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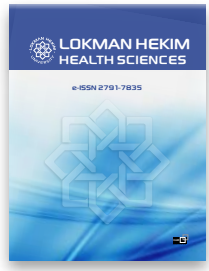

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ORIGINAL ARTICLE

Course Dependent Variation of the Vertebral Artery: A Computed Tomography Angiography Study*

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Abstract

Introduction: The primary objective of this study is to determine the variations exhibited by the vertebral artery in the Turkish population when it branches off from the subclavian artery and reaches the cervical vertebrae.

Methods: A retrospective review of computed tomography angiography images from the picture archiving and communication systems (PACS) archive system in the Department of Radiology, between 2000 and 2024, was performed. Digital imaging and communications in medicine (DICOM) format images selected from the PACS archive system according to the exclusion criteria were transferred to Radiant DICOM Viewer (Version 2023.1). The anatomical course of the vertebral artery (right and left) and variations during this course were recorded on the scanned images.

Results: A total of 258 individuals and 516 vertebral arteries (right and left) were analyzed. After analyzing 516 vertebral artery, 3 (0.58%) vertebral artery (1 left, 2 right) entered the transverse foramen at the grade of the 3rd cervical spine, 2 (0.39%) vertebral artery (2 right) at the grade of the 4th cervical spine, 13 (2.52%) vertebral artery (3 left, 10 right) at the grade of the 5th cervical spine, and 498 (96.51%) vertebral artery (254 left, 244 right) at the grade of the 6th cervical spine. As a result of our study, it was observed that the vertebral artery entered the transverse foramen of the 4th and 5th cervical spine, mainly the 3rd cervical spine, outside the normal anatomical course.

Discussion and Conclusion: We believe that our work will contribute to the fundamental anatomical knowledge and treatment approaches in this region.

Keywords: Anatomical variation; Cervical vertebra; Transverse foramen; Vertebral artery

The vertebral artery, which initiates from the subclavian artery, is examined by dividing it into four segments. The first segment (extraosseous, pre-vertebral ostial, pre-foraminal segment) branches off from the subclavian artery and extends to the transverse foramen of the 6th cervical spine, the second segment (transverse, transforaminal, foraminal segment) is from the transverse foramen of the 6th cervical spine to the transverse foramen of the 1st cervical spine. The third segment (suboccipital, atlantal segment) is the distal extracranial segment from the transverse foramen of the 1st cervical spine to the medial aspect of the condylus occipitalis, and the fourth segment (intradural segment) is s the segment that enters the cranium from below through the foramen magnum.[1,2] The vertebral

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artery on both sides then merge under the postpontine groove to form the arteria basilaris.[3]

The vertebral artery provides about 1/3 of the blood supply of the brain's and ensures the supply of the brain's vital parts. The vertebral artery is therefore of critical importance for the human body.[4]

Anatomically, the vertebral artery may have some variations in its origin and segments.[5,6] These variations related to the course of the vertebral artery are of great importance in terms of the operational course in invasive interventions in this region (screw applications for pedicle fractures, craniovertebral junction microsurgery, traumatic vertebral artery injury surgery, aneurysm surgery, spinal laryngeal surgery, thyroid gland surgery).[3,4,6–9] For example, during anterior cervical spine surgery, injury to the vertebral artery occurs at a rate of 0.1–0.5%. However, significant neurological deficits may result from such injury. Injury to the vertebral artery is a common occurrence during posterior cervical spine surgery. Therefore, the course and variations of the vertebral artery must be fully identified before surgery. Cervical pedicle screw vertebral fixation is an important procedure in traumatic, neoplastic, and degenerative diseases of the spine. However, injury to the vertebral artery is frequently encountered during this procedure. In addition to clinical procedures, vertebral damage can occur due to trauma to the head and neck region, which can lead to many clinical conditions, including subarachnoid hemorrhages.[10–13]

There are some variations according to the segment at which the vertebral artery goes into the transverse foramen of the vertebrae. Among these vertebrae, the cases in which the vertebral artery goes into at the grade of the 3rd cervical spine are <1%.[14–17]

Computed tomography (CT) angio images, which provide high-resolution images and allow the evaluation of calcification and peripheral structures in the vessels, are prominent in the imaging of vessels. Therefore, CT angio images are an excellent tool used routinely for vascular imaging.[9]

In recent years, CT angiography has become the gold standard in the investigation of variations. It is noteworthy that there are very limited studies in the literature evaluating vertebral artery variations in the Turkish population with this method, and the number of populations is also limited. The purpose of the study was to define the diversities of the vertebral artery during its course using CT angiography in the Turkish population and to demonstrate the importance of this condition clinically.

Materials and Methods

Study Place and Design

This study was carried out at the Department of Radiology. It was designed as retrospectively analyze CT angiography images. The study was approved by the decision of Karabük University Non-Interventional Local Ethics Committee dated 2024 and numbered 1975. The study was performed in accordance with the Declaration of Helsinki and relevant ethical standards.

A retrospective review of CT angiography images from the picture archiving and communication systems (PACS) archive system in the Department of Radiology, Karabük University Faculty of Medicine, was performed between 2000 and 2024. The inclusion criterion was defined as clear visibility along the course of the vertebral artery. Exclusion criteria were low image quality because of motion artefacts, vascular surgery in the neck and head region, spinal fractures, tumours, or interventional procedures. The system scanned the period between 2000 and 2024, but the images used after the exclusion criteria were applied were from the period between 2018 and 2024.

Digital imaging and communications in medicine (DICOM) format images selected from the PACS archive system according to the exclusion criteria were transferred to Radiant DICOM Viewer (Version 2023.1). The transferred images were converted into 3D using the 3D Volume Rendering console of the programme and examined for vertebral artery variation. The first examination was performed by a radiologist with at least 10 years of experience in the field, and the second examination was performed by an anatomist with at least 5 years of experience in the field.

Data frequency, intraclass correlation coefficient (ICC), and Chi-square test results were presented using the Statistical Package for the Social Sciences 21 software package, and $p<0.05$ were considered statistically significant.

Results

The study included the 258 individuals' images. A total of 516 vertebral arteries (right and left) were analyzed. Of these 516 vertebral arteries, 3 vertebral arteries were found to go into the transverse foramen at the grade of the 3rd cervical spine (Fig. 1).

Two vertebral arteries were found to go into the transverse foramen at the grade of the 4th cervical spine (Fig. 2).

Thirteen vertebral arteries were found to go into the transverse foramen at the grade of the 5th cervical spine (Fig. 3).

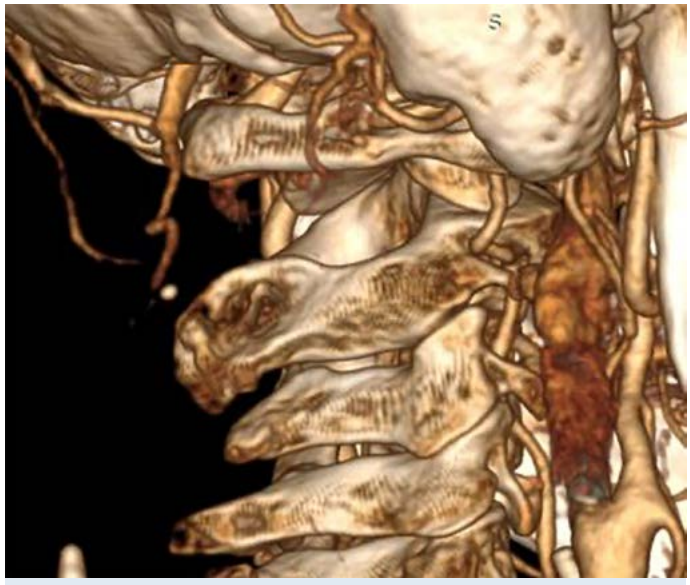

Figure 1. Entrance of the vertebral artery at the grade of the 3rd cervical spine.

Figure 2. Entrance of the vertebral artery at the grade of the 4th cervical spine.

The remaining 498 vertebral arteries were found to go into through the transverse foramen of the 6th cervical spine, which is the normal anatomical position.

The distribution of the variations on which side was also analyzed in the study. According to this distribution, two

Figure 3. Entrance of the vertebral artery at the grade of the 5th cervical spine.

(Female: 2) of the three vertebral arteries going into the transverse foramen from the 3rd cervical spine grade were on the right side and one (Male: 1) was on the left side. Two (Male:1, Female: 1) of the Two vertebral arteries going into the transverse foramen from the grade of the 4th cervical spine were on the right side. Of the 13 vertebral arteries going into the transverse foramen at the grade of the 5th cervical spine, 10 (Male: 4, Female: 6) were on the right side and 3 (Female: 3) were on the left side. The remaining 498 vertebral arteries entered the transverse foramen at the grade of the 6th cervical spine. Of these, 244 entered the transverse foramen from the right side and 254 from the left side (Fig. 4).

The results obtained by radiologists and anatomists specializing in the field were compared in the ICC test, and since the experts obtained the same results according to side and gender, the intraclass correlation was found to be 1.000, and the p-value was 0.000. The variations obtained were evaluated using the Chi-square test in terms of side and gender, and no significant results were obtained ($p>0.05$).

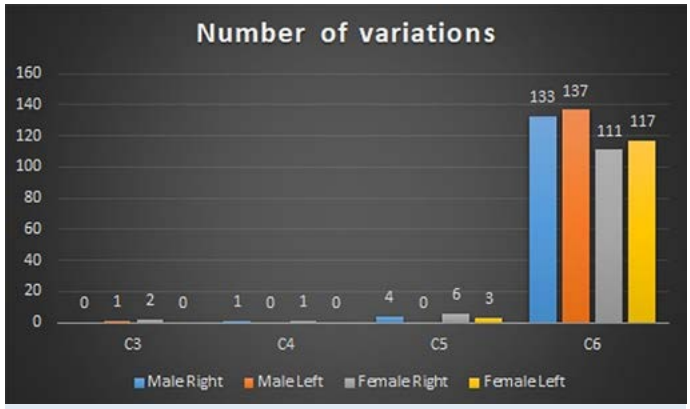

Figure 4. Classification of the degree to which the vertebral artery enters the transverse foramen according to the side of the cervical spine and gender.

Discussion

In this study, 0.58% of the vertebral artery entered from the 3rd cervical spine, 0.39% from the 4th cervical spine, 2.52% from the 5th cervical spine, and 96.51% from the transverse foramen of the 6th cervical spine.

The vertebral artery is a pair of arteries initiating from the subclavian artery, passing inside the transverse foramen of the cervical spine except the 7th cervical spine, going into the head through the foramen magnum, and forming the arteria basilaris.[18]

The vertebral artery is a vital vascular structure involved in the nutrition of the neck and head. Traumas in the vertebral artery may lead to visual impairment, paralysis, walking, speech, and eating disorders. Therefore, traumas occurring in these regions and incorrect interventions during surgical interventions are of great clinical importance.[4,8,9,19]

Vertebral artery variations are generally asymptomatic. In rare cases, vertebral artery variations may cause dizziness, ataxia during head rotation, vertebral artery dissection, and aneurysm. However, invasive procedures in this region may cause easy damage to this artery and lead to different clinical presentations.[20]

Although rare, vertebral artery injury may occur during anterior and posterior surgical procedures in the cervical region. In addition to being rare, when it does occur, it can result in permanent neurological damage and death.[13] Knowing the location of the vertebral artery is also critically important for surgical procedures, such as thyroidectomy, pharyngeal diverticulum excision, and esophageal surgery.[2] This situation demonstrates that knowledge of the anatomical structure and variations in this region is critically important.

To understand the embryological origin of the vertebral artery's variation, it is also necessary to have detailed knowledge about the branching pattern of the aortic arch. The aortic arch initially consists of and develops from six embryonic pairs. These embryonic arches then regress and form the large vessels in this region. During this regression, anatomical variations occur in this region. These variations in the aortic arch affect the formation of vertebral variations.[1,5]

In a study conducted by Uchino and colleagues, CT images of 2,287 individuals were retrospectively evaluated separately for the right and left vertebral arteries. As a result, 1.1% of vertebral arteries were on the right side, 0.7% on the left side at the 4th cervical vertebra, 4.4% on the right side, 4.9% on the left side at the 5th cervical vertebra, 93.8% on the right side and 93.0% on the left side at the 6th cervical vertebra, 0.6% on the right side and 1.2% on the left side at the 7th cervical vertebra level.[16]

In the study by Woraputtaporn et al.,[15] 266 cadavers were analysed, and the right and left vertebral arteries were considered separately. One of the 266 left vertebral arteries enters the transverse foramen at the level of the 4th cervical vertebra, 11 enter at the level of the 5th cervical vertebra, and 254 enter at the level of the 6th cervical vertebra. Of the 266 right vertebral arteries, 1 was found to enter the transverse foramen at the level of the 3rd cervical vertebra, 1 at the level of the 4th cervical vertebra, and 264 at the level of the 6th cervical vertebra.

Bruneau et al.[14] analysed 500 vertebral artery of 250 individuals and found that 0.2% of the vertebral artery entered the transverse foramen at the grade of the 3rd cervical spine, 1% at the grade of the 4th cervical spine, 5% at the grade of the 5th cervical spine, 93.0% at the grade of the 6th cervical spine and 0.8% at the grade of the 7th cervical spine. In a study by Hong et al.[21] 700 vertebral artery of 350 individuals were analysed by CT scan and it was reported that 1.6% of the vertebral artery entered the transverse foramen at the grade of the 4th cervical spine, 3.3% at the grade of the 5th cervical spine, 94.9% at the grade of the 6th cervical spine and 0.3% at the grade of the 7th cervical spine. In a study by Zibis et al.,[22] CT images of 50 individuals were retrospectively analysed and the grade at which the vertebral artery entered the transverse foramen was examined; as a result, it was observed that the vertebral artery entered at the grade of the 4th cervical spine in 2% of the individuals, the 5th cervical spine in 8%, the 6th cervical spine in 86%, and the 7th cervical spine in 4%.In a study by Wakao et al.[23] CT images of 919 individuals were analysed; 0.5% of the 1838 vertebral arteries entered the transverse foramen at the grade of the 4th cervical spine, 3.1% at the

grade of the 5th cervical spine, 95.6% at the grade of the 6th cervical spine, and 0.8% at the grade of the 7th cervical spine. In the study by Kim et al.,[17] 4414 vertebral arteries of 2207 patients were analysed, and as a result; One vertebral artery from the 3rd cervical spine grade, 52 vertebral arteries from the 4th cervical spine grade, 214 vertebral artery from the 5th cervical spine grade, 4128 vertebral artery from the 6th cervical spine grade, 19 vertebral artery from the 7th cervical spine grade into the transverse foramen. In a study by Eskander et al.[24] 500 vertebral artery of 250 individuals were analysed and it was observed that 1.8% of them entered the transverse foramen at the grade of the 4th cervical spine, 5.6% at the grade of the 5th cervical spine, 92% at the grade of the 6th cervical spine and 0.6% at the grade of the 7th cervical spine. The study by Tellioglu et al.[25] showed that 0.45% of the 218 vertebral arteries entered the transverse foramen at the grade of the 4th cervical spine, 1.84% at the grade of the 5th cervical spine, 95.87% at the grade of the 6th cervical spine, and 1.84% at the grade of the 7th cervical spine.

Limitations

The fact that the study could not be conducted in larger populations and did not include different ethnic groups can be stated as a limitation of the study. In future studies, these limitations can be addressed by repeating this study in larger populations and different ethnic groups.

Conclusion

In this study, we aimed to determine at which levels the vertebral artery can enter the transverse foramen in the Turkish population. According to the data obtained from the study, we found that the vertebral artery can enter the transverse foramen of the third vertebra, which is located much lower than the others, and can continue upward. We believe that specialists should consider these variations in vascular approaches, particularly in posterior screw applications during posterior and lateral approach surgeries and adapt the surgical procedure accordingly. Furthermore, our study will support future large-scale prevalence studies.

Ethics Committee Approval: The Karabük University Non-Interventional Local Ethics Committee granted approval for this study (date: 05.11.2024, number: 1975).

Informed Consent: This study is a retrospective study conducted using images scanned from the radiology archive system. Informed consent is not required.

Conflict of Interest: None declared.

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Authorship Contributions: Concept: YS, HŞE; Design: YS, HŞE; Supervision: YS; Resource: YS, NKK; Materials: YS, NKK; Data Collection or Processing: YS, HŞE, NKK; Analysis or Interpretation: YS, HŞE, NKK; Literature Search: YS, HŞE, ŞT; Writing: YS, HŞE, ŞT; Critical Review: YS.

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