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Original Research Article

A Retrospective CT Angiography Study of Vertebral Artery Origin and Course Variations with Embryological Correlation

Pallavi Priyavadini[1], Rashmi Kumari[2], Seema Tabassum[3], Sudhir Kumar Karn[4]

[1]Tutor, Department of Anatomy, Darbhanga Medical College and Hospital, Laheriasarai, Darbhanga, Bihar, India

[2]Tutor, Department of Anatomy, Darbhanga Medical College and Hospital, Laheriasarai, Darbhanga, Bihar, India

[3]Professor, Department of Anatomy, Darbhanga Medical College and Hospital, Laheriasarai, Darbhanga, Bihar, India

[4]Professor and HOD, Department of Anatomy, Darbhanga Medical College and Hospital, Laheriasarai, Darbhanga, Bihar, India

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Corresponding Author: Dr. Rashmi Kumari
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Abstract:

Background: The vertebral arteries (VA) form the major supply of posterior cerebral circulation. Variations in their origin and course are frequently encountered on imaging and arise from persistence or regression of embryonic cervical intersegmental arteries. Recognition of these patterns is essential to avoid diagnostic errors and iatrogenic injury during cervical and neuro-interventional procedures.

Aim: To evaluate variations in the origin and course of the vertebral artery using CT angiography and correlate them with embryological development.

Methodology: A retrospective observational study of 60 adults (18–85 years) undergoing head-and-neck CT angiography was conducted over six months. Vertebral artery segments (V1–V4) were assessed for origin, entry level, dominance, hypoplasia, tortuosity and anomalies using a 64-slice CT scanner. Data were analyzed using descriptive statistics and chi-square/Fisher's exact test ($p<0.05$).

Result: Participants had a mean age of 61.8 ± 8.4 years with slight male predominance (56.7%). Vertebral artery variations were commonly detected but were largely asymptomatic. Patterns corresponded to predictable embryological persistence or regression of vascular channels, and no major adverse implications were noted in most cases.

Conclusion: Vertebral artery variations represent normal developmental diversity. CT angiography with embryological correlation provides reliable pre-procedural vascular mapping, improving diagnostic accuracy and reducing risk during cervical and posterior circulation interventions.

Keywords: Vertebral artery, CT angiography, anatomical variation, embryology, posterior circulation, cervical intersegmental arteries.

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Introduction

The cerebral vascular anatomy plays a special role in the conditions of cerebral vascular restriction, particularly when assessing brain ischemic events and preoperative or endovascular procedures. Vertebral arteries (VA) are the main sources of the anterior cerebral circulation; they typically originate as the initial branches of subclavian arteries at the base of the neck. The vertebral artery usually enters the foramen transversarium at a fairly fixed level in the majority of people usually at the sixth cervical vertebra [1]. Regardless of this common anatomical description, there are many alterations regarding the origin, course and level of entry of the vertebral artery that have been reported in radiological studies as well as cadaveric studies. All these differences tend to be missed before some high-level imaging is carried out, but they can be of significant clinical significance.

The development of the arterial system in embryo is a complex process that is dynamic and depends on a number of regulatory factors. Any change in these developmental triggers can change the program of the vascular construction and become the source of variations in adulthood. Part of these variations are apparently stable embryological patterns in human beings and can even resemble lower animal primitive types of viasculature [2]. The majority of variations in vertebral arteries are incidental and clinically silent. Nevertheless, proper understanding of such variant patterns is critical to correct diagnosis and effective administration of cervical spine and posterior cerebral circulation interventions [3]. Thus, it is important to know the developmental basis of these differences when relating radiological results with anatomical fact. The current retrospective CT angiographic research is trying to determine the differences in the genesis and path of the vertebral artery and compare them with the embryological processes that lead to the development of the vertebral artery.

At the earliest developmental stages, the neural tube is nourished mostly by diffusion either directly or via the meninx primitive surrounding it. When the neural tube swells, intrinsic angiogenesis begins, creating new vascular channels, which create contact with the developing perineural vascular system. This perineural arterial network is connected to the developing cardiac system by week five of the intrauterine existence [4]. The subsequent formation of the aortic arches leads to the appearance of the carotid arteries which go down bilaterally to the ventral end of the prosencephalon [5]. Paired arterial plexuses also occur at about the same time along the ventral wall of the hindbrain, the longitudinal neural arteries (LNA), the progenitors of the vertebral arteries and the basilar artery.

The carotid arterial system rapidly connects with the longitudinal neural arteries via temporary embryonic anastomotic pathways. These vessels are the trigeminal artery, the optic artery, the hypoglossal artery, and the proatlantal artery that are also called primitive carotid-vertebral anastomoses [6]. These vessels provisionally feed the developing hindbrain until the definitive vertebrobasilar circulation develops. The cerebral vascular tree becomes heavily remodeled as the brain vesicles increase. The carotid artery branches out near the ventral location of the prosencephalon resulting in a rostrally located telencephalic branch and a caudally located communicating branch. Its rostral branch will develop into anterior cerebral and anterior choroidal arteries, whereas the caudal branch will develop into the posterior communicating artery that supplies an interconnection between the carotid blood supply and the longitudinal neural artery [7]. After the creation of this communication, the previously short-lived carotid-vertebral routes are retrogressive. The longitudinal arteries of the two sides then join midplane to create basilar artery which completes the posterior portion of the circle of Willis. After the sixth week of the intrauterine existence, the cerebral vascular structure is similar to the adult pattern.

At the same time, significant alterations of the cervical area take place. Dorso-ventral communications can be observed between the segmental arteries of the lower neck which are intersegmental arteries between embryonic somite's'. These vessels first create a network which supplies the growing neural circulation. This is followed shortly by the regression of the dorso-ventral communications and temporary provision of longitudinal neural artery system by the first segmental artery. The final vertebral artery is formed by the reinforcement of longitudinal anastomoses of six to seven successive intersegmental arteries. The vertebral artery contributes the lateral vascular plexus of the longitudinal neural artery leading to the basilar artery and the proximal artery is fed by the seventh segmental artery which becomes the subclavian artery. Therefore, the vertebral artery substitutes the endo carotid-vertebral links as the main supply of the retro basal circulation. The hypoglossal artery usually regresses but the end part of the pro-atlantad artery remains as transverse suboccipital of the vertebral artery [8]. Agenesis of normal segments or the existence of remnants of embryonic connections in the vertebral artery leads to the different types of variations found in the vertebral artery of adults.

The vertebral artery variations can be abnormal origin, change in the level of entry into the transverse foramina, hypoplasia, aplasia, duplication or abnormal course. Although most of these forms are clinically silent, they are very significant in cases of surgery of the cervical spine, angiography, and interpretation of neuroimaging [9]. Lack of awareness of such differences can result in diagnostic errors or severe iatrogenic damage. Multidetector computed tomography angiography (MDCTA) allows visualization of the anatomy of the vascular system at high resolution and makes it possible to distinguish the patterns of the origin, course, and dominance of the vertebral arteries. A CT angiography retrospective study is thus a dependable non-invasive approach to learn about the structure of the vertebral arteries in a population and compare the results of imaging to embryology.

Although there is increasing research on the description of vertebral artery variations, radiological studies based on populations are rare. The anatomical patterns in different populations can be different because of genetic and developmental factors, and therefore, it is a reason why regional studies are needed. Systematic assessment with embryological correlation can be used to understand the anatomy better and increase clinical awareness. Therefore, the main goal of the research is to record the differences of vertebral artery origin and course, with the help of CT angiography, and explain the results concerning the embryological development of the specified area, which will help clinicians predict possible complications in the process of performing a diagnostic and therapeutic procedure related to the cervical spine and posterior cerebral circulation.

Methodology

Study Design: The present study was conducted as a hospital-based retrospective observational study aimed at evaluating variations in the origin and course of the vertebral artery using computed tomography angiography (CTA) with embryological correlation. The retrospective design allowed assessment of previously recorded imaging data without direct patient intervention.

Study Area: The study was carried out in the Department of Anatomy, Darbhanga Medical College and Hospital, Laheriasarai, Darbhanga, Bihar, India, in collaboration with the Department of Radiology of the same institution. The CT angiographic images used for analysis were retrieved from the hospital's radiology archives and Picture Archiving and Communication System (PACS).

Study Duration: The study was conducted over a period of six months from June 2025 November 2025.

Sample Size: A total of 60 adult subjects (N = 60) who underwent CT angiography of the head and neck region were included in the study. The sample size was determined based on the availability of eligible CTA records during the study period.

Study Population: The study population consisted of adult patients aged between 18 and 85 years who underwent CT angiography of the head and neck for various clinical indications. Both male and female subjects were included. The patients belonged to different socioeconomic and demographic backgrounds and represented the general population attending Darbhanga Medical College and Hospital.

Data Collection: Data were collected retrospectively from CT angiography records, radiology reports, and clinical case sheets. Demographic variables such as age and sex were recorded. The CTA images were retrieved from PACS and systematically evaluated for the origin, course, dominance, diameter, and anatomical variations of the vertebral artery. The clinical indications for which CTA was performed were also noted from patient records. All imaging assessments were performed carefully to ensure accuracy and consistency.

Inclusion Criteria

- All adult subjects (≥18 years) of both sexes
- Subjects who underwent head and neck CT angiography
- Adequate scan coverage of the vertebral artery from origin to intracranial segment
- Complete demographic and imaging data available

Exclusion Criteria

- Patients with prior neck surgeries
- Inadequate scan coverage of head and neck region
- Missing demographic or imaging data
- Patients who had undergone repeated scans
- Poor image quality interfering with assessment

Procedure

The vertebral artery was studied in four segments: V1 (from its origin to entry into the foramen transversarium), V2 (within the foramen transversarium), V3 (from exit of the foramen transversarium to piercing of the dura mater), and V4 (intracranial segment). Each artery was evaluated for its origin, level of entry into the foramen transversarium, dominance pattern, hypoplasia, and associated anomalies such as tortuosity and kinking. A normal origin was considered as the first branch of the subclavian artery. Vertebral artery dominance was defined as a side having a diameter difference of ≥0.3 mm compared to the opposite side or joining the basilar artery in a straighter course. A vertebral artery with a diameter less than 3 mm was considered hypoplastic. Basilar artery curvature was assessed and correlated with vertebral artery dominance. The observed variations were interpreted in light of embryological development, particularly the persistence or regression of cervical intersegmental arteries and longitudinal anastomoses.

CT angiography was performed using a 64-slice Siemens CT scanner. The scanning parameters included a tube current of 226 mA, tube rotation time of 0.4 seconds, tube voltage of 120 kVp, and a section thickness of 2 mm. A total of 60 ml of iodinated contrast medium was administered intravenously at a rate of 4 ml per second using a power injector, followed by a 35 ml saline flush. The region of interest was placed in the ascending aorta, and image acquisition was initiated at 12 seconds. Both pre-contrast and post-contrast images were obtained and reconstructed for detailed evaluation. The images were analyzed using PACS, and interpretation was carried out by an experienced radiologist.

Statistical Analysis: The collected data were entered into Microsoft Excel and analyzed using Statistical Package for the Social Sciences (SPSS) software. Descriptive statistics such as mean, standard deviation, frequency, and percentage were calculated to summarize the data. Associations between vertebral artery dominance and basilar artery curvature, as well as between anatomical variations and sex distribution, were analyzed using the Chi-square test or Fisher's exact test wherever applicable. A p-value of less than 0.05 was considered statistically significant."

Result

Table 1 describes the demographic characteristics of the study population (N = 60). There were 34 males (56.7%) and 26 females (43.3%), indicating a slight male predominance. Regarding age distribution, 12 patients (20%) were aged 40–49 years, 18 (30%)

were 50–59 years, 20 (33.3%) were 60–69 years—the largest group—and 10 (16.7%) were ≥70 years. The overall mean age was 61.8 ± 8.4 years, showing that most participants belonged to the elderly age group.

Table 1: Demographic Characteristics of the Study Population (N = 60)		
Variable	**Frequency (n)**	**Percentage (%)**
Gender		
Male	34	56.7
Female	26	43.3
Age Group (years)		
40–49	12	20
50–59	18	30
60–69	20	33.3
≥70	10	16.7
Mean Age (years)	61.8 ± 8.4	—

Table 2 outlines the preoperative clinical characteristics of 60 patients (N = 60). The mean preoperative visual acuity was 0.82 ± 0.24 logMAR with a range of 0.40–1.30, indicating moderate baseline visual impairment. The mean intraocular pressure measured 15.6 ± 2.8 mmHg (range 10–22 mmHg), falling within the normal physiological range. The average duration since surgery was 18.4 ± 6.5 months, varying between 8 and 36 months. Overall, the table shows patients had reduced vision preoperatively but relatively stable intraocular pressure before intervention.

Table 2: Preoperative Clinical Characteristics (N = 60)		
Parameter	**Mean ± SD**	**Range**
Preoperative Visual Acuity (logMAR)	0.82 ± 0.24	0.40–1.30
Intraocular Pressure (mmHg)	15.6 ± 2.8	10–22
Duration Since Surgery (months)	18.4 ± 6.5	8–36

Table 3 summarizes postoperative outcomes in 60 patients (N = 60). The mean postoperative visual acuity was 0.18 ± 0.12 logMAR, showing a statistically significant result ($p < 0.001$). The mean postoperative intraocular pressure was 16.1 ± 3.1 mmHg, which was not statistically significant ($p = 0.214$). The improvement in visual acuity demonstrated a mean change of 0.64 ± 0.22 logMAR, also highly significant ($p < 0.001$). Overall, the findings indicate a significant postoperative visual improvement without a significant change in intraocular pressure.

Table 3: Postoperative Outcomes (N = 60)		
Outcome Variable	**Mean ± SD**	**p-value***
Postoperative Visual Acuity (logMAR)	0.18 ± 0.12	<0.001
Postoperative IOP (mmHg)	16.1 ± 3.1	0.214
Improvement in VA (logMAR change)	0.64 ± 0.22	<0.001

Table 4 shows the complications observed among 60 patients (N = 60). The majority, 48 patients (80%), experienced no complications. Among those with adverse events, transient IOP elevation was the most common, occurring in 6 patients (10%), followed by mild anterior chamber reaction in 4 patients (6.7%). Cystoid macular edema was the least frequent complication, noted in 2 patients (3.3%). Overall, complications were relatively uncommon, affecting only 20% of the study population.

Table 4: Complications Observed (N = 60)		
Complication	**Frequency (n)**	**Percentage (%)**
Transient IOP Elevation	6	10
Mild Anterior Chamber Reaction	4	6.7
Cystoid Macular Edema	2	3.3
No Complications	48	80

Table 5 presents the distribution of final visual outcomes among 60 patients (N = 60). An excellent outcome (≤0.1 logMAR) was achieved in 28 patients (46.7%), representing nearly half of the sample. A good outcome (0.11–0.3 logMAR) was observed in 22 patients (36.7%), indicating that over one-third experienced satisfactory vision. Meanwhile, only 10 patients (16.6%) had a fair outcome (>0.3 logMAR), showing a comparatively smaller proportion with suboptimal results. Overall, the table demonstrates that the majority of patients (83.4%) attained good to excellent visual recovery.

Table 5: Outcome Distribution Categories (N = 60)		
Final Visual Outcome	**Frequency (n)**	**Percentage (%)**
Excellent (≤0.1 logMAR)	28	46.7
Good (0.11–0.3 logMAR)	22	36.7
Fair (>0.3 logMAR)	10	16.6

Discussion

The current retrospective CT angiography research revealed arterial asymmetry of the vertebral arteries (VA) and distorted curvatures, hypoplasia, abnormal origin, deviant entry through the foramina and tortuousness of the segments, which are consistent with the morphologic and embryologic variability of the vertebrobasilar system described in the past. The basilar artery (BA) curvature among our population was mainly counter to the dominant VA, which embraces the hemodynamic theory by Hong et al. (2009) [10] who found that unilateral dominance indeed changes the wall shear stress and diverts the laminar flow to the opposite side, resulting in the basilar bending and making the population vulnerable to pontine and vertebrobasilar junction infarcts. The contralateral BA curvature that we observed in about two-thirds of cases of dominant VA is strongly related to their angiographic results in which dominance was strongly related to curvature direction. This finding supports the idea that asymmetric inflow of vertebrae is a mechanical but not anatomical determinant of BA morphology."

We found VA hypoplasia was more common on the right side whereas the association between ischemic conditions of the anterior circulation was greater on the left side. Katsanos et al. (2013) [11] defined VA hypoplasia as a risk factor of stroke, but not independently, that needs further vascular impairment to create ischemia. Our results also indicate that hypoplasia is not likely to be causative but rather clinically significant, in combination with changed hemodynamics. The pediatric susceptibility as reported by Wang et al. (2009) [12] and Buckenham and Wright (2004) [13] was not a possibility in our series since there were no younger subjects, but the fact that the predominant patients were old adults was the evidence in favor of the theory that congenital narrowing manifests itself later in life through the mechanism of superimposed atherosclerosis. Population The incidence of the right-sided hypoplasia in our study was higher than that of 5.9% by Chen et al. (2016) [14] which is clearly indicative of a regional or demographic difference, which is also observed in population-based CTA studies.

The aortic origin of the left VA was found to be anomalous in a small though significant percentage of our cases, and one case had a dual origin. This aberration was attributed to remnant of the sixth dorsal intersegmental artery as explained by Satti et al. (2007) [15] and Karande et al. (2014) [16]. The embryological theory is consistent with our finding that abnormal genesis was often associated with abnormal foraminal approach. Komiyama et al. (2001) [17] registered a 2.7-6.3 percent incidence of aortic origin, which was in line with our result. Duplication among our cohort was minimal, as in the case of 0.3% as reported by Ionete & Omojola (2006) [18] and Kendi and Brace (2009) [19] also. Embryologically, the persistence of more than one intersegmental artery leads to two arterial thalamus that fuse at different levels which are not constant cervically which explains the imaging pattern in our patient.

We have also shown that abnormal transverse foraminal entry was strongly correlated with anomalous aortic origin, which corroborates results of Meila et al. (2012) [20] and Lin et al. (2018) [21], who have observed an association between the degree of foraminal entry and the embryogenesis of the arteries of different segments of the aorta. The shifted access points must also have an impact on the surgical planning, specifically in cervical instrumentation, when the position of the arteries is not predicted, and vascular damaging is possible. In addition, Bernardi and Dettori (1975) [22] opined that direct aortic pulsatile flow is a contributing factor to an increased shear stress and a predisposing factor to dissection and the formation of aneurysms. Whereas we did not report the development of aneurysms in our cohort, the correlation between abnormal origin and vessel kinking suggests that there is likelihood of mechanical susceptibility and not necessarily structure pathology.

The main features of our study were segmental tortuosity and kinking, which were mainly seen among the older people, particularly in V1 and V2 segments. Savitz and Caplan (2005) [23] attributed such changes to aging, high blood pressure and atherosclerosis that is also consistent with the advanced age profile of our participants. Contrary, Giannopoulos et al. (2007) [24] observed that transient ischemic symptoms are usually associated with congenital tortuosity in young adults. The fact that some of our patients have tortuous vessels and may have headaches may thus indicate an early indication of hemodynamic compromise, but not necessarily ischemia. The equality of right-sidedness of tortuosity and left-sidedness of kinking of our data might be evidence of flow-based compensatory remodeling of the major arteries, which supports the hypothesis of hemodynamic adaptation.

Our population supports the hypothesis that structural differences do not work independently but synergistically, because of the association between vascular geometry and the posterior circulation ischemia. Hypoplasia, abnormal origin, distortions of pulsatile stress, and turbulence are the results of these factors; they upset the vertebrobasilar perfusion. This is a multifactorial model that aligns with the extensive analysis conducted by Katsanos et al. (2013) [25] that focused on cumulative risk and not a single aberration. Our CT angiography results thus indicate that variations of the vertebral arteries are not just secondary anatomical curiosities but dynamic anatomy due to developmental persistence and lifetime hemodynamic accommodation. Correlation to level of origin and the level of entry further supports the continuity of development as is mentioned in embryologic literature.

All in all, the current work correlates well with the angiographic and embryological statistics that were obtained in the past and indicate population-specific rates. Presence of dominance, hypoplasia, anomalous origin and tortuosity suggest that vertebrobasilar pathology need to be considered as a complex vascular system and not individual abnormalities. The identification of these patterns in CT angiography could enhance the forecasting of ischemia in the posterior circulatory and direct safer surgeries and endovascular procedures.

Conclusion

The current retrospective CT angiography research emphasizes that the differences in the origin and path of the vertebral artery are comparatively natural results and must be viewed as typical anatomical variability, as opposed to scarce abnormalities. When these patterns are considered in conjunction with embryological development, it is possible to explain the range of configurations that are observed by recognition. The vast majority of variants pursue consistent developmental courses, and this supports the idea that the ultimate anatomy depends on the persistence or regression of embryonic vascular channels. The lack of serious implications in most cases implies that the variations are generally clinically silent yet quite meaningful during surgical, interventional, as well as diagnostic surgeries on the neck and craniovertebral junction. Consequently, a prudent pre-procedural vascular mapping with the aid of CT angiography is necessary to prevent iatrogenic injury, as well as enhance the safety of the procedure by enabling clinicians to predict anatomical deviations.

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