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MORPHOMETRIC STUDY OF THE POSTERIOR ARCH OF ATLAS VERTEBRA IN THE SERBIAN POPULATION

MORFOMETRIJSKA STUDIJA ZADNJEG LUKA ATLASA U SRPSKOJ POPULACIJI

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Summary

Introduction. Groove for the vertebral artery and the suboccipital nerve, is located on the superior surface of the posterior arch of the first cervical vertebra (the atlas). Presence of bony variations may transform the groove into incomplete/complete canal, causing compression of its structures and consequently symptoms of vertebro-basilar insufficiency. The aim of the present study was to determine the incidence and extent of morphological variations of the posterior arch of the atlas vertebra. **Material and Methods.** The investigation was conducted on 41 atlas vertebrae, part of the Osteological Collection of the Department of Anatomy of the Faculty of Medicine in Novi Sad and the Faculty of Medicine in Niš. According to the shape of the posterior arch, the atlas vertebrae were classified into three classes. The measurements of maximum width and height diameters of the incomplete/complete canal for the vertebral artery were performed. All the measurements were done using open source software for image analysis, Image J. **Results.** The results of the study showed that in our sample of atlases the most common class was class I (78.05%), and class III the least frequent (7.32%). There was no statistically significant difference in the observed measurements of the atlas anatomical variations between the right and left side. **Conclusion.** Morphometric analysis of the superior surface of the posterior arch of the atlas vertebra has shown the existence of variations and their importance has been discussed.
Key words: Cervical Atlas; Anatomic Variations; Vertebral Artery; Image Processing, Computer-Assisted; Morphological and Microscopic Findings; Serbia

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Sažetak

Uvod. Na gornjoj strani zadnjeg luka prvog vratnog pršljena (atlas) nalazi se žleb kojim prolazi kičmena arterija na svom putu ka lobanjskoj duplji, a praćena je potpotiljačnim živcem. Prisustvom koštane varijacije, žleb može biti pretvoren u nepotpuni/potpuni kanal, što može dovesti do kompresije struktura koje njime prolaze, a tako i pojave simptoma vertebrobazilarne insuficijencije. Cilj rada bio je da se odrede učestalost i dimenzije morfoloških varijacija na zadnjem luku atlasa. **Materijal i metode.** Istraživanje je sprovedeno na 41 atlasu koji pripadaju Osteološkoj zbirci Zavoda za antomiju Medicinskog fakulteta Univerziteta u Novom Sadu i Medicinskog fakulteta Univerziteta u Nišu. Atlasi su prema izgledu gornje strane zadnjeg luka klasifikovani u tri klase, a potom su merene maksimalna širina i visina nepotpunog/potpunog kanala kojim prolazi kičmena arterija. Merenja su vršena u javno dostupnom programu za analizu i obradu slika *ImageJ*. **Rezultati.** Najzastupljeniji su atlasi klase I, na čijem je zadnjem luku prisutan žleb kičmene arterije (78,05%), dok su najmanje zastupljeni pršljenovi klase III, sa žlebom koji je pretvoren u potpuni koštani kanal (7,32%). Ne postoji statistički značajna razlika između merenih parametara sa desne i leve strane posmatranih atlasa. **Zaključak.** Morfometrijskom analizom gornje strane zadnjeg luka atlasa pokazano je da postoje varijacije izgleda žleba kičmene arterije čiji je značaj opisan u radu.
Ključne reči: prvi vratni prsljen; anatomske varijacije; vertebralna arterija; kompjuterska obrada slike; morfološki i mikroskopski nalazi; Srbija

artery, as well as the suboccipital nerve. In the classical literature, described as an anatomical variation, groove for the vertebral artery may sometimes be converted into an incomplete/complete foramen or canal by an ossified bridge between the back of the superior articular facet and the superolateral part of the posterior arch [12].

The prevalence of this anatomical variation has been described differently in different populations (from 6.57% in Northern Indians to 52.94% in Kenyans), in cadaveric and radiographic studies [13].

Ponticulus posticus/posterior ponticulus (PP), pons posticus/arcuate foramen, Kimmerle anomaly/variant/deformity, retroarticular ring, posterior atlantoid fo-

Introduction

Atlas is the first cervical vertebra that supports the head. Due to its morphology, frequent pathology and clinical importance associated with craniovertebral junction, the posterior arch of the atlas vertebra has been extensively studied [1–11]. Behind each superior articular process is a groove which transmits the vertebral

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Abbreviations
W   – width
H   – height

ramen are some of the synonyms which are used to describe morphological variations of the groove for the vertebral artery [14–18]. A clear mechanism of their formation is not well understood and is still a subject of debate [19]. Because of the close relationship between the groove and the atlanto-occipital membrane, age-related ligamentous ossification may be considered as a potential cause, but the predilection in older population has not been proved [20]. As PP has been found in children as well, Schilling et al. [21] claimed that this structure should not be considered as a process of calcification, but ossification formed to protect the vertebral artery passing the area susceptible to compression or damaged as a result of craniocervical dynamics, that was later supported by other authors [22].

The importance of such anatomical variation is still controversial, from incidental finding to its involvement in causes of the upper cervical syndrome. Compression of the vertebral artery (primarily during extensive rotation of the head and neck) and consequential vertebrobasilar ischemia with symptoms such as headache, vertigo, photophobia, dizziness, head and neck pain, gives significant clinical importance to morphometric analysis of the posterior arch of the atlas vertebra [23–28].

The aim of the present study was to determine the prevalence of the morphological variations of the posterior arch of the atlas vertebra is Serbian population and to discuss the gathered results.

Material and Methods

The study was conducted in a sample of 41 undamaged, thoroughly boiled, cleaned and macerated human atlas vertebrae, of unknown sex, age and race. The analyzed vertebrae are part of the Osteological Collection of the Department of Anatomy of the Faculty of Medicine in Novi Sad (Serbia) and the Department of Anatomy of the Faculty of Medicine in Niš (Serbia). This research was approved by members of the Ethics Committees of both Faculties of Medicine. This was a two-part research study.

Part I
The first, descriptive part of study included morphological analysis of the superior surface of the posterior arch of the atlas vertebra. In accordance with Mitchell's classification [29], atlas vertebrae were classified into three classes: class I – groove for the vertebral artery; class II – vertebrae with an incomplete bony ring with a missing middle part; class III – vertebrae with a complete bony ring which encloses the vertebral artery.

During further observation of the class I vertebrae, it seemed that the groove for the vertebral artery varies in depth, which explains why we used Hasan's [30] classification for the detailed analysis.

According to the depth, a groove for the vertebral artery was described as a small impression or as a specified sulcus that transmits the vertebral artery.

Part II
All the atlas vertebrae were numbered. They were photographed (Sony W830 Compact camera, 10x
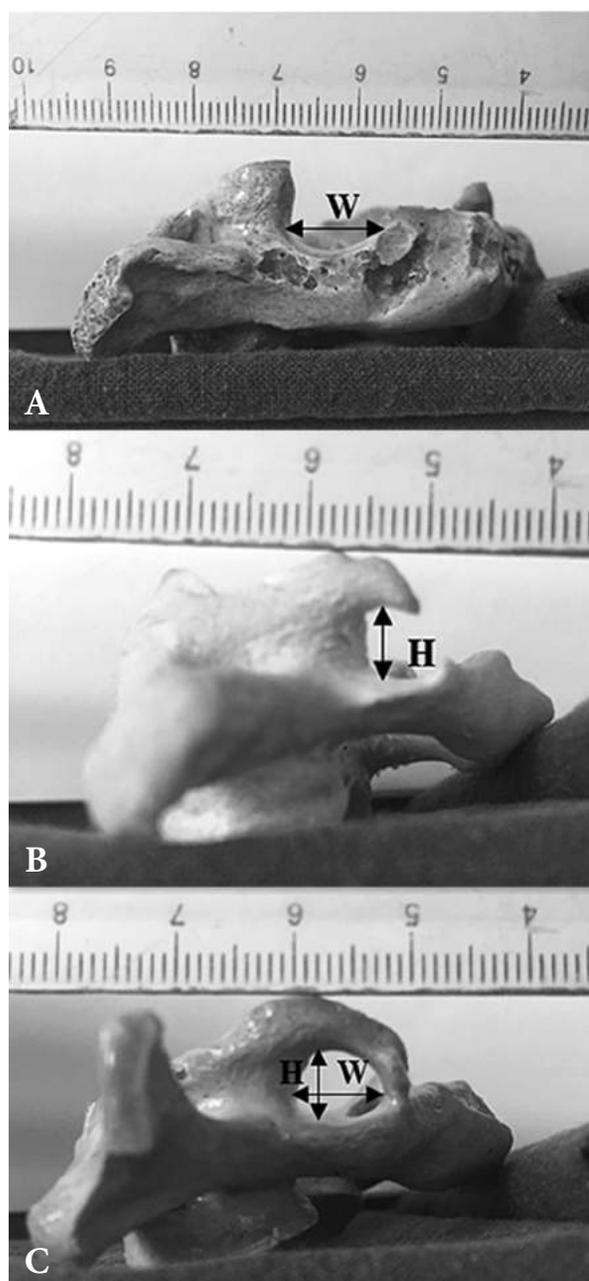

Figure 1. Morphometric analysis of the atlas vertebrae by measuring width and height of the anatomical variations of the groove for the vertebral artery: A - atlas class I; B - atlas class II; C- the atlas class III
Slika 1. *Morfometrijska analiza atlasa merenjem širine (W) i visine (H) anatomske varijacije žleba kičmene arterije: A – atlas klase I; B – atlas klase II; C-– tlas klase III*

optical zoom) from the lateral view, placed in the same position on the osteometric table and at the same distance from the camera eyepiece. The digital images were loaded into open source software for image reconstruction and analysis – Image J (National Institute of Health, Bethesda, MD; http://rs-bweb.nih.gov/ij). All the measurements were made using the 'Ruler' tool. Morphology of the groove for the vertebral artery was evaluated quantitatively using two parameters: width (W) and height (H) of the incomplete/complete anatomical variation of PP. Measurements were taken as maximum dimensions of the groove/foramen in both, antero-posterior (width) and superio-inferior (height) planes **(Figure 1)**. The exception was made for the atlas vertebrae class I in which only W was measured.

The obtained results were evaluated by Student's T-test and presented comparing the side of orientation.

Results

Part I - results
The results of the qualitative analysis of the examined vertebrae are shown in **Table 1**. Forty-one

human atlas vertebrae were examined. Out of these, in six cases (7.32%) complete bony bridge was found over the superior surface of the atlas vertebra posterior arch, bilaterally in one case. Class II atlas vertebrae with incomplete bony ring were found in 12 cases (14.63%), bilaterally in three vertebrae. The most common was the class I atlas vertebrae, found in 64 cases (78.05%), bilateral in 28 vertebrae. The latter one was an expected result, since the superior surface of the atlas posterior arch is most commonly converted into a groove for vertebral artery, as described in classic anatomical literature.

Descriptive analysis showed that class I vertebrae may be divided into two subclasses according to the depth of the groove for the vertebral artery **(Table 2)**.

Part II - results
Table 3 shows statistical morphometric analysis of the atlas vertebral artery groove class I with minimum and maximum values of measured parameters, mean values and standard deviations. It can be seen that there is no statistically significant difference between the W of the groove for the ver-

Table 1. Prevalence of various classes of the atlas vertebrae in the examined sample (*n* = 41)
Tabela 1. Prevalencija različitih klasa atlasa u ispitivanom uzorku (n = 41)

Atlas vertebrae/*Atlas*	Unilateral/*Jednostrano*		Bilateral/*Obostrano*
	Right side/*Desna strana*	Left side/*Leva strana*	
Class I/*Klasa I*	35 (85.36%)	29 (70.73%)	28 (68.29%)
Class II/*Klasa II*	4 (9.75%)	8 (19.51%)	3 (7.37%)
Class III/*Klasa III*	2 (4.87%)	4 (9.75)	1 (2.43%)

Table 2. Morphological analysis of the atlas vertebrae class I based on the description of the depth of the groove for the vertebral artery
Tabela 2. Morfološka analiza atlasa klase I zasnovana na opisu dubine žleba kičmene arterije

Atlas vertebrae class I/*Atlasi klase I*	Right side/*Desna strana*	Left side/*Leva strana*
Shallower groove for vertebral artery/*Plići žleb kičmene arterije*	25 (60.97%)	11 (26.39%)
Deeper groove for vertebral artery/*Dublji žleb kičmene arterije*	10 (24.39%)	18 (43.90%)

Table 3. Morphometric analysis of the class I atlas vertebrae posterior arch (All the measures are given in cm)
Tabela 3. Morfometrijska analiza zadnjeg luka atlasa klase I. Sve mere su date u cm

Parameter *Parametar*	Right side/*Desna strana*			Left side/*Leva strana*			p
	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	
Width (W)/*Širina*	0.46	0.867	0.634±0.11	0.446	0.932	0.63±0.06	0.43

Table 4. Morphometric analysis of the class II atlas vertebrae posterior arch (All the measures are given in cm)
Tabela 4. Morfometrijska analiza zadnjeg luka atlasa klase II. Sve mere su date u cm

Parameters *Parametri*	Right side/*Desna strana*			Left side/*Leva strana*			p
	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	
Width (W)/*Širina*	0.41	0.72	0.57±0.12	0.43	0.69	0.56±0.1	0.42
Height (H)/*Visina*	0.43	0.51	0.47±0.04	0.34	0.56	0.44±0.08	0.27

Table 5. Morphometric analysis of the class III atlas vertebrae posterior arch (All the measures are given in cm)
Tabela 5. Morfometrijska analiza zadnjeg luka atlasa klase III. Sve mere su date u cm.

Parameters Parametri	Right side/*Desna strana*			Left side/*Leva strana*			p
	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	Minimum *Minimum*	Maximum *Maksimum*	X ± SD	
Width (W)/*Širina*	0.43	0.573	0.5±0.1	0.44	0.67	0.57±0.09	0.23
Height (H)/*Visina*	0.385	0.45	0.42±0.04	0.42	0.5	0.44±0.03	0.24

tebral artery on the right and left sides of the examined vertebrae.

Table 4 and **Table 5** show that there is no statistically significant difference between results obtained by morphometric analysis on the posterior arch of the atlas vertebrae class II and III.

Discussion

The existence of bony bridges (ponticles) may reduce the area through which the vertebral artery passes, compromising its blood flow and causing vertebrobasilar insufficiency. Having that in mind, knowledge of the anatomical variations of the posterior arch of the atlas vertebra should be considered during diagnostic, surgical and other therapeutic manipulations of the cervical spine [24]. The morphometric analysis of the posterior arch of the atlas vertebra is done in order to investigate the association between their anatomy and certain clinical symptoms, as well as to improve diagnostic and surgical procedures by indicating possible complications and contraindications.

During phylogeny, the cervical and the upper thoracic part of the vertebral column are the most susceptible to changes, which may lead to certain morphological variations [2]. Among all cervical vertebrae, the atlas vertebra shows the highest variability [28]. After 1869, when Macalister [3] first described the PP, many anatomists started studying the morphology of the atlas vertebrae. The bony bridges of the atlas vertebrae are found in humans as well as in non-human primates [29]. The origin of the bridges is a matter of much debate and numerous theories have been explained in the available literature [4–6, 14, 19, 31]. It could be a congenital phenomenon due to the persistence of the superior oblique process [5], or it could be developed from the pro-atlas as a part of the occipital vertebra [6, 31]. Saunders and Popović [7] conducted family studies and noted a significant correlation of the atlas bony bridges among parents and children, as well as among siblings [8]. While a group of authors stated that such anatomical variations could be due to the ossification of the posterior atlanto-occipital membrane or acquired ossification of the oblique ligament (lateral border of the posterior atlanto-occipital membrane which forms the aperture for the vertebral artery and the suboccipital nerve) as a consequence of the vertebral artery pulsation [3, 9], others claimed that the PP might be related to erect posture and bipedalism [14, 17]. There

was a belief that development of the bony bridges could be caused by external stimuli and that a study on Bedouin women would be of interest to determine whether carrying heavy objects may contribute in formation of such variations [14, 25].

Studies of the first cervical vertebrae were performed on dry bones and radiographic images (computed tomography and X-ray images) of cervical part of vertebral column. It was noted that radiographic researches give less detailed data [22]. Examination performed on dry bones and three-dimensional images of computed tomography have an advantage over X-ray images because they provide better insight and transparency of the observed region [23].

Part I

In the present research, the overall prevalence of PP was 21.95% (14.63% cases of incomplete and 7.32% cases of complete bony bridges). The prevalence of this anatomical variation has been reported differently by different authors. The incomplete PP is found in 9.8 - 25.9% of the general population [2, 4, 14, 29]. Taitz and Nathan [25] found incomplete PP in 25.9% and complete PP in 7.9% of the population. This coincides with the results of the present study. Patel et al. [28] found a prevalence of complete PP of 13% in the Gujarat region, while Ckmak et al. [26] found a prevalence of complete PP of 11.6% in the sample of 60 atlas vertebrae in the Turkish population.

The data in **Table 1** show that in the sample of atlas vertebrae found in the territory of Serbia, unilateral complete, as well as incomplete, bony bridges are more frequent than bilateral, which is in accordance with the findings of other authors [11, 14, 22]. The reason why such variations are more often found on the left side may be explained by right handedness and consequently larger and stronger sternocleidomastoid muscle on the same side which tilts the head to the opposite side [32]. Dhall et al. also reported higher prevalence of left-sided PP [11] as well as Hasan et al. [30], which also correlated with the larger superior articular facets on the left side.

Apart from Mitchell's classification, Hasan et al. [30] described six classes of atlas vertebrae bridges. In order to describe the posterior arch of atlas vertebra extensively, we used Hasan's protocol and divided the class I vertebra into two subclasses – with deeper and with shallower groove for the vertebral artery. As the bony bridges are more likely present on the left side of the atlas posterior arch, deeper

grooves for the vertebral artery are common on the same side, but this is inconsistent with the results from the sample of Northern Punjabi population [17].

Part II

In the present research, the morphometric analysis of class II atlas vertebrae **(Table 4)** shows that the mean W of the PP is 0.57 ± 0.12 cm on the right side, vs. 0.56 ± 0.1 cm on the left side, while the mean H of the PP is 0.47 ± 0.04 cm on the right side, vs. 0.44 ± 0.08 on the left side. **Table 5** presents the same data for class III atlas vertebrae – the mean W of the PP (0.5 ± 0.1 cm on the right vs. 0.57 ± 0.09 cm on the left side) and the mean H of the PP (0.42 ± 0.04 cm on the right vs. 0.44 ± 0.03 cm on the left side). Krishnamurthy et al. [18] noted that the mean vertical H of the complete PP was 6.52 mm on the right side and 6.57 mm on the left side in bilateral samples, while it was 5.38 mm and 4.91 mm, respectively in the unilateral samples of the atlas vertebrae, which is higher than findings in the present study. Unur et al. [1] studied dimensions of the complete PP on radiographic images and found that the mean H was higher than in the present research (5.7 mm), which can be explained by using a different material.

The presence of anatomical variations on the posterior arch of the atlas vertebra is a common cause of vertebro-basilar insufficiency. Any abnormal course of the vertebral artery can lead to deficiency in vascular supply of the brainstem and the cerebellum [27]. The importance of this anatomical variation is underestimated in practice and clinicians must be alert about its possible presence in patients complaining of dizziness, vertigo, higher headache ratio, temporal pain, photophobia, pain in the arm and shoulder [16, 20]. Cervical spine radiography is a very useful technique to detect PP [26].

Study limitations

The limitation of this study is the small sample size, as well as that it attempted to explore the characteristics of the superior surface of the posterior arch on dry atlas vertebrae of unknown sex and age.

Our idea is to expand the research by using magnetic resonance images of patients with symptoms of vertebro-basilar insufficiency.

Conclusion

A thorough knowledge of the anatomy of the first cervical vertebra is of great importance not only for anatomists and anthropologists, but also for neurologists, neurosurgeons and vascular surgeons. This research showed that the most common are atlas vertebrae that, according to Mitchell's classification, belong to the class I (78.05%) and the least common are class III atlas vertebrae (7.32%). There is no statistically significant difference in the dimensions of the anatomical variations of all three classes of atlas vertebrae between the right and the left side.

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