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MORPHOLOGICAL CHARACTERISTICS OF THE FIRST PART OF THE VERTEBRAL ARTERY

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Abstract: Because of their anatomical localization, vertebral arteries were neglected in research for a long period of time. Vertebral arteries are responsible for about 30% of the brain blood supply. The aim of this study was to examine the vertebral artery's course in the first segment, and to define the anatomic variations and percentage of their appearance in the adult population using CT angiography. The data derived from this study may find useful application in a wide range of medical fields, such as anatomy, radiology and surgery. For that purpose during a 6-month period we examined 30 patients with CT angiography. The origin of the vertebral artery in all 30 patients was from the subclavian artery. The diameter of the left vertebral artery was from 1.6–5.20 mm., average 3.35 mm. The diameter of the right vertebral artery was from 1.64–5.40 mm., average 3.19 mm. Hypoplasia of the vessel was found in four patients. We found no aplasia of the vessel in this series. A contorted course was found in 12 (40%) patients. In all 30 (100%) patients the vertebral artery entered the *foramen transversum* at the level of the sixth cervical vertebra. Although the incidence of anatomical variations is rare, their presence is significant in the diagnostic and surgical procedures in the head and neck region. Insufficient knowledge can lead to serious iatrogenic injures.

Key words: vertebral artery, anatomy, variations, origin, hypoplasia, tortuosity.

Introduction

The major source of blood to the head and neck is provided by common carotid, internal carotid, and external carotid arteries. Additional arteries arise from branches of the subclavian artery, particularly the vertebral artery (VA) responsible for about 30% of the brain's blood supply [9].

The vertebral artery is the first and the largest branch of the subclavian artery arising from the posterosuperior aspect of its first part. It runs upwards and backwards in the scalenovertebral triangle formed by the *scalenus anterior* and *longus colli* muscles. The common carotid artery and the vertebral vein are in front of it. It is crossed by the inferior thyroid artery and by the thoracic duct on the left side and the right lymphatic duct on the right side. The seventh cervical transverse process, the inferior cervical ganglion and ventral rami of the seventh and eight cervical spinal nerves lie posterior to the artery. Then the vessel reaches the sixth cervical vertebra to enter the foramen of the transverse processus. It passes through the foramina in the transverse processes of all of the cervical vertebrae except the seventh, curves medially behind the lateral mass of the atlas and enters the cranium via the *foramen magnum*. At the lower pontine border it unites with its contralateral fellow to form the basilar artery [9, 20, 22].

The VA is divided into four segments. The segment of the artery from its origin at the subclavian artery to its entry into the respective transverse foramen is called the pretransverse, prevertebral or V1 segment of the VA. The second segment, vertebral or V2 segment extends from the *foramen transversarium* (FT) of the C6 vertebra till the VA exits the axis. The third segment, the suboccipital or V3 segment, extends from the FT of the C2 vertebra to the *for amen magnum*. The fourth segment, the cranial or V4 segmen,t is intracranial and terminates as a basilar artery [5, 9, 20, 21, 28].

The VA supplies blood to the upper part of spinal cord and its membranes, the brain stem, cerebellum, occipital and temporal lobe of the cerebrum, muscles of the neck and inner ear [3, 9, 20, 21, 22].

The vertebral artery lies buried in a sea of generalities, prejudices, fear and ignorance (Carney A, 1981). Because of their anatomic location and inconvenient access for surgical procedures, vertebral arteries remained neglected by research for a long time. Since Egas Moniz performed the first vertebral angiography in 1933, the vertebral artery has become more and more important in different clinical fields. In 1958 Crawford and DeBakey described one of the first surgical approaches to this region for lesions causing ostial stenosis. In addition to angiography, continuous wave Doppler sonography and colour coded Doppler sonography have been the most important tools for noninvasive investtigation of the extra cranial part of the VA for many years. In surgery, angiography, and in all noninvasive procedures it is of great importance to know the exact details of the course and the origin of this segment of the vessel as well as in which percentages real abnormalities can be found [21].

The aim of this study is to describe the morphological features of the first part of the VA. The data received from this study may be applied in different fields of medicine. For anatomists, the results obtained from this study present the most valuable teaching material for students and postgraduates. Additionally, it will give them knowledge about some anatomical variations of the VA. The applicative value for radiologists is in diagnostic and intervention procedures such as CT, MRI, angiography and endovascular procedures. These data are valuable for vascular and neck surgeons during planning and accomplishing surgical procedures in order to prevent complications. They are important for neurologists in the assessment of strokes in the VA vascular area.

Material and Methods

During a 6-month period, from February 1st 2010 to July 31st 2010, 30 patients from the University Radiology Institute in Skopje, R. Macedonia were investigated. This is a prospective study and includes 14 females and 16 males, ranging in age between 19 and 75 years, mean age of 57.8 ± 3.02 years. Patients were investigated with computed tomography angiography (CTA). The CTA is a relatively new imaging method in the study of anatomy, with the characterristics of practical and accurate orientation. In the past CTA was considered a relatively safe, fast and minimally invasive procedure, which was a reliable tool for investigation of the vessels. It can be used to measure the size, shape and course of VA, and provide a reliable basis for clinical diagnosis and treatment. CTA was performed with scanner Siemens Somatom Volume Zoom 4-slice CT scanner. Contrast material was injected by using an intravenous catheter placed in the peripheral vein, a total of 100 ml. at a rate of 3 ml/s with a pressure injecttor. After the contrast medium was injected, scanning was carried out automatically within one breath by use of bolus tracking software. The data were transferred to a workstation for post-processing. Reconstruction included the following: maximum intensity projection-MIP; four-dimensional CTA with volume rendering; reformatted multiplanar reformation-MPR performed through each of the VA. The first part of the VAs was clearly and directly shown in the high quality images, and satisfied the requirements of our study. In all of our 30 patients, the course of the first segment of VA, extending from its origin at the subclavian artery to the FT of C6 vertebrae, was clearly observed.

We analysed CT reports for the following parameters: origin of the VA, diameter of the VA, tortuosity of the VA, and level of entry at the FT. We made measurements at three consecutive points, 5 mm apart, starting from the origin of the VA at the subclavian artery. The diameter of each vessel was calculated as the average of the three measurements. By measuring the average diameter of the vessel, asymmetry, hypo- or hyperplasia and aplasia of the VA can be defined. In this study we defined VA asymmetry, hypoplasia and aplasia of the vessel. The criterion for the VA asymmetry was a side-to-side diameter difference of more than 1 mm. The VA with a larger diameter was defined as dominant. The VA hypoplasia (VAH) was defined as a lumen diameter of 2 mm or less, mean blood flow velocities under 0.35 m/s, and increased resistance pattern.

Results

In all 30 (100%) patients the origin of the VA was visualized on the left and right side, and without exception the VA had its origin from the SA. In this series we found no origin of the VA from other than the subclavian artery. (Fig. 1)

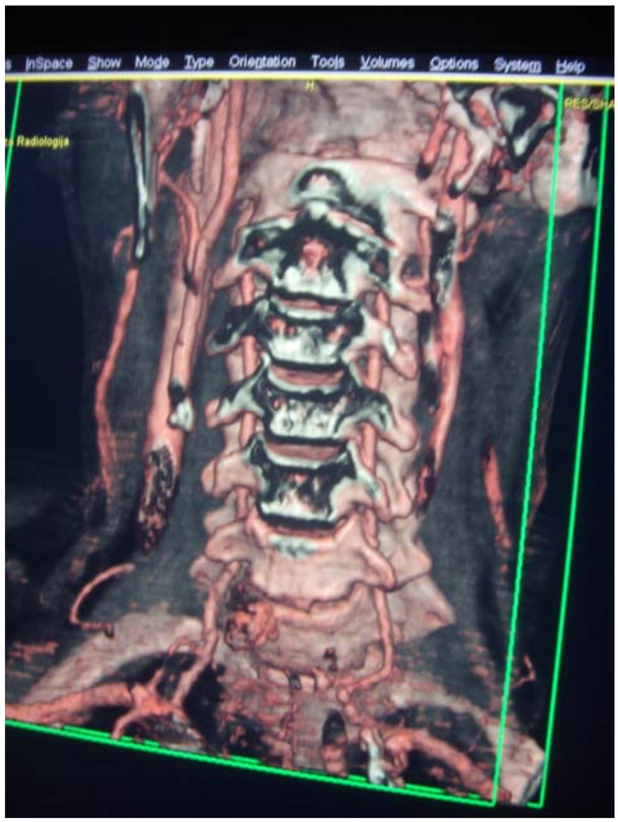

Figure 1 – Origin of the vertebral arteries from the subclavia

The diameter of the VA at its origin on the left side was in the range between 1.60–5.2 mm, mean 3.33 ± 0.89 mm, and on the right side from 1.64–5.40 mm, mean 3.19 ± 0.98 mm. The VAs on both sides were equal in diameter in seven (23.3%) patients. The right VA (RVA) was larger in nine (30%) patients, and the left VA (LVA) was larger than the right in 14 (46.6%) patients. Hypoplasia of the vessel was found in 4 (6.67%) patients. In two patients hypoplasia was on the right side, in one patient on the left side, and in one patient we found bilateral hypoplasia of the vessel on the left and right sides. In this study aplasia of the vessel was not found. (Fig. 2)

Figure 2 – Hypoplasia of the right vertebral artery

Of the vessels examined, 18 (60%) followed a relatively straight course from their origin to their entry into the FT. The other 12 (40%) patients showed some form of tortuosity. (Fig. 3A and 3B)

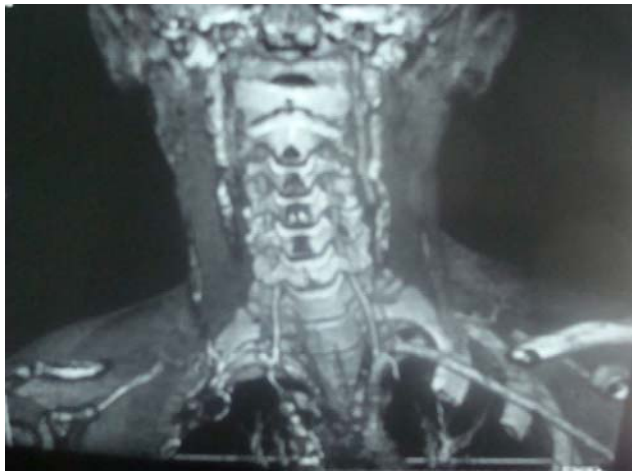

Figure 3A – Straight course of the vertebral artery

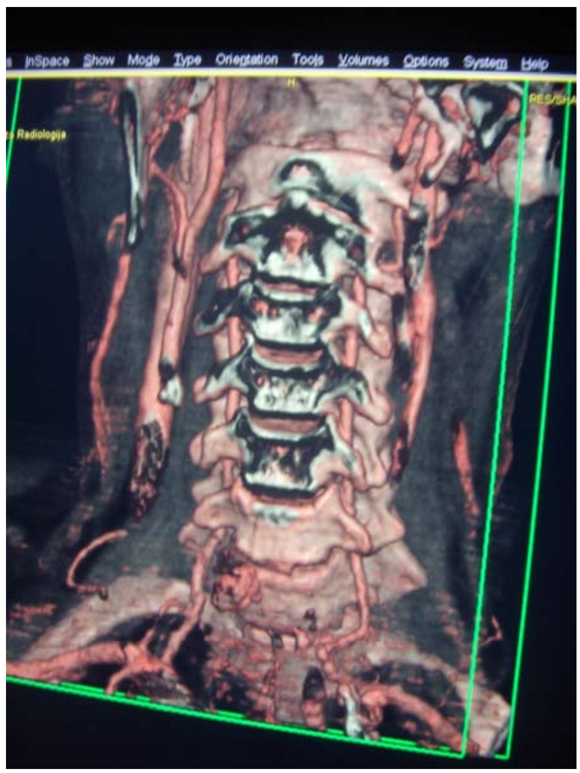

Figure 3B – Tortuous course of the vertebral artery

In 30 (100%) patients the left and the right VA entered the FT of the sixth cervical vertebrae. Entry into the FT of other cervical vertebrae was not noticed. (Fig. 4)

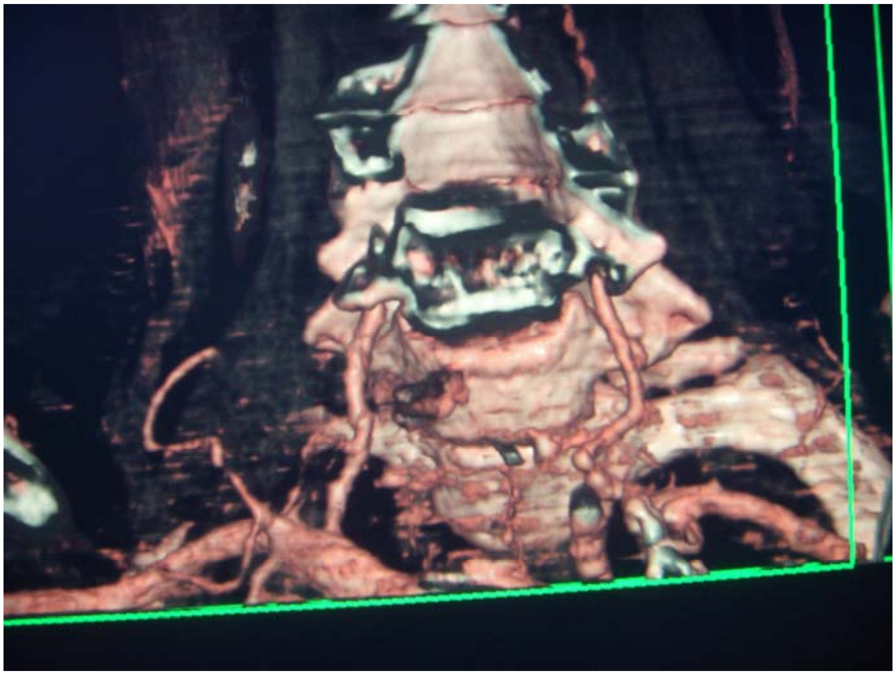

Figure 4 – Level of enterance of the vertebral arteries into the FT

Discussion

In anatomy, surgery, angiography and in all non-invasive procedures it is very important to know the exact course of the artery and the possible variations [21].

Origin of the VA

Although the VA is classically described as the first branch from the subclavian artery, multiple variations in the origin of this vessel have been reported in the literature [1]. Several researches have reported anomalous origins, in which the origin point of the VA is from the aortic arch [10, 15, 21, 24, 26, 28, 31, 34], from the thyrocervical trunk [21, 32, 34], from the brachiocephalic trunk [3], from the common carotid artery [5, 21, 34], and from the external carotid artery [21, 28, 34]. Though the overall incidence of the anomalous origin of the VA is low, it occurs mostly on one side, usually on the left [26, 28]. Anomalous origin of the right side is a rare anatomic variant [16]. VA may have duplicate origin, generally from the aortic arch and subclavian artery [12]. Bilateral aortic arch origin of the VA is an exceptional anatomic variant [1].

The complex embryologic evolution of the vessel accounts for the wide range of possible origins. The vertebral artery is formed between the 32nd and the 40th gestational day (7–18 mm embryo) from fusion of secondary persistent segments of cervical arteries and the primitive dorsal aortic arch. Abnormal arrangements of this fusion process undoubtedly account for any abnormal origins. It is possible that abnormalities in fusion also contribute to some tortuosities of the vessel [21].

In most cases described in the literature, anomalous VA origin did not result in clinical symptoms [1, 16, 31]. In rare cases, patients complained of dizziness and vertigo, which was thought to have no connections to the anomalous origin of the vertebral artery [16, 31]. Bernardi and Dettori in their study hold the hypothesis that anomalies of origin, of calibre and of distribution of the large vessels of the aortic arch may favour cerebral disorders because of alterations in the cerebral haemodynamics [2]. There is no conclusive evidence that these variants lead to a predisposition to cerebrovascular disorders [16, 31].

Komiyama *et al*. in their study detected arterial dissection in 17 patients, an incidence of 1.9%. They analysed the incidence of arterial dissection of the VA of aortic origin and VA of subclavian origin. According to their studies left VA (LVA) of aortic origin was associated with a significantly higher incidence of arterial dissection of its own vessel than LVA of left subclavian artery origin and right VA (RVA) of right subclavian origin. The reasons for the high incidence of arterial dissection associated with VA of aortic origin remain to be elucidated. However, there could be two anatomical explanations: congenital structural defects of the arterial wall and alteration of cerebral haemodynamics [13].

The prevertebral segment of VA is frequently affected with atherosclerosis. The frequency has been found in postmortem examinations to be similar in the carotid and vertebrobasilar system. Significant stenosis was observed principally in the V1 segment of the VA, not distally. Specifically, the greatest site of atherosclerotic stenosis is at the origin of the vessel from the subcalvian artery [4, 10, 21, 22, 34].

The most common anomalous origin is LVA arising from the arch of aorta. In the studies conducted by different authors the frequency of aortic arch origin of the LVA is in the range between 2.4 to 6.9 % (Table 1).

Table 1

Aortic arch origin on the left vertebral artery

Study (year)	Prevalence
Adachi (1928)	5.4%
Aso (1932)	3.2%
Mori (1941)	6.9%
Vorster (1998)	5%
Matula (1997)	3.5%
Komiyama (2001)	2.4%
Panicker (2002)	5%

According to Matula the variations of the origin of the vertebral artery can be divided by two criteria: first, the vessel of origin of the vertebral artery and second, the origin from the subclavian artery with respect to circumferential division. Origin from a vessel other than the subclavian was found in 8 (3.48%) cases. The location of the origin on the circumference of the subclavian artery was found to be cranial in 47% (33 cases), dorsal in 44% (31 cases), caudal in 6% (four cases), and ventral in 3% (two cases) [21].

Sastry *et al*. in their series of 19 formalin-fixed cadavers and ten formalin-fixed newborn foetuses found that in all instances the VA originated from the subclavian artery [29].

In this study we found VA origin from the subclavian artery in all of the cases. There are no previous data about VA origin from the subclavian artery in our country. In the study conducted by Zivadinovik *et al*. on variations of the aortic arch in 110 cases, the VA had its origin from aortic arch in 4 cases (3.64%). Three of the specimens had an aortic arch with four branches, with separate origin of the left VA between the left common carotid and left subclavian artery. One of the cases had an aortic arch with five branches, with a separate origin of the left vertebral artery as the fourth branch between the left common carotid and left subclavian artery [37].

Tortuosity

From the point of origin towards the foramen of the transverse processsus of the vertebrae, the VA may show different levels of tortuosity. A suggested congenital origin is difficult to assess since tortuosity has been shown to increase with age [34].

Clinically, tortuosity of the V1 segment does not have a haemodynamically significant consequence. However, loops of the vessel have been described to cause several problems. Loops of the V1 segment have been reported to cause radicular symptoms via nerve root compression. Cervical spinal fracture has been reported secondary to bony erosion from a V1 loop in contact. Also, a vertebral loop caused by displacement from a mass lesion in the scalenovertebral trigone may be compressed and lead to vertebrobasilar insufficiency. Symptomatic loops may be corrected by a bypass procedure. From a surgical standpoint it can be of great importance to know whether the VA is straight or tortuous in, for example, operative transposition of the VA to the carotid artery because of high-grade stenosis at its origin [14, 16, 21, 25, 34].

Matula *et al*. in their series found that in 52.9% of the cases the VA followed a non- tortuous path from the origin to the transverse foramen and in 47.2% followed a tortuous path. Furthermore, they have classified tortuosity according to the geometric plane as horizontal (44.9%), sagittal (33.7%), and frontal (21.4% cases) [21].

Curylo *et al.* found the VA course tortuous in 27% of their cases [6].

Sastry *et al*. observed a tortuous course in nine cases, or 23.7%, and in all cases the plane of the tortuosity was horizontal [29].

In the present study we found that the VA had a tortuous course in twelve cases, or 40%. A relatively high incidence of tortuosity of the first segment of the VAs could be explained by the mean age of our patients. There was a high statistically significant difference between the subjects with and without tortuosity according to age ($p < 0.01$).

Dimensions of the VA

The two VAs are usually different in calibre, with the left being more often larger or dominant [36]. Table 2 presents the results of the VA diameter obtained by different researchers.

Table 2

Diameter of the V1 segment of the vertebral artery reported in the literature

Author	Right	Left
Wollschlaeger	0.92–4.09 mm. (2.47 mm)	1.60–3.60 mm. (2.61 mm)
Matula	2.2–5.5 mm (4.1 mm)	3.3–6.2 mm. (5.0 mm)
Sastry	1.5-7.3 mm. (4.09 ± 1.78)	2.0–5.2 mm. (3.06 ± 1.25)
Huzijan	3.37 ± 0.60 mm.	3.55 ± 0.61 mm.

Congenital variations in the arrangement and size of the VA are frequently recognized, ranging from asymmetry of both VAs to severe hypoplasia or aplasia of the VA [27]. The VAs are commonly asymmetric. In 45% of people the LVA is larger, in 21% the RVA is larger, and in 24% the arteries are of equal size [22]. The study conducted by Karayenbuehel and Yasargil in 1957 demonstrated that the VA had different diameters in 74% of the population, a dominant LVA in 42%, and a dominant RVA in 32% of the population. In 26% of the patients the VAs had equal diameters [36]. Touboul *et al*. found a dominant LVA in 24 out of 50 cases (48%), and RVA in 7 out of 50 cases (14%) [33].

The percentage of VAH is in the range between 2 and 20% in the reports from different countries. There are various definitions for VAH. However, here we have to mention that there is no clear consensus about VA diameter value. Different authors give different values for VAH. Matula *et al.,* Sastry *et al*., Touboul *et al*. and Buckenham *et al.,* defined VAH as diameter < 3mm [4, 21, 29, 33]. A study conducted by Chen *et al*. reported that a VA diameter ≤ 2.5 mm is an ideal value to define VAH. Frequency of VAH defined as VA diameter < 2.2 mm was shown to be 11.6% in 447 patients examined by Jeng *et al*. Most of the studies conducted by different authors consider the value of ≤ 2 mm as the cut-off diameter for hypoplasia [18, 23, 27, 30, 35].

The reported frequency of VAH is dependent on the definition used for VAH. In the study conducted by Matula *et al*., a hypoplastic artery diameter < 3.5 mm was found in 16 (6.96 %) cases. Eleven (4.78%) cases of hypoplasia were found on the right side and five (2.17%) cases on the left side. Aplasia of the vessel was not found in the study [21].

Sastry *et al*. defined value < 3.5 mm, in five cases (three on the right and two on the left side) or in 13.16% VA was found to be hypoplastic [29].

Investigations for VAH conducted by Huzijan *et al.* showed 2.34% prevalence in the general population [17].

Karayenbuehel and Yasargil reported VAH in 25 (6.2%) cases on the RVA, in 18 (4.5%) cases on the LVA, and in 3 (0.75%) cases bilateral hypoplasia of the VA [36].

Traditionally, most physicians have regarded an asymmetric VA as a congenital variant or a clinically meaningless finding, unless vertebrobasilar insufficiency occurs. However, recent studies have regarded VAH as a risk factor for posterior circulation stroke. Studies conducted by Lovrencic-Huzijan *et al*. and Chuang *et al*. reported the important role of VAH in migraine pathogenesis. A higher frequency of hypoplastic vertebral arteries in migraine with aura was observed [8, 18].

VA diameters described by other authors are in agreement with the measurements we made. In our study the diameter of the VA at the origin was larger on the left side than on the right side, but with no statistical significance. We decided that the best cut-off diameter for the definition of VAH is ≤ 2 mm.

VAH was found in four cases (6.67%), one on the left and two on the right side. We found bilateral hypoplasia of the VAs in one patient.

The level of entry into the FT

The most important variation is the level of entrance of the VA into the transverse foramen. In normal conditions the level of entrance is at C6. But some percentage of VAs shows a variable level of entry into the transverse foramen. Matula *et al*. found a level of entry of the VA into the FT at C6 in 91% of their cases. They also found two cases of the VA entering at C4 and C5 and two cases of VA entering at the level of C7 [21]. Sastry *et al*. found that the VA entered the FT at the level of C6 in over 71% of the cases. The next highest frequency was C7 (18.42%) and in a small percentage of the cases at C5 (5.3%) C4 (2.6%) and C3 (2.6%) [29]. In the study conducted by Kajimoto *et al.* 37 of 40 dissected vertebral arteries entered the transverse foramen at the sixth cervical vertebra (C6-92.5%) and three of them through the C7 transverse foramen (7.5%) [11]. Heary *et al*. and Touboul *et al*. have reported VA entering into the FT at the level of C6 in 100% of their series [29, 33]. The level of entry described by other authors [33] coincides with the findings in this study; in 60 VAs of all the cases the VA entered the transverse foramen at the level of C6, without any variations.

In the case of entrance above C6, the VA runs anterior to the C6 transverse process, between the *longus colli* muscle, unprotected by bony structures and at risk of injury when the muscle is divided. Surgical exposure of the VA V1 segment is indicated for several reasons. The posterior stabilization of the cervical spine is commonly used when treating an unstable cervical spine resulting from trauma, neoplasia or degenerative conditions. These techniques do not always provide enough stability; sometimes they require subsequent additional anterior stabilization procedures. With the increased popularity of this technique, there has also been an increased incidence of complications such as VA injuries. Laceration of the VA is a most challenging surgical dilemma during anterior cervical spine surgery; gaining control of the massive hemorrhage from a ruptured VA is difficult and could possibly result in an uncertain neurological morbidity [4, 11, 29].

Conclusion

In conclusion, we found that the VA arises from the subclavian artery and enters the transverse foramen at the sixth cervical vertebrae in all patients. LVA was dominant or wider, and the RVA was more often hypoplastic than the left one. Both VAs showed a high incidence of tortuosity. Although anatomically interesting, an awareness of the VA anatomy and variations is Also clinically important. This knowledge may find clinical application in diagnostic procedures of pathology of the VA such as CT, MRI, angiographic and ultrasound investigations and treatment of VA pathology during surgical and endovascular procedures.

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Резиме

МОРФОЛОШКИ КАРАКТЕРИСТИКИ НА ПРВИОТ СЕГМЕНТ НА ’РБЕТНАТА АРТЕРИЈА

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Поради својата анатомска локализација ’рбетната артерија долго време беше запоставена во клиничките истражувања. Таа обезбедува околу 30% од артериската крв за мозокот. Целта на оваа студија беше да се прикажат морфолошките карактеристики на првиот сегмент на ’рбетната артерија, како и можните варијации и процентот во кој тие се јавуваат кај возрасната популација со помош на КТ ангиографија. Резултатите добиени од овој труд имаат апликативна примена во повеќе медицински гранки: во анатомијата во текот на едукативниот процес, во дијагностичката и интервентната радиологија и во повеќе области од хирургијата. За таа цел, во период од 6 месеци, беа испитани 30 пациенти со компјутеризирана томографска ангиографија. Резултатите од анализата покажаа дека кај сите 30 (100%) пациенти ’рбетната артерија води потекло од потклучната артерија. Дијаметарот на левата ’рбетна артерија се движеше од 1,6–5,2 мм или просечно 3,35 мм, додека, пак, дијаметарот на десната ’рбетна артерија изнесуваше од 1,64–5,4 мм или просечно 3,19 мм. Хипоплазија на крвниот сад беше утврдена кај 4 пациенти, додека аплазија на крвниот сад не беше пронајдена во оваа студија. Тортуозен курс на крвниот сад беше потврден кај 12 (40%) пациенти. Кај сите 30 (100%) пациенти ’рбетната артерија навлегуваше во отворот на напречниот израсток од шестиот вратен прешлен. Иако инциденцијата на анатомските варијации на ’рбетната артерија е редок наод, лекарите мора да бидат запознаени за можноста од нејзино постоење. Непознавањето на нормалниот курс и варијациите на ’рбетната артерија може да доведе до сериозни последици, какви што се јатрогените повреди за време на хируршките интервенции или погрешно протолкувани радиолошки наоди.

Клучни зборови: ’рбетна артерија, анатомија, варијации, потекло, хипоплазија, тортуозитет.

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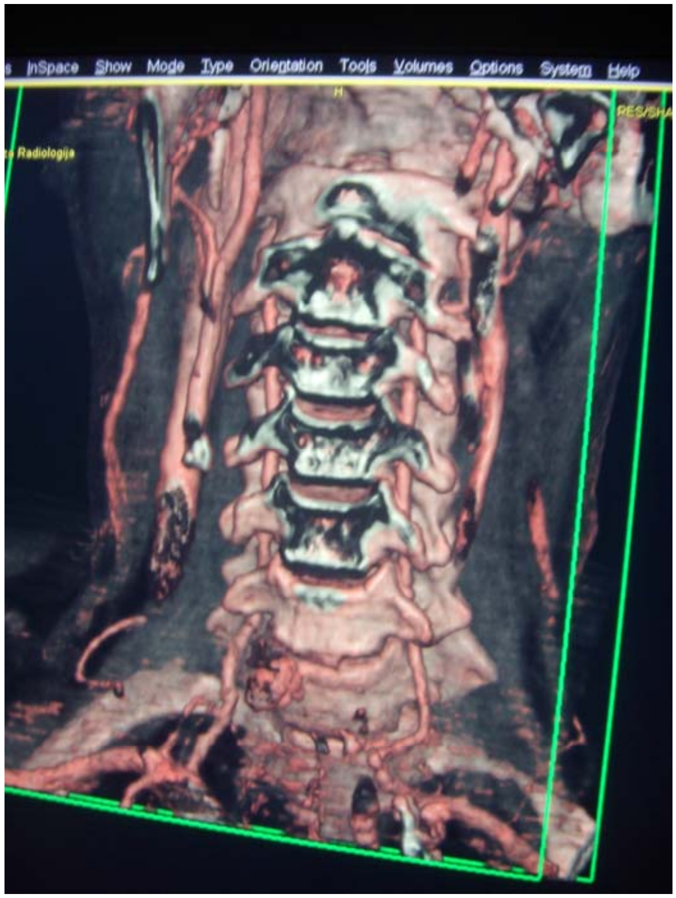
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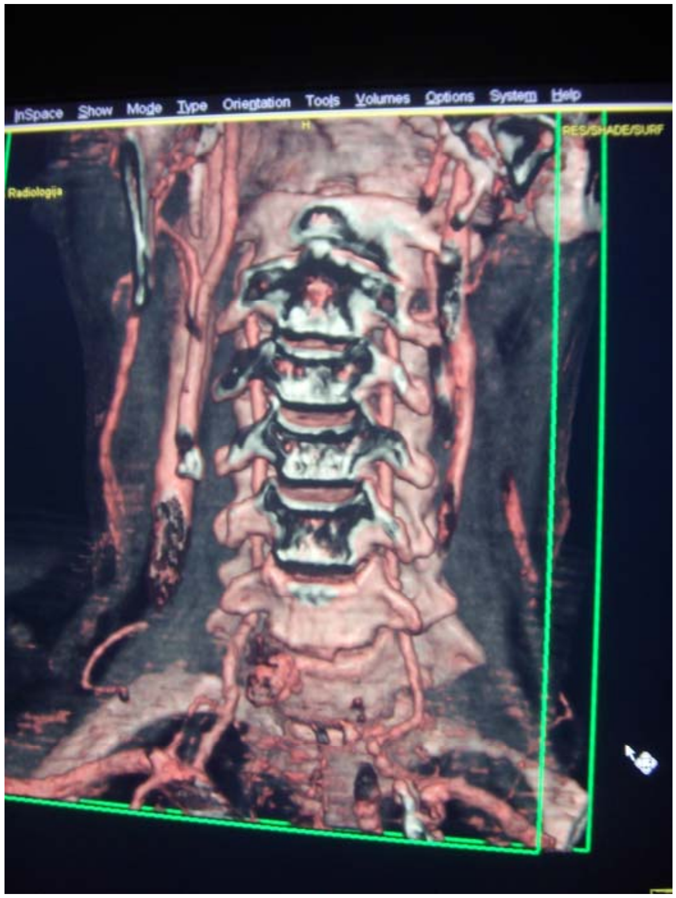
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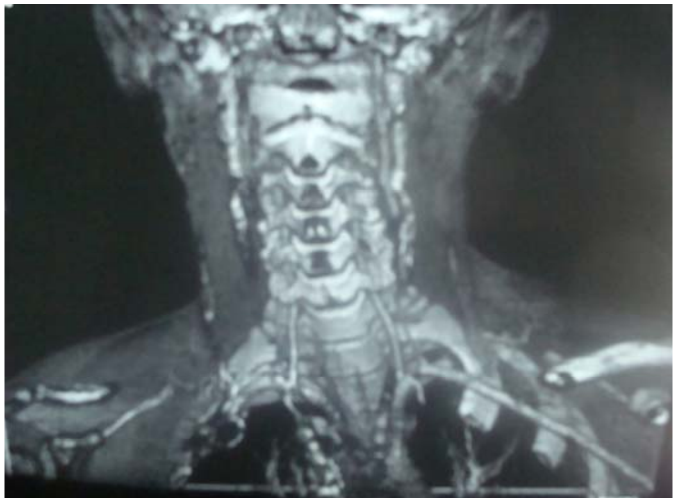

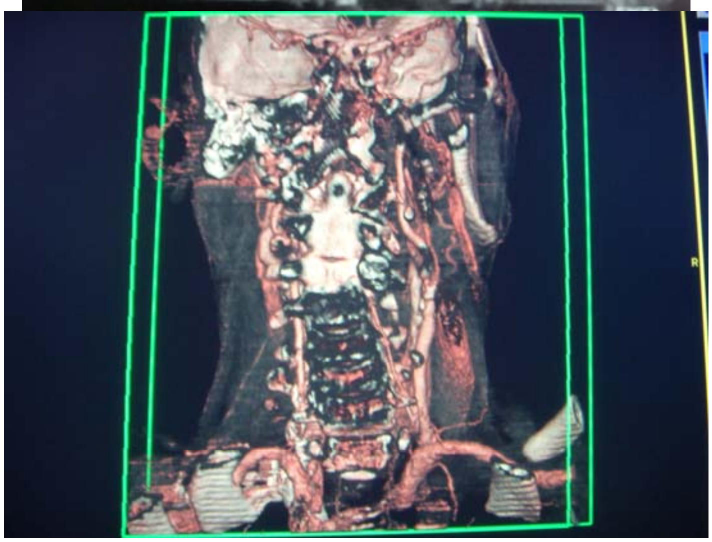
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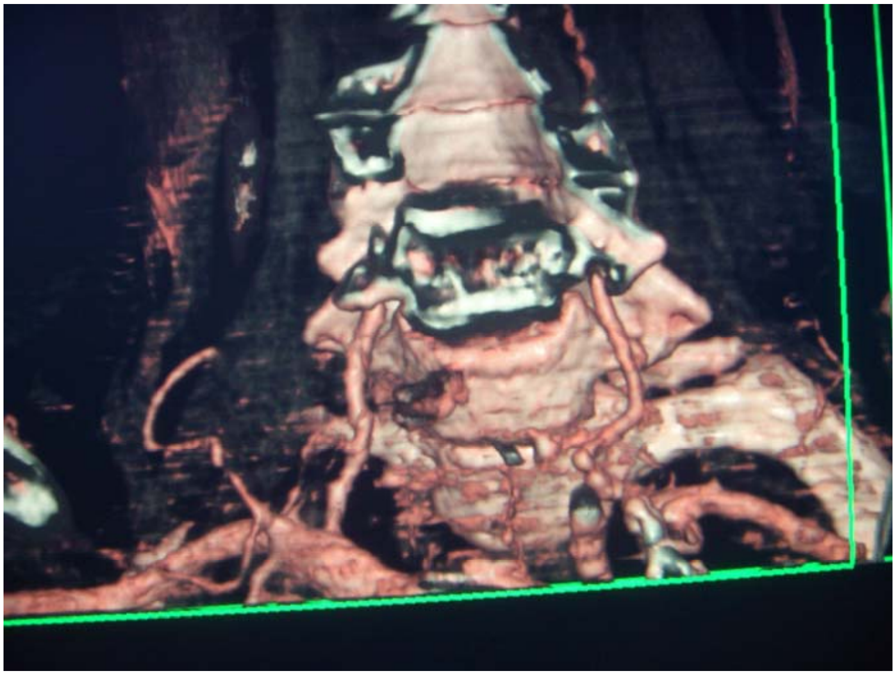

Figure 1 – Origin of the vertebral arteries from the subclavia
Figure 2 – Hypoplasia of the right vertebral artery
Figure 3 – A Straight course of the vertebral artery
Figure 3 – B Tortuous course of the vertebral artery
Figure 4 – Level of enterance of the vertebral arteries into the FT