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Clinical Study

Prevalence of ponticuli posticus among patients referred for dental examinations by cone-beam CT

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Abstract

BACKGROUND CONTEXT: Ponticulus posticus (PP) is the bony bridge that can completely or partially embrace the vertebral artery and the suboccipital nerve root at the atlas posterior arch. The PP can be a possible cause of vertigo, vertebrobasilar insufficiency, neck pain, shoulder pain, and cervicogenic headache. Moreover, the vertebral artery injury may happen during atlas lateral mass screw insertion in the presence of PP.

PURPOSE: The purpose of this study was to determine the prevalence of PP in a population of patients undergoing dental cone-beam computed tomography (CBCT) and the association between PP and atlas superior articular facet (SAF).

STUDY DESIGN: This is a retrospective study.

PATIENT SAMPLE: Five hundred consecutive patients who had undergone dental CBCT scans were included.

OUTCOME MEASURES: Outcome measures were age, sex, and radiologic measures.

METHODS: The maximum anteroposterior and transverse dimensions of atlas SAF were measured on the axial image, and then the area was calculated by using the formula for an elliptical area. The left-right differential ratios of the SAF in patients with unilateral PP were compared with those in age- and gender-matched patients without PP. The relationships among imaging findings, age, and sex were assessed with the two-tailed paired *t* test, χ^2 test, and logistic regression model, as appropriate.

RESULTS: The overall prevalence of PP was 7% (35 of 500 patients). There were no significant differences in the prevalence of PP with gender and age. The anteroposterior dimension, transverse dimension, and area of atlas SAF on the PP side were significantly larger than those on the non-PP side in the 18 unilateral complete PP patients ($p<.001$, $p<.001$, and $p<.001$, respectively) and in the 11 unilateral partial PP patients ($p=.001$, $p=.007$, and $p<.001$, respectively). The SAF area differential ratios in patients with unilateral PP were greater than those in the patients without PP (29.8% vs. 2.9%, $p=.002$ for 18 complete lesions, and 23.5% vs. 1.8%, $p<.001$ for 11 partial lesions).

CONCLUSIONS: The prevalence of PP and the measurement of SAF can be assessed by CBCT. The imaging findings show the larger SAF on the PP side and greater left-right difference of SAF area in the patients with unilateral PP.

Keywords: Cone-beam computed tomography; Cervical atlas; Ponticulus posticus; Superior articular facet; Epidemiology; Incidental findings

Introduction

The sulcus for the passage of the vertebral artery from the transverse foramen into the foramen magnum is situated on the posterolateral margin of the atlas posterior arch. At times, the sulcus is completely or partially bridged by a small bony prominence, called ponticulus posticus (PP), arising from the posterior portion of the superior articular

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facet (SAF) or from the posterolateral portion of the posterior arch superior margin [1–3]. The PP embracing the vertebral artery and the suboccipital nerve root can be a possible cause of vertigo, vertebrobasilar insufficiency, neck pain, shoulder pain, and cervicogenic headache [4,5]. Some studies have reported the possible injury of vertebral artery during screw insertion into the atlas lateral mass in the presence of PP [6–9]. Dhall et al. [10] have observed the larger SAF on the side of PP. Alterations in the morphometry of SAF will alter ergonomic of the atlantooccipital joint [11]. Various techniques have been used to evaluate the prevalence of PP in different populations, mostly performed by plain radiographs or dried atlas specimens [2,3,12–14]. Radiographic analysis with lateral cervical spine or cephalometric radiographs can only evaluate the PP in two dimension. However, cone-beam computed tomography (CBCT) enables evaluation of the vertebral column in three different planes, thereby providing additional benefits of lower radiation exposure and higher spatial resolution compared with conventional CT [15]. Moreover, the detailed three-dimensional images of dentomaxillofacial structures derived from CBCT may allow more accurate determination of the demographic features, morphology pattern, and SAF measurement. [16–19].

The purpose of this study was to determine the prevalence of PP in a population of patients undergoing dental CBCT and the association between PP and atlas SAF.

EVIDENCE & METHODS

Context
The ponticulus posticus (PP) is a normal variant that may be present involving the arch of the C1 vertebrae. Its presence is of interest to spine surgeons as it may impact surgical dissection in the vicinity of C1 as well as instrumentation placement. The prevalence of PP has not been well described previously.

Contribution
In this series of 500 patients, the prevalence of PP was 7%. Morphologic anomalies may be present in the superior articular facet on the ipsilateral to the PP.

Implications
This paper operates on the assumption that there would be no correlation between a need for dental CT and the presence of PP. That is the main reason through which this data could be considered generalizable, as it would be tantamount to a random sample of the population. The findings encountered in this population may not necessarily be translatable to others if the predilection for PP is genetic in nature.

—*The Editors*

Materials and methods

Study subjects

This retrospective study was approved by the ethics committee and institutional review boards. The requirement to obtain an informed consent was waived. Between January 2009 and November 2010, a total of 500 consecutive patients (mean age, 49.4±14.2 years; range, 20–86 years) including 265 women (mean age, 48.8±13.8 years; range, 20–86 years) and 235 men (mean age, 50.1±14.7 years; range, 20–84 years) received CBCT examination for orthodontic diagnosis and treatment planning from a random sample of the population. No information was provided regarding the patients' medical history or signs and symptoms of disease in the head and neck area. No specific inclusion and exclusion criteria were applied for this study.

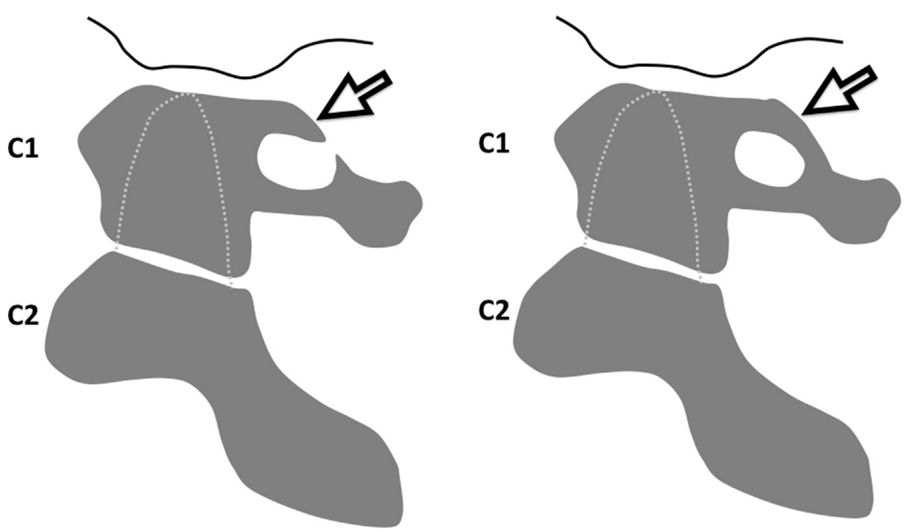

Fig. 1. Schematic drawings of a partial (Left) or complete (Right) ponticulus posticus (open arrow).

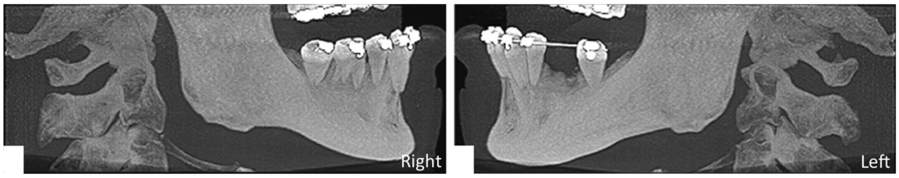

Fig. 2. A 38-year-old woman with bilateral partial ponticuli posticus. There were incomplete bony bridges between superior articular facet and posterior arch on right (Left) and left (Right) 15-mm-thick parasagittal views of cone-beam computed tomographic image in maximal intensity projection mode.

Additionally, the patients were stratified into five age groups as follows: 20–29, 30–39, 40–49, 50–59, and 60 years and older.

Imaging acquisition and analysis

The CT images were obtained by using a CBCT unit i-CAT (Imaging Sciences International, Hatfield, PA, USA) with default parameters (120 kV and 5 mA, scanning time, 20 seconds; imaging field of view, 16×13 cm, pixel resolution, 0.4/0.4 mm; slice thickness, 0.4 mm; and medium sharpness filter). The CBCT unit was calibrated at least once per week. The occlusal plane of each patient was set parallel to the horizontal plane by using a chin rest. The axial images were reconstructed to generate multiplanar reformatted coronal and sagittal images. The bilateral parasagittal views with 15 mm in thickness were displayed in maximal intensity projection mode.

Two independent readers (with 4 and 6 years of experience in CBCT imaging interpretation, respectively) analyzed all the CBCT images in a randomized fashion with i-CAT Vision software, version 1.8.1.10, on a flat screen desktop monitor with 1,024×780 spatial resolution. The two readers were blinded to patient identity and could freely rotate and scroll all the images. A complete PP (arcuate foramen) was considered as a circumferential bony bridge over the posterior vertebral sulcus of atlas, and a partial PP was defined when there was a distinct bony spicule downward from the SAF or upward from the posterior arch that did not enclose circumferentially (Figs. 1–3). The bone protrusion because of deep impression of vertebral artery was not included. The unilateral or bilateral presence of PP and whether it was complete or partial were recorded. If consensus between the two readers could not be reached, a board-certified radiologist with 14 years of experience in spine image interpretation was requested to make the final decision. Because the SAFs are usually concave with concavity in both longitudinal and transverse directions, the measurement of the area was performed on the axial view that was selected by the radiologist (with 14 years of experience) with a 10-mm thickness and magnification ×2. The maximum dimensions of the SAF in the long axis of anteroposterior dimension (D_1) and long axis of transverse dimension (D_2) were measured by two independent readers (with 4 and 6 years of experience, respectively) blind to patient identity and whether presence or absence of PP. The cross-sectional areas of the SAFs were calculated from the earlier measurements using the formula for the area of an ellipse: area $(A)=\pi\times D_1\times D_2\times 1/4$ [2] (Fig. 4). The differential ratio of SAF area in the patients with unilateral PP was calculated by the area difference between the PP and non-PP sides divided by the area on the non-PP side. However, the area differential ratio in the patients with either complete or partial PP on both sides was showed by the difference between bilateral SAFs divided by the area of the smaller facet. One of the readers performed the measurements twice.

Statistical analyses

The continuous variables were reported as means±standard deviations and analyzed via *t* test, whereas the categorical variables were analyzed via χ^2 test. Analyses were performed using the statistical software SPSS, version 15.0 (SPSS, Chicago, IL, USA). A p value less than .05 was considered an indication of a statistically significant difference. The study population was described, and the relationship among PP, age, and sex was assessed with the *t* test and χ^2 analysis, respectively. Logistic regression was used to model the presence of PP as a function of age and sex combined. The dimension and area differences of the atlas SAF between PP and non-PP sides were analyzed

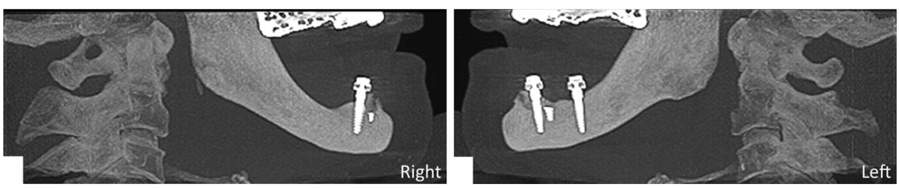

Fig. 3. A 65-year-old woman with right unilateral complete ponticulus posticus. The 15-mm-thick parasagittal image (Left) of cone-beam computed tomography in maximal intensity projection mode displayed a circumferential bony structure between right superior articular facet and posterior arch. There was no bony bridge on left parasagittal image (Right).

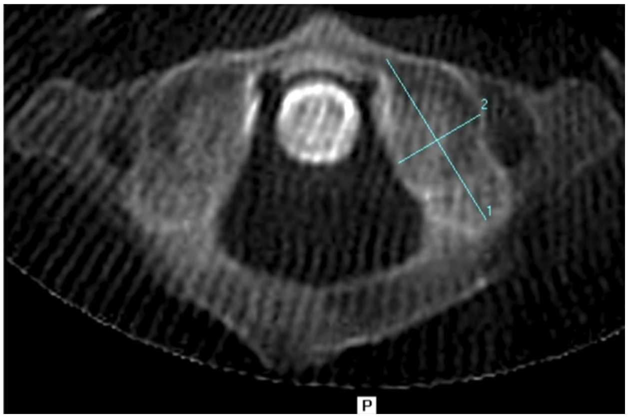

Fig. 4. Method of measurement of superior articular facet. A 10-mm-thick axial section corresponding to level of superior articular facet was selected and magnified. Electronic calipers were used to measure the long axis of anteroposterior dimension (Line 1) and long axis of transverse dimension (Line 2), which, in this case, were 24.97 and 12.55 mm, respectively.

with the paired *t* test. Agreement of measurements between readers and within one reader was determined by intraclass correlation coefficients.

Results

The overall prevalence of PP was 7% (35 of 500 patients), and at least 1 complete PP was detected in 4.6% (23 of 500 patients). Age and sex distributions are shown in Table 1. The mean age of the patients with PP was 44.8 years (standard deviation, 13.6 years), whereas the mean age of patients without PP was 49.7 years (standard deviation, 14.2 years; p=.05, *t* test). Of the 35 patients with PP, the mean age of the patients with at least one complete PP (n=23) was 43.2 years (standard deviation, 14.7 years), whereas the mean age of patients with partial PP (n=12) was 47.9 years (standard deviation, 11.1 years; p=.161, *t* test). The prevalence of PP (12% [8 of 65 patients]) was higher at the 20- to 29-year age group. There was no significant difference for comparisons of the prevalence of PP by age level (χ^2=8.906, p=.064). However, after adjusting for gender, for the patients of 20–29 and 50–59 years, the prevalence was significantly higher than that in the patients of 60 years and older (p=.013 and p=.045, respectively). There was no significant difference in the prevalence between women and men (χ^2=2.492, p=.114). However, a small female predominance (9% [23 of 265 patients] in women vs. 5% [12 of 235 patients] in men) was noted. Of the 35 PP, 18 were categorized as unilateral complete, 11 unilateral partial, 3 bilateral complete, 2 right complete and left partial, and 1 bilateral partial. The most frequently involved type was left unilateral complete PP (40% [14 of 35 patients]) and followed by right unilateral partial PP (17% [6 of 35 patients]) (Table 2).

Table 1
Distribution of study population

Characteristics	Patients without PP (n=465)	Patients with PP (n=35)	χ^2	p Value
Age (y)*	49.7±14.2 (20–86)	44.8±13.6 (21–66)		.05
Age groups (y)				
20–29 (n=65)	57 (88)	8 (12)	8.906	.064
30–39 (n=51)	49 (96)	2 (4)		
40–49 (n=111)	102 (92)	9 (8)		
50–59 (n=152)	139 (91)	13 (9)		
≥60 (n=121)	118 (98)	3 (2)		
Gender				
F	242 (91)	23 (9)	2.492	.114
M	223 (95)	12 (5)		

F, female; M, male; PP, ponticuli posticus.

Note: Unless otherwise indicated, data are numbers of cases, with percentages in parentheses.

* Data are reported as means and standard deviations. Data in parentheses are ranges.

Table 2
The frequency and various types in 35 patients with ponticuli posticus

Laterality	Complete type	Partial type
Bilateral (n=6)		
Homogeneous (n=4)	3 (9)	1 (3)
Heterogeneous* (n=2)	2 (6)	
Unilateral (n=29)		
Left (n=19)	14 (40)	5 (14)
Right (n=10)	4 (11)	6 (17)
Total	23 (66)	12 (34)

Note: Data are presented as numbers of patients, with percentages in parentheses.

* Right, complete lesions; left, partial lesions.

To investigate the differences of the atlas SAFs on the PP and non-PP sides, the mean values of the anteroposterior dimension long axis, the transverse dimension long axis, and the elliptical area were, respectively, compared in the unilateral complete PP (n=18) and the unilateral partial PP (n=11) groups. Our data showed significant increase in the mean anteroposterior dimension, transverse dimension, and area on the PP side compared with those on the non-PP side in the unilateral complete PP (19.73 vs. 17.29 mm, p<.001; 12.37 vs. 10.89 mm, p<.001; and 191.62 vs. 147.79 mm^2, p<.001, respectively) and in the unilateral partial PP (19.08 vs. 16.86 mm, p=.001; 11.23 vs. 10.42 mm, p=.007; and 167.65 vs. 136.63 mm^2, p<.001, respectively) (Table 3). The differential ratios of atlas SAF area in patients with unilateral complete/partial PP were compared with those in age- and gender-matched patients without PP. The mean area differential ratio of atlas SAF in patients with unilateral complete PP was greater than that in patients without PP (29.8%±12.8% [95% CI: 23.4, 36.2] vs. 2.9%±2.4% [95% CI: 1.7, 4.1], respectively, p=.002) and that in patients with unilateral partial PP greater than that in patients without PP (23.5% ±10.2% [95% CI: 16.6, 30.4] vs. 1.8%±1.6% [95% CI: 0.7, 2.9], respectively, p<.001) (Fig. 5). In the six patients

Table 3
Mean values of atlas superior articular facets in patients with unilateral ponticuli posticus

	Unilateral complete group (n=18)			Unilateral partial group (n=11)		
Parameters	PP side	Non-PP side	p Value	PP side	Non-PP side	p Value
D1 (mm)	19.73±2.45	17.29±1.95	<.001	19.08±2.09	16.86±2.54	.001
D2 (mm)	12.37±1.49	10.89±1.13	<.001	11.23±1.51	10.42±1.82	.007
Area (mm^2)	191.62±32.97	147.79±22.46	<.001	167.65±27.02	136.63±26.82	<.001

Area, elliptical area; D1, long axis of anteroposterior dimension; D2, long axis of transverse dimension; PP, ponticuli posticus.
Note: Data are means±standard deviations. p Values less than .05 denote significant differences and are calculated with the two-sample *t* test.

with bilateral either complete or partial PP, the mean area differential ratio of SAF was 9.2%±4.5% (95% CI: 4.5, 13.9). The intrareader and interreader reliabilities of our measurements were excellent with intraclass correlation coefficient values of 0.91 and 0.87, respectively.

Discussion

In this study, we used CBCT to assess the prevalence of PP in a population of dental patients regardless of the presence or absence of cervical or neurologic symptoms. We have confirmed that the larger anteroposterior dimension, transverse dimension, and elliptical area of the SAF are present on the PP side [2,10]. Additionally, the differential ratio of SAF area in the patients with unilateral complete/partial PP was significantly larger than that in the patients without PP.

Superior articular facet is present on the upper surface of atlas lateral mass, and forms an atlantooccipital joint with occipital condyle, which provides the vertical loading for the weight of the head, and is responsible for nodding movement [11]. Previous studies have reported left-right asymmetry of SAF that can be hypothesized by the unequal weight-bearing and/or asymmetric use of the cervical spine as a result of more common left-tilted head posture in a right hander with the stronger right sternocleidomastoid muscle [10,20–22]. There are only a few published studies regarding the measurements of the SAFs, but they have primarily performed on the dry atlas vertebrae [11,22]. Using multiplanar CBCT imaging, the metric values of the surface area could be accurately calculated with excellent intrareader and interreader reliabilities in the present study. The metrical changes in the articulating surfaces of atlantooccipital joint lead to asymmetric motion in the intervertebral motion segment. Therefore, the ergonomic changes may constitute the reasonable factors in the mechanisms of migraine, neck strains, or tension-like headache. Because only six patients of either complete or partial PP on both sides were included in the study, we could not draw a conclusive result because of the small numbers. However, we found the smaller left-right asymmetry of SAF in such types of patients than that in the patients with unilateral PP.

The relationship between PP and vertebral artery has been reported in the several studies [6,23–25]. During rotational and bending movements of the neck, the physiological stretching and compression of the vertebral artery by the bony posterior bridge of the atlas can lead to impaired arterial flow, therefore causing vertebrobasilar insufficiency syndrome or vertebral artery tethering and dissection [5,13,23,26]. Some studies have cautioned that interpretation of PP as false impression of a thick dorsal arch by the neurosurgeon can lead to the erroneous placement of C1 lateral mass screws for the treatment of atlantoaxial instability. The superior screw insertion site at the lamina may cause vertebral artery injury in the presence of PP [6,27–29]. For these reasons, the radiologists should

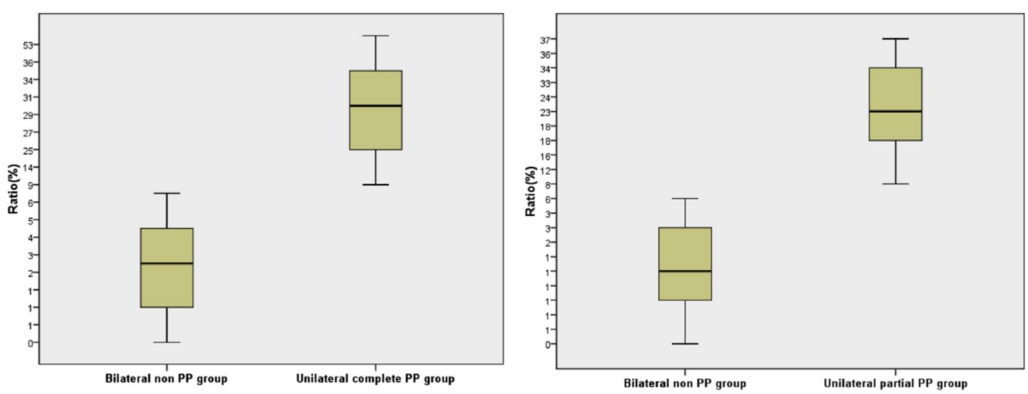

Fig. 5. Box plots showing mean left-right area differential ratio of superior articular facet. Note significantly larger area differential ratios of atlas superior articular facet between unilateral complete ponticulus posticus (PP) group and no PP group (Left) (p=.002) and unilateral partial PP and non-PP groups (Right) (p<.001).

carefully evaluate the atlas for ponticuli with patients complaining of vertigo, headache, neck pain, or unexplainable vertebral artery disorders. For the patients under consideration of atlas lateral mass screw insertion, careful imaging assessment and screw placement planning should be recommended.

Although Paraskevas et al. [3] have reported that progressive mineralization of the bony bridge from a partial to complete ossification is possible over time. In our study, the prevalence of PP did not appear to vary with age. The mean age of the patients with at least one complete PP was slightly younger than that of patients with partial PP. Moreover, the prevalence was higher at the 20- to 29-year age group that was followed by the 50- to 59-year age group. Taken altogether, PP may not be a degenerative change related to aging and more common in individuals who bear greater external stress in the craniovertebral junction [13,29]. Thus, although ossification is a possible gradual process, the occurrence of PP seems to be a congenital osseous anomaly of the atlas with varying degrees of ossification. The concept may be supported by the findings of the cartilaginous PP in fetuses and children reported by the previous study [26].

The overall prevalence of PP in the present study was smaller than that in the meta-analytic study by Elliott and Tanweer [30]. The published data represent many different racial and patient groups and include the findings in skeletal samples and radiographic examinations, which may explain the wide range and variability of percentages about the PP. A study on dry bone specimen or in the symptomatic patient group cannot actually represent the general population. The reason for the present study was more representative of the general population because there would be no correlation between a need for dental CT and the presence of PP. It is also possible that the absence of standardized criteria for partial PP may affect the data. The small spicule caused by the deep sulcus in the posterior arch might be classified as a mild form of a partial PP, making comparisons between reports difficult [14]. We tried to resolve the problem by requesting the third reader to decide the presence of partial PP or not. In our study population, there were a greater frequency of unilateral PP than that of bilateral PP and a higher prevalence on the left side compared with the right side. The findings were consistent with the meta-analytic study of Elliott and Tanweer [30].

The study had limitations: whether only metrical changes in the atlas superior articulating surfaces, leading to restricted movements in the intervertebral motion segment, could completely explain the mechanisms of neck strains or tension-like headache. We did not evaluate the nonmetrical change of superior facet, including shape, separation, or constriction, which might be a concordant factor of restriction of a craniovertebral junction. Further investigations addressing the relationship between the SAF morphometric changes and the clinical symptoms are recommended. Using the formula of an elliptical area to calculate the area of SAF could not be necessarily representative of the facet because the different shapes of the SAFs have been reported [11,20,21]. Nevertheless, our data closely approximate the measurements from the dry atlas vertebrae reported by Motagi and Ranganath [11]. Another limitation of this study was that the numbers of bilateral PP lesions were small for statistical analysis of the differential area ratios of superior articular joints.

In conclusion, the prevalence of PP can be assessed by CBCT. The imaging findings show the larger SAF on the side of PP and the greater left-right difference of SAF area in the patients with unilateral PP.

References

[1] Mitchell J. The incidence and dimensions of the retroarticular canal of the atlas vertebra. Acta Anat (Basel) 1998;163:113–20.

[2] Hasan M, Shukla S, Siddiqui MS, Singh D. Posterolateral tunnels and ponticuli in human atlas vertebrae. J Anat 2001;199:339–43.

[3] Paraskevas G, Papaziogas B, Tsonidis C, Kapetanos G. Gross morphology of the bridges over the vertebral artery groove on the atlas. Surg Radiol Anat 2005;27:129–36.

[4] 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.

[5] Chitroda PK, Katti G, Baba IA, Najmudin M, Ghali SR, Kalmath B, 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.

[6] Elgafy H, Pompo F, Vela R, Elsamaloty HM. Ipsilateral arcuate foramen and high-riding vertebral artery: implication on C1-C2 instrumentation. Spine J 2014;14:1351–5.

[7] Ahmad FU, Wang MY. Lateral mass of C1 fixation and ponticulus-posticus. World Neurosurg 2014;82:e145–6.

[8] Gebauer M, Barvencik F, Briem D, Kolb JP, Seitz S, Rueger JM, et al. Evaluation of anatomic landmarks and safe zones for screw placement in the atlas via the posterior arch. Eur Spine J 2010;19: 85–90.

[9] 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.

[10] Dhall U, Chhabra S, Dhal JC. Bilateral asymmetry in bridges and superior articular facets of atlas vertebra. J Anat Soc India 1993;42:23–7.

[11] Motagi MV, Ranganath V. Morphometric analysis of superior articular facets of atlas vertebra and its clinical applications in ergonomics of atlanto-occipital joints. J Clin Diagn Res 2013;7:2674–6.

[12] Kavakli A, Aydinlioglu A, Yesilyurt H, Kus I, Diyarbakirli S, Erdem S, et al. Variants and deformities of atlas vertebrae in Eastern Anatolian people. Saudi Med J 2004;25:322–5.

[13] 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.

[14] Kuhta P, Hart J, Greene-Orndorff 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.

[15] Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;106:106–14.

[16] 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.

[17] Geist JR, Geist SM, Lin LM. A cone beam CT investigation of ponticulus posticus and lateralis in children and adolescents. Dentomaxillofac Radiol 2014;43:20130451.

[18] Miracle AC, Mukherji SK. Conebeam CT of the head and neck, part 2: clinical applications. AJNR Am J Neuroradiol 2009;30:1285–92.

[19] Sharma V, Chaudhary D, Mitra R. Prevalence of ponticulus posticus in Indian orthodontic patients. Dentomaxillofac Radiol 2010;39:277–83.

[20] Van Roy P, Caboor D, De Boelpaep S, Barbaix E, Clarys JP. Left-right asymmetries and other common anatomical variants of the first cervical vertebra. Man Ther 1997;2:24–36.

[21] Paraskevas G, Papaziogas B, Tzaveas A, Natsis K, Spanidou S, Kitsoulis P. Morphological parameters of the superior articular facets of the atlas and potential clinical significance. Surg Radiol Anat 2008;30:611–7.

[22] Mysorekar V, Nandedkar A. Surface area of the atlanto-occipital articulations. Cells Tissues Organs 1986;126:223–5.

[23] Cushing KE, Ramesh V, Gardner-Medwin D, Todd NV, Gholkar A, Baxter P, et al. Tethering of the vertebral artery in the congenital arcuate foramen of the atlas vertebra: a possible cause of vertebral artery dissection in children. Dev Med Child Neurol 2001;43:491–6.

[24] 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.

[25] Cakmak O, Gurdal E, Ekinci G, Yildiz E, Cavdar S. Arcuate foramen and its clinical significance. Saudi Med J 2005;26:1409–13.

[26] Lamberty BG, Zivanovic S. The retro-articular vertebral artery ring of the atlas and its significance. Acta Anat (Basel) 1973;85:113–22.

[27] Wakao N, Takeuchi M, Nishimura M, Riew KD, Kamiya M, Hirasawa A, et al. Vertebral artery variations and osseous anomaly at the C1-2 level diagnosed by 3D CT angiography in normal subjects. Neuroradiology 2014;56:843–9.

[28] Yeom JS, Kafle D, Nguyen NQ, Noh W, Park KW, Chang BS, 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.

[29] Hong JT, Lee SW, Son BC, Sung JH, Yang SH, Kim IS, 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.

[30] 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:e335–43.