Original Article

Prevalence and Patterns of Vascular Anatomical Variations: A Retrospective Anatomical Audit

Shaily Verma[1], Prateek Shrivastava[1], V.D Ashok Patarlapalli[1]

[1]Assistant Professor, Department of Anatomy, TMMC & RC, Teerthanker Mahaveer University, Moradabad, India.

Abstract

Background: Vascular anatomy variations are normal deviations of classical arterial branching patterns and can have a significant impact on surgical, interventional, and radiological surgery. Modern methods of imaging allow the accurate detection of these variants, but the prevalence and morphological pattern are variable based on population. The aim is to define the prevalence and morphology of the vascular anatomy variations by conducting a retrospective radiological audit as well as to examine their correlation with demographic factors. **Material and Methods:** 250 contrasting CT and MR angiographic studies against adults (>18 years) were involved in this retrospective observational study. The vascular pattern of major arteries was assessed, and these were upper limb arteries, aortic arch, and its branches, abdominal aorta and major branches, renal arteries, and selected cerebral vessels. The differences were classified according to origin, pattern of branching and structure. The Chi-square test was used to perform a comparison of descriptive statistics, associations with age, and sex ($p < 0.05$ was significant). **Results:** Vascular anatomical anomalies were found in 162/250 cases (64.8%). The highest proportion of variations was registered in the upper limb arterial system (29.6%), abdominal aortic branches (23.5%), aortic arch branches (19.8%), renal arteries (17.9%), and cerebral arteries (9.3%). The most common morphological pattern was an aberrant origin (33.3%) and accessory vessels (25.3%). Despite a higher occurrence among males and middle-aged individuals, vascular variations showed no statistically significant relationship with demographic factors ($p > 0.05$). Furthermore, single variations were more prevalent than the presence of multiple simultaneous anomalies. **Conclusion:** Vascular anatomical variability is frequent and mostly relates to the abdominal and upper limb arteries. It is important to identify these patterns during the complex imaging procedure before the start of operations in order to reduce the risk during surgeries and maximize the clinical outcome. An anatomical audit that is undertaken retrospectively gives useful epidemiological information that enhances surgical plan and interventional safety measures.

Keywords: Vascular anatomical variations, arterial branching patterns, aberrant origin, accessory vessels, computed tomography angiography.

Received: 18 February 2026 **Revised: 09 March 2026** **Accepted: 25 March 2026** **Published: 24 April 2026**

Introduction

Anatomical variations of the human vascular system represent naturally occurring deviations from the classical descriptions of vessel origin, course, branching, and termination. These differences, which are usually asymptomatic, have serious clinical and surgical consequences, and they involve the interpretation of the diagnosis, a plan of intervention, access to the blood vessels, and the results of the intervention, both open and endovascular.[1] Iatrogenic injuries, optimal surgical approach, and patient safety should be minimized by considering such variations.

The occurrence of the vascular anatomical variants is diverse across the arterial and different venous territories. To illustrate this, analysis of the brachial artery, a large branch of the upper limb, indicates that about 10% of people will have some form of deviation of their origin or branching path, with some of the differences being commonly seen in the number of brachioradial arteries and superficial brachial arteries; it is also important to note that these variations are known to be frequent during orthopaedic and reconstructive surgeries.[2] Equally, systematic reviews of the circle of Willis, which is a key cerebral collateral area, indicate that over half of the general population has some amount of anatomical variability especially in the posterior communicating arteries that may affect cerebral hemodynamics and predisposition to cerebral vascular complications.[3]

There is also significant variability in the vertebral artery, where in particular, the suboccipital (V3) section shows much greater variability; large cohort studies indicate persistent embryologic origin, including the first intersegmental artery and extradural anterior inferior cerebellar artery origin, in only a small but clinically significant proportion of the population (around 1-2%), hence variant awareness is of importance in neurosurgical and radiologic practice.[4] Similarly, imaging studies and other reports have reported divergences in renal arteries, replaced

Address for correspondence: Dr. V.D Ashok Patarlapalli, Assistant Professor, Department of Anatomy, TMMC & RC, Teerthanker Mahaveer University, Moradabad, India.
E-mail: drashokkumarp@gmail.com

DOI:
10.21276/amit.2026.v13.i1.609

How to cite this article: Verma S, Shrivastava P, Patarlapalli VDA. Prevalence and Patterns of Vascular Anatomical Variations: A Retrospective Anatomical Audit. Acta Med Int. 2026;13(1):1120-1124.

hepatic arteries, and atypical celiac trunks, which have been associated with higher operative complexity in laparoscopic and minimally invasive surgeries.[5]

Outside arterial systems, there are also venous and thoracic vascular differences, which create clinical issues. The patterns of the pulmonary vascular and its abnormalities affect segmental resections, imaging reconstruction and uncommon venous anomalies can cause difficulty in interventions like central lines or use of a vena cava filter.[6] Also, case series still present hitherto-not-recorded mixes of upper limbs and aortic arch types, highlighting the vast range of human vascular variability and the urge to conduct systematics audit.[7]

Although there is increasing literature, there is still heterogeneity in the prevalence and patterns of all reports across populations, and this has always been so with the methodology, imaging modalities and sample sizes varying. The gaps in the knowledge can be addressed with detailed retrospective anatomical audits using radiologic and cadaveric data as well, these provide a comprehensive prevalence estimate and help disclose clinically relevant patterns in a specific population.

This paper will provide a retrospective anatomical audit of vascular variations, including the patterns and prevalence of such variations between various vascular territories. The results of this study will contribute to anatomy databases and help clinicians in evaluating the anatomy before surgery, planning, and decrease the number of procedural complications related to vascular malformation.

Materials and Methods

This retrospective observational study was conducted in the Department of Anatomy in collaboration with the Department of Radiodiagnosis at Teerthanker Mahaveer Medical College and Hospital, Moradabad. Archived records of radiological imaging were utilised in the audit, and this period was defined (January 2021 to December 2024). Ethical approval was taken in the form of institutional approval before the data collection process.

Population of the study and Inclusion criteria: Contrast-enhanced computed tomography (CECT) and magnetic resonance angiography (MRA) images of adult patients (>18 years) were evaluated. The inclusion criteria were imaging studies that had adequate vascular visualization and full demographic information. Patients that had been previously operated on the vascular and those with vascular trauma, congenital vascular malformations, and poor-quality images were excluded.

Measurement of Vascular Change and Data Collection: The data were obtained by accessing institutional Picture Archiving and Communication System (PACS) using imaging data. The key arterial territories assessed were the upper limbs arteries, arch of the aorta and its branches, abdominal arteries and its major branches, renal arteries and selected cerebral vessels.

The vascular anatomical variations were determined by the variations of the normal systemic descriptions. The variations were classified based on origin, course, and bifurcation as well as termination. Two senior radiologists and anatomists reviewed each case independently to ensure that the diagnosis was done effectively. Dissenting and agreed points were settled together.

Statistical Analysis: Data were measured in an organized database and processed with the help of the relevant statistical package (SPSS version26). Each vascular variation was determined as a percentage of the overall number of samples. The summary of the findings was given in descriptive statistics, frequencies, and proportions. When needed, the relationships between vascular changes and demographics (age and sex) were compared via Chi-square test with $p < 0.05$ being a statistically significant value.

Results

The retrospective audit covered 250 radiological cases. A proportion of 162 cases (64.8) of them exhibited any vascular anatomical variation.

The population under the study was 140 males (56%) and 110 females (44%). Most patients were between 31-45 years (34%), 46-60 years (28%), 18-30 years (24%) and above 60 years (14%) (Table 1). Of 162 previously reported vascular variations, the upper limb arterial system was the most popular territory (29.6%), then abdominal aortic branches (23.5%), then aortic arch and aortic branches (19.8%), renal arteries (17.9%), and cerebral arteries (9.3%) (Table 3).

The most frequent patterns of variations of morphological variants according to morphological classification were aberrant origin (33.3%), accessory vessels (25.3%), early branching (17.3%), common trunk formation (13.6%), and hypoplasia/aplasia (10.5%) (Table 4). Vascular differences were found in 96 males (68.6) and 66 females (60.0%). Comparatively high prevalence was observed in males (Table 2).

Graph 1 illustrates the prevalence of the variations in the vasculature as per different age groups. The most prevalence was noted in the group 46-60 years group (71.4%), 31-45 years group (68.2), >60 years group (62.9), and 18-30 years group (53.3). This shows a trend of more vascular variations to be detected on middle-aged people. Graph 2 depicts the illustration of the variation complexity distribution. Most patients had one vascular variation (72.8%), 27.2% had more than one variant of vascular variation indicating that isolated anomalies are prevalent compared to combined patterns.

Table 1: Age-wise Distribution and Association with Vascular Variations

Age Group	Total Cases (n)	Cases with Variation (n)	Cases without Variation (n)	Prevalence (%)	Chi-square (χ^2)	Degrees of freedom (df)	p-value
18–30 yrs	60	32	28	53.3	5.87	3	0.118
31–45 yrs	85	58	27	68.2			
46–60 yrs	70	50	20	71.4			
>60 yrs	35	22	13	62.9			

Table 2: Sex-wise Association with Vascular Variations

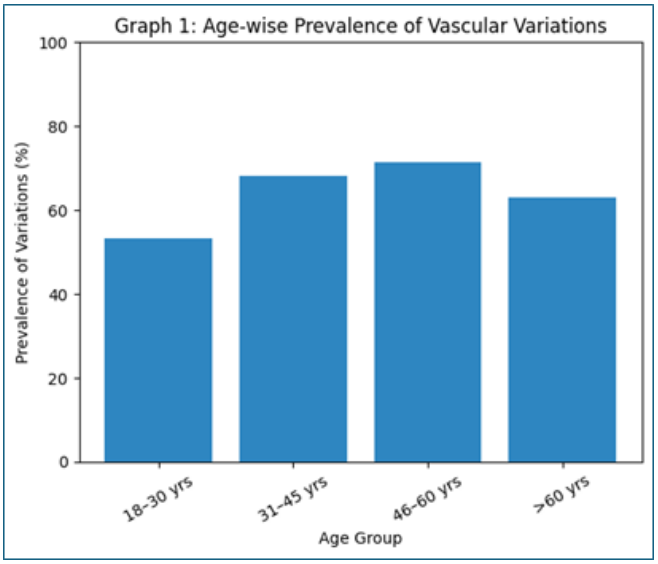
Sex	Total (n)	With Variation (n)	Without Variation (n)	Prevalence (%)	Chi-square (χ^2)	Degrees of freedom (df)	p-value
Male	140	96	44	68.6	1.97	1	0.16
Female	110	66	44	60.0			

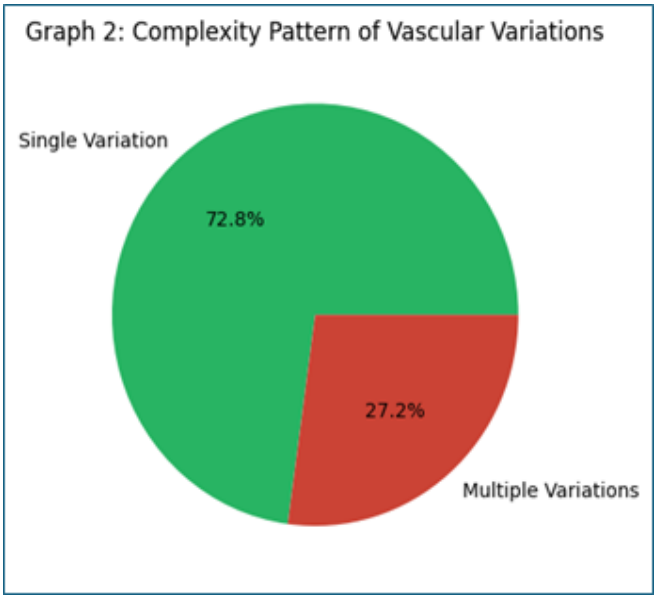
Table 3: Distribution of Vascular Variations by Anatomical Territory

Anatomical Territory	Number of Variations (n)	Percentage of Total Variations (%)
Upper Limb Arteries	48	29.6
Aortic Arch & Branches	32	19.8
Abdominal Aorta & Branches	38	23.5
Renal Arteries	29	17.9
Cerebral Arteries	15	9.3

Table 4: Morphological Classification of Vascular Variations

Morphological Pattern	Frequency (n)	Percentage (%)
Aberrant Origin	54	33.3
Accessory Vessel	41	25.3
Early Branching	28	17.3
Common Trunk Formation	22	13.6
Hypoplasia/Aplasia	17	10.5





Discussion

The current retrospective audit has indicated the presence of an overall prevalence of vascular variation of 64.8 percent, with the highest approvals coming in the upper limb arteries (29.6 percent), abdominal aortic branches (23.5 percent), aortic arch branches (19.8 percent), renal arteries (17.9 percent), and cerebral arteries (9.3 percent). Aberrant origin (33.3%) and accessory vessels (25.3) were morphologically the most frequent patterns. Such observations are supported by the recent literature on CT angiography, which reports a high degree of variability in the major abdominal and supra-aortic vessels.

Abdominal findings in the current study included differences in the celiac trunk and common hepatic artery. Turkyilmaz et al,[8] found a high prevalence of celiac and hepatic arterial branching variations using CT angiography and proposed a new classification model to standardise reporting. In the same way, Jalamneh et al,[9] identified common aberrations in the abdominal artery branch patterns, highlighting their surgical and interventional consequences. Sheta,[10] also reported a substantial incidence of both celiac and superior mesenteric arteriovenous anomalies in an Egyptian cohort, giving additional support to the geographic consistency of the results. Our (23.5) percentage variation rate in the abdominal aortic branch compares well with these statistics, which shows that preoperative vascular mapping is needed.

Regarding vertebral artery differences, our results on cerebral and supra-aortic vessels align with those of Phukan et al,[11] who described significant embryologically based variations in the vertebral arteries on CT angiography. The difference in the prevalence of cerebral arterial variations was slightly lower than some published data; however, differences in methodology and territorial distribution may account for this. Baz et al,[12] also support the identification of aortic arch abnormalities in our cohort and identified clinically significant branching variants of the aortic arch, which are detectable on CTA, and justify the use of audits based on imaging.

The distribution of hepatic artery variants in our morphological range resembles that reported by Bolintineanu Ghenciu et al,[13]

who showed that common hepatic artery variants are common on MDCT angiography. In their work, Ramputi et al,[14] outlined the rare sources of the internal carotid artery, highlighting the heterogeneity of abnormal branching at the supra-aortic origins, which correlates with the distribution of aberrant origin patterns observed in our study. More than that, Kumar et al,[15] found substantial variability in the patterns of celiac trunk formation, which reflects the similar pattern of common trunk development observed in our morphological classification.

There were significant numbers of accessory hepatic arteries and others replaced, similar to the findings already noted by Malviya and Verma,[16] who pointed out the surgical significance of the diversity of hepatic arteries. The coeliac trunk and renal artery variants coexisted significantly on contrast-enhanced CT, as indicated by Omar et al,[17] with a 17.9% variation rate in the renal artery, similar to what we recorded in our series. Similarly, Samuolyte et al,[18] emphasised the high frequency and clinical significance of hepatic arterial variants in contemporary imaging-based research, in line with our observation that the most common morphological patterns are aberrant origin and accessory vessels.

The mildly significant difference between male and middle-aged participants in our study did not reach statistical significance, indicating that vascular variability can be considered a constant anatomical process rather than highly dependent on demographic variables. The isolated (single) preponderance in our audit is also correlated with recent population analyses using imaging: single-territory deviations are more frequent than combined ones.

In general, our results support current evidence indicating that vascular anatomical variations are pervasive, regional, and are usually found in the abdominal and supra-aortic branches. Given its high prevalence of aberrant aetiologies and accessory vessels, the relevance of fine-grained pre-procedural imaging remains strong.

Limitations: It was a single-centred, retrospective study, which may limit generalisability. The fact that radiological imaging has been relied upon as a method of correlation, as opposed to cadavers, may have underreported the small-caliber or subtle forms. Also, analytical grouping of vascular territories could have affected direct comparison with studies that used isolated arterial systems as an independent variable. The use of standardised classification systems in larger multi-centric studies would increase the accuracy of comparison.

Conclusion

The current retrospective anatomy audit has shown that vascular anatomical differences are extremely common, occurring in almost two-thirds of the sample population analysed. The abdominal arterial systems and upper limb were the most frequently affected, and the unusual origin and accessory vessels were the most common morphological patterns. The demographic associations were not statistically significant, but the burden of vascular variability as a whole supports the problem's clinical importance.

These results once again confirm that vascular anatomy often does not match classical descriptions, and that the aberrations are not occasional findings but typical anatomical features. Due to the expanding scope of minimally invasive, endovascular, hepatobiliary, neurovascular, and transplant procedures, preoperative vascular mapping with advanced imaging is essential.

Regional prevalence data, better surgical risk stratification, and more effective procedural planning are the benefits of systematic, anatomical audits of the same type as the current study. Integration of homogenised classification systems and multi-centric datasets into future studies will further enhance the translational utility of investigating vascular variation in contemporary clinical practice.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Kusztal M, Weyde W, Letachowicz K, Gołebiowski T, Letachowicz W. Anatomical vascular variations and practical implications for access creation on the upper limb. J Vasc Access. 2014;15 Suppl 7:S70-5. doi:10.5301/jva.5000257. Available from: https://pubmed.ncbi.nlm.nih.gov/24817459/
2. Abdu SM, Muhaba ES, Assefa EM. Anatomical variations of the brachial artery: a systematic review and meta-analysis. FASEB J. 2025;39(23):e71268. doi:10.1096/fj.202502920. Available from: https://pubmed.ncbi.nlm.nih.gov/41305981/
3. Jones JD, Castanho P, Bazira P, Sanders K. Anatomical variations of the circle of Willis and their prevalence, with a focus on the posterior communicating artery: a literature review and meta-analysis. Clin Anat. 2021;34(7):978-990. doi:10.1002/ca.23662. Available from: https://pubmed.ncbi.nlm.nih.gov/32713011/
4. Omotoso BR, Harrichandparsad R, Lazarus L. Prevalence of anatomical variations at the suboccipital (V3) segment of the vertebral artery: a systematic review. Neuroradiology. 2023;65(12):1677-1684. doi:10.1007/s00234-023-03223-9. Available from: https://pubmed.ncbi.nlm.nih.gov/37878031/
5. Dabria N, Galhotra A, Galhotra RD, Galhotra A, Sharma I, Kakkar C, et al. Analysis of anatomical variations of the main arteries branching from the abdominal aorta by multidetector computed tomography: a prospective study of 500 patients in a tertiary center. J Anat Soc India. 2022;71(2):128-134. doi:10.4103/jasi.jasi_137_21.
6. Smith R, Mathangasinghe Y, Gonsalvez D. Rare bilateral vascular variations of the upper limb: a cadaveric case study. J Cardiothorac Surg. 2024;19(1):683. doi:10.1186/s13019-024-03158-z. Available from: https://pubmed.ncbi.nlm.nih.gov/39731103/
7. Barfzadeh A, Saba M, Pourzand P, Jalalifar MR, Alizadeh SD, Mirkamali H, et al. Anatomical variations of the extracranial internal carotid artery: prevalence, risk factors, and imaging insights from CT-angiography. Surg Radiol Anat. 2024;46(8):1295-1299. doi:10.1007/s00276-024-03425-7. Available from: https://pubmed.ncbi.nlm.nih.gov/38926226/
8. Türkyılmaz Z, Kula O, Çelik AO, Demirel T, Günay B. Evaluation of celiac artery and common hepatic artery variations by CT-angiography and new classification model. Surg Radiol Anat. 2023;45(8):1037-1047. doi:10.1007/s00276-023-03180-1. Available from: https://pubmed.ncbi.nlm.nih.gov/37340150/

9. Jalamneh B, Nassar IJ, Sabbooba L, Ghanem R, Nazzal Z, Kiwan R, et al. Exploring anatomical variations of abdominal arteries through computed tomography: classification, prevalence, and implications. Cureus.2023;15(7):e41380. doi:10.7759/cureus.41380. Available from: https://pubmed.ncbi.nlm.nih.gov/37546145/
10. Sheta AA. Prevalence of anatomical variants in the branches of celiac and superior mesenteric arteries among Egyptians. Anat Cell Biol. 2024;57(3):353-362. doi:10.5115/acb.23.316. Available from: https://pubmed.ncbi.nlm.nih.gov/38916081/
11. Phukan P, Saikia B, Sarma A, Baruah SD, Das GC, Gayan PS. Retrospective study of normal variations in vertebral artery on computed tomography angiography with special emphasis on relevant embryology. Cureus.2023;15(4):e38063. doi:10.7759/cureus.38063. Available from: https://pubmed.ncbi.nlm.nih.gov/37234137/
12. Baz RO, Refi D, Scheau C, Axelerad A, Baz RA, Niscoveanu C. CT angiography for aortic arch anomalies: prevalence, diagnostic efficacy, and illustrative findings. Diagnostics (Basel). 2024;14(17):1851. doi:10.3390/diagnostics14171851. Available from: https://pubmed.ncbi.nlm.nih.gov/39272636/
13. Bolintineanu Ghenciu LA, Bolintineanu SL, Iacob N, Zăhoi DE. Clinical consideration of anatomical variations in the common hepatic arteries: an analysis using MDCT angiography. Diagnostics (Basel). 2023;13(9):1636. doi:10.3390/diagnostics13091636. Available from: https://pubmed.ncbi.nlm.nih.gov/37175027/
14. Ramputi L, Mazzaccaro D, Tissir K, Trevisan MB, Conte G, Nano G, et al. Anatomical variations of origin of the internal carotid artery: report of two cases and systematic review of the literature. Vascular. 2025;33(5):1191-1199. doi:10.1177/17085381241283095. Available from: https://pubmed.ncbi.nlm.nih.gov/39292968/
15. Kumar P, Singh A, Triveni GS, Chandrashekhara SH, Gamanagatti S, Nichat V. Celiac trunk arterial variations and their clinical implications: role of imaging. Indian J Gastroenterol. 2024;43(6):1099-1110. doi:10.1007/s12664-024-01656-5. Available from: https://pubmed.ncbi.nlm.nih.gov/39243342/
16. Malviya KK, Verma A. Importance of anatomical variation of the hepatic artery for complicated liver and pancreatic surgeries: a review emphasizing origin and branching. Diagnostics (Basel). 2023;13(7):1233. doi:10.3390/diagnostics13071233. Available from: https://pubmed.ncbi.nlm.nih.gov/37046451/
17. Omar R, Kisansa M, Dehnavi AD. The prevalence of anatomical variants of the coeliac trunk and renal arteries on contrast-enhanced abdominal computed tomography scans. SA J Radiol. 2021;25(1):1990. doi:10.4102/sajr.v25i1.1990. Available from: https://pubmed.ncbi.nlm.nih.gov/33604070/
18. Samuolyte A, Luksaite-Lukste R, Kvietkauskas M. Anatomical variations of hepatic arteries: implications for clinical practice. Front Surg. 2025;12:1593800. doi:10.3389/fsurg.2025.1593800. Available from: https://pubmed.ncbi.nlm.nih.gov/40607371/.