann MJ, Anderson PA, Riew KD. The ponticulus posticus: implications for screw insertion into the first cervical lateral mass. *J Bone Joint Surg Am* 2005;87:2495–8.
- Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. *Am J Orthod Dentofac Orthop* 1995;107:58–66.
- Sharma V, Chaudhary D, Mitra R. Prevalence of ponticulus posticus in Indian orthodontic patients. *Dentomaxillofac Radiol* 2010;39(5):277–83.
- Elliott RE, Tanweer O. The prevalence of the ponticulus posticus (arcuate foramen) and its importance in the Goel-Harms procedure: meta-analysis and review of the literature. *World Neurosurg* 2014;82:e335–343.
- Goel A, Laheri V. Plate and screw fixation for atlanto-axial subluxation. *Acta Neurochir (Wien)* 1994;129:47–53.
- Fiore AJ, Haid RW, Rodts GE, et al. Atlantal lateral mass screws for posterior spinal reconstruction: technical note and case series. *Neurosurg Focus* 2002;12E–15.
- Harms J, Melcher RP. Posterior C1-C2 fusion with polyaxial screw and rod fixation. *Spine* 2001;26:2467–71.
- Pan J, Li L, Qian L, Tan J, Sun G, Li X. C1 lateral mass screw insertion with protection of C1-C2 venous sinus: technical note and review of the literature. *Spine (Phila Pa 1976)* 2010;35:1133–6.
- Geist JR, Geist SM, Lin LM. A cone beam CT investigation of ponticulus posticus and lateralis in children and adolescents. *Dentomaxillofac Radiol* 2014;43(5):20130451, <http://dx.doi.org/10.1259/dmfr.20130451> [Epub 2014 Apr 30].
- Kavaklı A, Aydınlioglu A, Yesilyurt H, et al. Variants and deformities of atlas vertebrae in Eastern Anatolian people. *Saudi Med J* 2004;25(3):322–5.
- Hasan M, Shukla S, Siddiqui MS, Singh D. Posterolateral tunnels and ponticuli in human atlas vertebrae. *J Anat* 2001;199:339–43.
- Simsek S, Yigitkanli K. Posterior osseous bridging of C1. *J Clin Neurosci* 2008;15:686–8.
- Paraskevas G, Papaziogas B, Tsonidis C, Kapetanios G. Gross morphology of the bridges over the vertebral artery groove on the atlas. *Surg Radiol Anat* 2005;27(2):129–36.
- Selby S, Garn SM, Kanareff V. The incidence and familial nature of a bony bridge on the first cervical vertebra. *Am J Phys Anthropol* 1955;13:129–41.
- Pyo J, Lowman RM. The ponticulus posticus of the first cervical vertebra. *Radiology* 1959;72:850–4.
- Kendrick GS, Biggs NL. Incidence of the ponticulus posticus of the first cervical vertebra between ages six to seventeen. *Anat Rec* 1963;145:449–51.
- Romanus T, Tovi A. A variation of the atlas. Roentgenologic incidence of a bridge over the groove of the atlas for the vertebral artery. *Acta Radiol Diagn (Stockh)* 1964;2:289–97.
- Lamberty BGH, Zivanovic. The retro-articular vertebral artery ring of the atlas and its significance. *Acta Anat* 1973;85:113–22.
- Saunders SR, Popovich F. A family study of two skeletal variants: Atlas bridging and clinoid bridging. *Am J Phys Anthropol* 1978;49:193–203.
- Farman AG, Nortje CJ, Joubert JJ. Radiographic profile of the first cervical vertebra. *J Anat* 1979;128:595–600.
- Dugdale LM. The ponticulus posterior of the atlas. *Australas Radiol* 1981;25:237–8.
- Taitz C, Nathan H. Some observations on the posterior and lateral bridge of the atlas. *Acta Anat (Basel)* 1986;127:212–7.
- Ruprecht A, Nashashibi I, Lambourne A. Ponticles of the atlas. *Dentomaxillofac Radiol* 1988;17:67–71.
- Hoening JF, Schoener WF. Radiological survey of the cervical spine in cleft lip and palate. *Dentomaxillofac Radiol* 1992;21:36–9.
- Stubbs DM. The arcuate foramen: Variability in distribution related to race and sex. *Spine* 1992;17:1502–4.
- Prescher A. The craniocervical junction in man, the osseous variations, their significance and differential diagnosis. *Ann Anat* 1997;179:1–19.
- Mitchell J. The incidence and dimensions of the retro-articular canal of the atlas vertebra. *Acta Anat (Basel)* 1998;163:113–20.
- Wight S, Osborne N, Breen AC. Incidence of ponticulus posterior of the atlas in migraine and cervicogenic headache. *J Manipulative Physiol Ther* 1999;22:15–20.
- Manjunath KY. Posterior bridging of the atlas vertebra in south Indians. *Indian J Med Sci* 2001;55:488–90.
- Wysocki J, Bubrowski M, Reymond J, Kwiatkowski J. Anatomical variants of the cervical vertebrae and the first thoracic vertebra in man. *Folia Morphol (Warsz)* 2003;62:357–63.
- Le Minor JM, Trost O. Bony ponticles of the atlas (C1) over the groove for the vertebral artery in humans and primates: Polymorphism and evolutionary trends. *Am J Phys Anthropol* 2004;125:16–29.
- Cakmak O, Gurdal E, Ekinci G, Yildiz E, Cavdar S. Arcuate foramen and its clinical significance. *Saudi Med J* 2005;26:1409–13.
- Lee MJ, Cassinelli E, Riew KD. The feasibility of inserting atlas lateral mass screws via the posterior arch. *Spine* 2006;31:2798–801.
- Tubbs RS, Johnson PC, Shoja MM, Loukas M, Oakes WJ. Foramen arcuale: Anatomical study and review of the literature. *J Neurosurg Spine* 2007;6:31–4.
- Kim SH, Shin HC, Shin DA, Kim KN, Yoon DH. Early clinical experience with the Mobi-C disc prosthesis. *Yonsei Med J* 2007;48:457–64.
- Gupta T. Quantitative anatomy of vertebral artery groove on the posterior arch of atlas in relation to spinal surgical procedures. *Surg Radiol Anat* 2008;30:239–42.
- Kobayashi Y, Kikuchi S, Konno S, Sekiguchi M. Insertion of lateral mass screw of the atlas via the posterior arch: Anatomical study of screw insertion using dry bone samples of the atlas from Japanese cadavers. *J Orthop Sci* 2008;13:452–5.

41. Hong JT, Lee SW, Son BC, et al. Analysis of anatomical variations of bone and vascular structures around the posterior atlantal arch using three-dimensional computed tomography angiography. *J Neurosurg Spine* 2008;8:230–6.
42. Cho YJ. Radiological Analysis of Ponticulus Posticus in Koreans. *Yonsei Med J* 2009;50:45–9.
43. Karau PB, Ogengo JA, Hassanali J, Odula P. Anatomy and prevalence of atlas vertebrae bridges in a Kenyan population: An osteological study. *Clin Anat* 2010;23:649–53.
44. Kuhta P, Hart J, Greene-Omdorff L, McDowell-Reizer B, Rush P. The prevalence of posticus ponticus: Retrospective analysis of radiographs from a chiropractic health center. *J Chiropr Med* 2010;9:162–5.
45. Yeom JS, Kaffle D, Nguyen NQ, et al. Routine insertion of the lateral mass screw via the posterior arch for C1 fixation: Feasibility and related complications. *Spine J* 2012;12:476–83.
46. Chitroda PK, Katti G, Baba IA, et al. Ponticulus posticus on the posterior arch of atlas, prevalence analysis in symptomatic and asymptomatic patients of gulbarga population. *J Clin Diagn Res* 2013;7:3044–7.
47. Bayrakdar IS, Miloglu O, Altun O, Gumusoy I, Durna D, Yilmaz AB. Cone beam computed tomography imaging of ponticulus posticus: Prevalence, characteristics, and a review of the literature. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2014;118:e210–9.
48. Schilling J, Schilling A, Galdames SI. Ponticulus posticus on the posterior arch of atlas, prevalence analysis in asymptomatic patients. *Int J Morphol* 2010;28:317–22.
49. von Torklus D, Gehle W. The upper cervical spine. Regional anatomy, pathology and traumatology. A systematic radiological atlas and textbook. New York: Grune & Stratton; 1972.
50. Split W, Lukomski M. Clinical and electrony stigmographic picture of Kimmerle anomaly. *Pol Tyg Lek* 1985;35:989–90.
51. Takaaki M, Masanori O, Hidenori U, Eikazu H, Seisuke T, Sotaro I. Ponticulus ponticus: Its clinical significance. *Acta Med Kinki Univ* 1979;4:427–30.
52. Koutsouraki E, Avdelidi E, Michmizos D, Kapsali SE, Costa V, Baloyannis S. Kimmerle's anomaly as a possible causative factor of chronic tension- type headaches and neurosensory hearing loss: Case report and literature review. *Int J Neurosci* 2010;120:236–9.
53. Split W, Sawrasiewicz-Rybak M. Character of headache in Kimmerle anomaly. *Headache* 2002;42:911–9.
54. Goel A, Desai KI, Muzumdar DP. Atlantoaxial fixation using plate and screw method: a report of 160 treated patients. *Neurosurgery* 2002;51:1351–6.
55. Ma XY, Yin QS, Wu ZH, Xia H, Liu JF, Zhong SZ. Anatomic considerations for the pedicle screw placement in the first cervical vertebra. *Spine* 2005;30:1519–23.
56. Ma XY, Yin QS, Wu ZH, et al. C1 pedicle screws versus C1 lateral mass screws: comparisons of pullout strengths and biomechanical stabilities. *Spine (Phila Pa 1976)* 2009;34:371–7.
57. Kim KH, Park KW, Manh TH, Yeom JS, Chang BS, Lee CK. Prevalence and morphologic features of ponticulus posticus in Koreans: Analysis of 312 Radiographs and 225 three dimensional CT Scans. *Asian Spine J* 2007;1:27–31.
58. Vernon H. Cervicogenic headache. In: Gatterman M, editor. *Foundations of the Chiropractic Subluxation*. St Louis, MO: Mosby; 1995. p. 306–16.
59. Vernon H. *Vertebrogenic Headache in Upper Cervical Syndrome*. Baltimore, MD: Williams & Wilkins; 1988:152–8.
60. Haynes MJ, Cala LA, Melsom A, Mastaglia FL, Milne N, McGeachie JK. Posterior ponticles and rotational stenosis Bayrakdars of vertebral arteries. A pilot study using Doppler ultrasound velocimetry and magnetic resonance angiography. *J Manipulative Physiol Ther* 2005;28:323–9.