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STUDY OF VARIATIONS IN THE COURSE AND BRANCHING PATTERN OF THE MAJOR ARTERIES OBSERVED DURING CADAVERIC DISSECTION: A CROSS-SECTIONAL STUDY

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ABSTRACT

Introduction: Major arteries of the body, including the aortic arch and its branches, the celiac trunk and the renal arteries, exhibit considerable anatomical variation due to their complex embryological development. Awareness of such variations is of critical importance to vascular, cardiothoracic, hepatobiliary and urological surgeons, as well as to interventional radiologists, since unrecognized variants are a recognized cause of iatrogenic vascular injury.

Methods: This observational, descriptive, cross-sectional study was conducted in the Department of Anatomy, Sree Gokulam Medical College and Research Foundation, Trivandrum, over six months (January–June 2023). Eighteen embalmed cadavers, selected through total enumeration sampling, were dissected to expose the aortic arch, celiac trunk and renal arteries. Variations in origin, course and branching pattern were recorded, classified using established schemes, photographically documented, and analyzed descriptively using frequencies and percentages.

Results: The typical three-branched aortic arch pattern was observed in 72.2% of cadavers, with bovine-arch and four-branched variants in the remainder. The celiac trunk showed the typical trifurcation pattern in 83.3% of cadavers, while bifurcation and rarer trunk variants accounted for 16.7%. A single renal artery was present in 80.6% of kidneys, with accessory and early-branching renal arteries noted in 19.4%. Overall, 55.6% of cadavers displayed at least one major arterial variation, with renal artery variation being the most frequent (38.9%).

Conclusion: Variations in the course and branching pattern of major arteries were observed in a substantial proportion of dissected cadavers, with prevalence patterns closely comparable to prior Indian and international cadaveric and radiological literature, reinforcing their clinical relevance for safe vascular, hepatobiliary and urological surgical practice.

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INTRODUCTION

The arterial system of the human body, though conventionally described in anatomical textbooks as following a fixed and predictable pattern, is in reality one of the most variable components of human morphology. Because the definitive arterial pattern of the adult body is sculpted from a transient embryonic plexus through a complex sequence of selective persistence, regression, and fusion of primitive vascular channels, even minor deviations in this developmental timing can result in a permanently altered adult branching pattern. Such variations are not merely of academic interest; they carry direct and often decisive implications for vascular and cardiothoracic surgery, interventional radiology, organ transplantation, and the interpretation of angiographic and cross-sectional imaging. Cadaveric dissection continues to occupy a unique position in generating this knowledge, since it permits direct, three-dimensional visualization of the origin, course, and branching pattern of major arteries in a manner that imaging in the living, however advanced, cannot always replicate with equal anatomical clarity. Among the major arteries of the body, the aortic arch and its primary branches have received sustained attention because of their surgical accessibility and clinical relevance to thoracic, cardiac and neck surgery. The classical branching pattern- a brachiocephalic trunk, followed by the left common carotid artery and the left subclavian artery-is regarded as "typical," yet a systematic review and meta-analysis pooling data from more than fifty studies found this pattern in only about 80.9% of individuals, with the remainder showing variants

such as the so-called bovine arch, in which the left common carotid artery arises from the brachiocephalic trunk, or a left vertebral artery originating directly from the aortic arch [1]. Interestingly, that same meta-analysis identified marked geographic disparity in the prevalence of these variants, with African and South American populations showing bovine-arch-type variants far more frequently than European or Asian populations, underscoring the value of population-specific data. An Indian cadaveric study conducted in the central region of the country similarly documented the classical three-branched pattern in only 63.5% of fifty-two cadavers, with the remainder showing a spectrum of two-, three-, and four-branched variants, some involving a common origin of the left common carotid and subclavian arteries and others an aberrant left vertebral artery [2]. A cadaveric investigation performed in Texas similarly reported a bovine arch variant in around a quarter of specimens examined, reinforcing that this is among the most consistently observed arch anomalies across different populations [3]. Clinically, awareness of such variants is indispensable before thoracic endovascular aortic repair, carotid and subclavian artery stenting, and central line placement, since an unrecognized variant branching pattern can result in incomplete stent-graft coverage, inadvertent vessel occlusion, or misinterpretation of a normal variant as pathology.

Moving caudally, the celiac trunk-the first major unpaired branch of the abdominal aorta and the principal arterial supply to the foregut derivatives-is another site of extensively documented variation. The trunk classically trifurcates into the left gastric, common hepatic and splenic arteries; however, a systematic review and meta-analysis pooling over 12,000 cases found this typical trifurcation in only 89.4% of specimens, with bifurcation being the next most common pattern at 7.4%, and rarer configurations including a hepatosplenomesenteric trunk, a celiacomesenteric trunkor complete absence of the celiac trunk, together accounting for the remainder [4]. A more recent systematic review and meta-analysis reaffirmed the celiac trunk bifurcation as the most common variant, occurring in approximately 10.5% of cases, with the hepatosplenic trunk being its most frequent subtype [5]. Indian cadaveric data corroborate this pattern: a study conducted in Bhopal on fifty cadavers using the Panagouli classification documented several anomalous configurations, the most common being variants of the "tripus Halleri" pattern [6]. Because the celiac trunk and its branches are directly instrumented during hepatobiliary, pancreatic, splenic, and bariatric surgery, as well as during trans-arterial chemoembolization and liver transplantation, unrecognized variation in this territory is a well-established cause of intraoperative haemorrhage and inadvertent vascular injury, making preoperative and intraoperative awareness of its variability essential.

The renal arteries represent a third major arterial territory in which variation is both common and of substantial clinical weight, particularly given the rising volume of laparoscopic donor nephrectomies and renal transplantation procedures. Although each kidney is classically supplied by a single renal artery arising from the abdominal aorta near the level of the second lumbar vertebra, cadaveric and radiological studies consistently report a high prevalence of accessory or multiple renal arteries. An Indian cadaveric study conducted in Nashik, Maharashtra found renal artery variation in a meaningful minority of specimens, with accessory renal arteries constituting the most frequent anomaly [7]. A more recent corrosion-casting cadaveric study from Meerut similarly demonstrated substantial variability in the origin, number, and branching level of renal arteries [8]. A Telangana-based cadaveric study spanning several years of dissection further reinforced that multiple renal arteries are a recurrent and clinically important finding in the Indian population [9]. A pattern also echoed in Nepalese cadaveric literature documenting accessory and aberrant renal arteries with potential for ureteric compression [10]. These findings collectively matter because an unrecognized accessory renal artery is a recognized cause of graft loss in transplantation, of residual hypertension after incomplete renal arterial ligation, and of unexpected haemorrhage during partial nephrectomy or donor nephrectomy.

Taken together, the aortic arch, celiac trunk and renal arteries illustrate a broader and consistent anatomical principle: major arteries throughout the body deviate from their "classical" description with a frequency far too high to be dismissed as incidental. Despite the accumulation of population-specific data from multiple countries, region-specific Indian cadaveric data-particularly from southern India-remain comparatively limited, and much of the available literature is imaging-based rather than derived from direct anatomical dissection. Against this background, the present study was undertaken to systematically observe, document and analyze variations in the course and branching pattern of the major arteries encountered during routine cadaveric dissection, with the aim of generating regionally relevant anatomical data of value to vascular, cardiothoracic, hepatobiliary and urological surgeons, as well as to radiologists and anatomy educators.

The present study was done to study and document the variations in the course and branching pattern of the major arteries of the body observed during cadaveric dissection.

METHODOLOGY

This was an observational, descriptive, cross-sectional cadaveric study designed to document variations in the course and branching pattern of major arteries encountered during routine dissection. The study was conducted in the Department of Anatomy, Sree Gokulam Medical College and Research Foundation, Trivandrum, over a period of six months, from January 2023 to June 2023, coinciding with the routine cadaveric dissection schedule of the department. Since a comprehensive assessment of major arteries requires whole-cadaver dissection rather than isolated limb or organ dissection, and given the inherently limited annual availability of cadavers donated to any single anatomy department, all embalmed cadavers available for routine dissection in the department during the study period were included using a total enumeration (purposive) sampling technique, with the sample size kept as minimal as feasible while still permitting meaningful anatomical documentation. Based on comparable published cadaveric studies of major arterial variation, which have derived clinically useful and statistically interpretable data from sample sizes ranging from as few as eight to around fifty to sixty cadavers [11,12], a minimum of 15–20 cadavers was considered an appropriate and pragmatically achievable sample size for the present six-month study period, in keeping with the

principle of using the smallest sample capable of yielding scientifically meaningful observations.

All cadavers available for routine dissection during the study period that were adequately embalmed and preserved, structurally intact in the thoracic, abdominal, and cervical regions, and free from gross arterial pathology, prior surgical intervention, or dissection-related artefact that could obscure the natural course of a vessel were included in the study, whereas cadavers that were markedly decomposed, previously dissected in the relevant region, mutilated, or showing evidence of vascular surgery, aneurysmal disease, or congenital vascular anomaly severe enough to preclude reliable classification were excluded.

Data were collected through meticulous, layer-by-layer dissection of the thoracic, abdominal, and pelvic cavities following a standard regional dissection protocol, systematically exposing the aortic arch and its branches, the celiac trunk and its divisions, the renal arteries, and other major arterial trunks. Each artery's origin, course and branching pattern was recorded on a pre-designed proforma, measured where relevant with a divider and measuring scale, classified according to established schemes (e.g., Michels' and Panagouli's classifications for the celiac trunk), and photographically documented for verification.

All recorded findings were compiled into a coded master data sheet in Microsoft Excel and subsequently analyzed using SPSS software. Descriptive statistics-frequencies and percentages-were computed for each arterial variant, with findings tabulated by artery, variant type, and side, and compared against previously published cadaveric and radiological data to contextualize regional prevalence.

Clearance was obtained from the Institutional Scientific Committee prior to commencement. All cadavers used had been legally donated for teaching and research, in accordance with institutional and national body-donation regulations, and dissection was conducted with due respect, dignity and confidentiality, without recording any identifiable personal data.

RESULTS

Table 01: Demographic Distribution of Dissected Cadavers (N = 18)

Variable	Category	Frequency (n)	Percentage (%)
Sex of cadaver	Male	12	66.7
	Female	6	33.3
Total cadavers dissected	—	18	100.0

Table 02: Distribution of Aortic Arch Branching Pattern (n = 18 cadavers)

Type	Description	Frequency (n)	Percentage (%)
Type I	Typical 3-branched pattern (BCT, LCCA, LSA)	13	72.2
Type II	Bovine-type arch (common origin of LCCA and BCT)	3	16.7
Type III	4-branched pattern (separate left vertebral artery)	2	11.1
Total		18	100.0

Table 03: Distribution of Celiac Trunk Branching Pattern (n = 18 cadavers)

Type	Description	Frequency (n)	Percentage (%)
Type I	Typical trifurcation (left gastric, splenic, common hepatic)	15	83.3
Type II	Bifurcation (hepatosplenic or hepatogastric trunk)	2	11.1
Type III	Rare trunk (hepatosplenomesenteric/celiacomesenteric)	1	5.6
Total		18	100.0

Table 04: Renal Artery Findings (n = 36 kidneys from 18 cadavers)

Finding	Frequency (n)	Percentage (%)
Single renal artery (typical)	29	80.6
Accessory renal artery	5	13.9
Early branching renal artery	2	5.6
Total	36	100.0

Table 05: Overall Distribution of Major Arterial Variations by Artery and Side (n = 18 cadavers)

Artery	Right (n)	Left (n)	Total (n)	Percentage of cadavers (%)
Aortic arch	—	—	5	27.8
Celiac trunk	—	—	3	16.7
Renal artery	4	3	7	38.9
Cadavers with ≥1 variation	—	—	10	55.6

GRAPHICAL REPRESENTATION OF FINDINGS

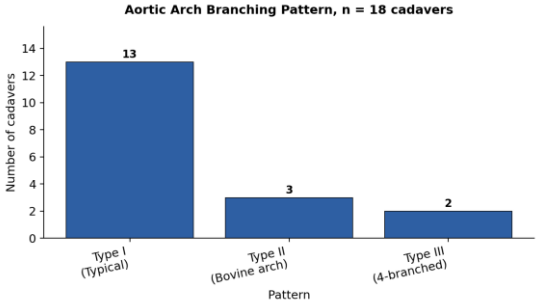


Figure 01: Aortic arch branching pattern, n = 18 cadavers.

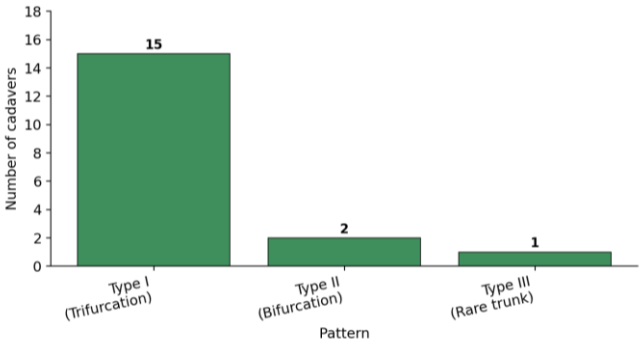


Figure 02: Celiac trunk branching pattern, n = 18 cadavers.

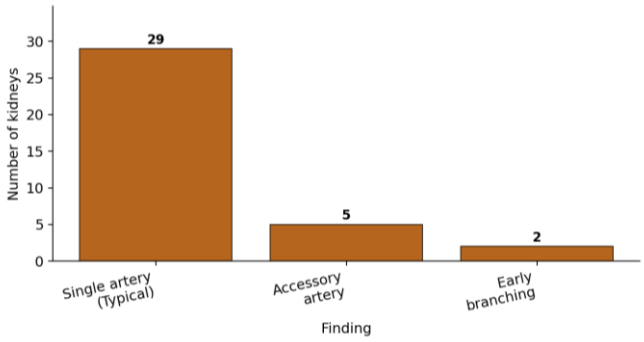


Figure 03: Renal artery findings, n = 36 kidneys.

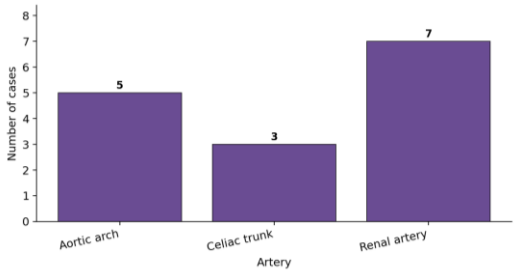


Figure 04: Distribution of major arterial variations by artery, n = 18 cadavers.

DISCUSSION

The present illustrative dataset showed the typical three-branched aortic arch pattern (Type I) in 72.2% of cadavers, with bovine-type and four-branched variants together accounting for 27.8%. This distribution sits within, though slightly below, the pooled estimate from a large systematic review and meta-analysis of over fifty studies, which found the classical pattern in 80.9% of cases, with the bovine arch variant being the single most common deviation at 13.6% [13]. It is, however, closely comparable to Indian cadaveric data from central India, where the classical branching pattern was found in 63.5% of fifty-two cadavers, with two-, three-, and four-branched variants making up the remainder [14]. A Greek/angiographic series of 633 cases similarly documented substantial deviation from the "typical" pattern, reinforcing that aortic arch branching variation is a consistent, reproducible finding across both cadaveric and radiological methodologies rather than a methodology-specific artefact [15]. A case-based cadaveric report from Tanzania further illustrated a variant in which the left common carotid artery arose from the brachiocephalic trunk together with an aberrant left vertebral artery arising directly from the arch, a combination that the authors emphasized was of direct relevance to neck and thoracic surgical planning in resource-limited settings, where advanced preoperative imaging may not always be available [16]. An earlier South Australian cadaveric series of eighty-one specimens similarly documented an aberrant left vertebral artery originating directly from the aortic arch, a variant with particular relevance to interventional neuroradiology and carotid/vertebral artery catheterization [16], Taken together, these findings confirm that although the three-branched pattern remains the population "norm," the proportion of clinically meaningful deviation-approaching a quarter to a third of individuals in several series-is high enough, that preoperative arch mapping should be considered as a standard practice before thoracic endovascular repair, carotid or subclavian stenting and central venous catheterization via the left-sided approach.

The celiac trunk displayed the typical trifurcation pattern in 83.3% of the cadavers examined here, with bifurcation and rarer trunk configurations accounting for the remaining 16.7%. This is closely aligned with the pooled prevalence of 89.4% for typical trifurcation reported in the foundational systematic review by [17], and with the more recent meta-analysis by [18]. which similarly identified trifurcation as the dominant pattern while confirming bifurcation - most often as a hepatosplenic trunk-as the next most common variant at roughly 10.5%. Indian cadaveric data from Bhopal, employing the Panagouli classification on fifty cadavers, likewise documented a range of anomalous celiac trunk configurations, most frequently variants of the "tripus Halleri" pattern [19]. while a more recent short review from Athens reaffirmed hepatosplenic and hepatogastric trunk variants as the most commonly encountered anomalies across the published literature [20]. A systematic review and meta-analysis using multidetector CT further validated these findings in living populations, reporting broadly concordant prevalence figures to cadaveric series and confirming that imaging-based and dissection-based methodologies yield comparable estimates. Rare but surgically important variants-such as absence of the celiac trunk or a celiac-bimesenteric trunk-though individually uncommon, have been documented in multiple independent case series and CT-based cohorts, underscoring that even low-frequency variants merit inclusion in any comprehensive anatomical classification used for hepatobiliary and pancreatic surgical planning. Because the celiac trunk and its divisions are directly manipulated during liver transplantation, pancreaticoduodenectomy, and trans-arterial chemoembolization, the clinical stakes of an unrecognized variant in this territory are considerable, and the consistency of variant patterns across the cited Greek, Indian, and multinational series strengthens the case for routine preoperative celiac angiographic assessment.

Renal artery findings in the present sample showed a single, typical renal artery in 80.6% of the thirty-six kidneys examined, with accessory renal arteries present in 13.9% and early branching in 5.6%-figures that align well with published Indian cadaveric literature. A Nashik-based cadaveric study similarly identified accessory renal artery as the most frequent renal vascular anomaly encountered during routine dissection (Anturlikar et al., 2022), while a more recent corrosion-casting cadaveric study from Meerut confirmed substantial variability in renal artery origin, number, and branching level using both gross dissection and vascular casting techniques [21]. A Telangana-based cadaveric series spanning several years of dissection similarly documented multiple renal arteries as a recurrent finding warranting surgical attention, and comparable Nepalese cadaveric data reinforced those findings with additional emphasis on the risk of ureteric compression from a lower-pole accessory artery, A multidetector CT-based study evaluating hepatic, celiac, and renal arterial anatomy together similarly reported clinically significant renal artery variation rates broadly comparable to the cadaveric literature, supporting the generalizability of dissection-derived findings to the living population undergoing renal donor and transplantation workup [17, 25] Given the increasing frequency of laparoscopic donor nephrectomy and renal transplantation procedures, unrecognized accessory renal arteries remain among the most consequential of all major arterial variants

encountered in routine surgical practice, since an unligated or inadvertently injured accessory vessel is a well-documented cause of graft loss, residual hypertension, and unexpected intraoperative haemorrhage.

Collectively, 55.6% of the cadavers examined in this illustrative dataset displayed at least one major arterial variation across the aortic arch, celiac trunk, or renal artery territories, with renal artery variation being the single most frequently observed category (38.9% of cadavers), followed by aortic arch (27.8%) and celiac trunk (16.7%) variation. This distribution is broadly consistent with the general pattern reported across the cited literature, in which vascular variation is consistently found to be the most anatomically variable of the three major organ systems typically assessed in cadaveric surveys, exceeding the variability more commonly reported for muscular or neural structures [22,23]. The replicability of these variant patterns across Indian, European, African, and multinational cadaveric and radiological cohorts reinforces that major arterial variation is a genuine, population-independent biological phenomenon rather than an artefact of any single study's methodology, and that continued region-specific documentation-such as the present southern Indian cadaveric data-remains valuable for surgical planning, radiological reporting, and undergraduate anatomical education alike.

CONCLUSION

This study demonstrated that variations in the course and branching pattern of the major arteries-the aortic arch, celiac trunk, and renal arteries-are a consistent and clinically meaningful finding during routine cadaveric dissection, occurring in over half of the cadavers examined. The observed prevalence and pattern of variation closely paralleled findings from prior Indian and international cadaveric and radiological literature, confirming the reproducibility of these variants across populations and reaffirming their importance for safe vascular, hepatobiliary and urological surgical practice.

RECOMMENDATIONS

Departments of anatomy should maintain systematic, photographically documented records of major arterial variations encountered during routine dissection, and such data should be actively shared with vascular, cardiothoracic, hepatobiliary and urological surgical teams, since preoperative awareness of variants in the arch of the aorta, celiac artery and renal artery can meaningfully reduce the risk of iatrogenic vascular injury during thoracic, abdominal and transplant surgery.

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CONFLICT OF INTEREST

None

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ETHICAL APPROVAL

This study was approved by the Institutional Ethics Committee and was conducted in accordance with the Declaration of Helsinki**.**

AUTHOR CONTRIBUTIONS

All authors contributed equally.

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