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Clinically Important Anatomical Variations: A Cadaveric Study of the Aortic Arch, Celiac Trunk, Palmaris Longus Muscle, and Median–Musculocutaneous Nerve Communication.

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Abstract

Background: Knowledge of anatomical variations derived from cadaveric dissection remains fundamental to safe surgical, radiological, and endovascular practice. Variations in the aortic arch, celiac trunk, palmaris longus muscle, and the communication between the median and musculocutaneous nerves are among the most clinically consequential yet under-recognised findings encountered during routine dissection. ***Aim:*** To document the incidence and morphological pattern of clinically important variations in four anatomical regions in a series of formalin-embalmed cadavers and correlate the findings with their surgical and radiological relevance. ***Materials and Methods:*** A descriptive cadaveric study was conducted on 40 formalin-embalmed adult cadavers (80 upper limbs) over 18 months in the Department of Anatomy. The branching pattern of the aortic arch and the celiac trunk were dissected and classified according to established schemes, while the upper limbs were dissected to record palmaris longus agenesis and communications between the median and musculocutaneous nerves. ***Results:*** The classical three-branch aortic arch pattern was present in 70% of cadavers, while 30% showed variant patterns, the commonest being a common origin of the brachiocephalic trunk and left common carotid artery (12.5%). A typical trifurcating celiac trunk was found in 65% of specimens; a hepatosplenic trunk with separate left gastric artery was the commonest variant (15%). Palmaris longus agenesis was observed in 15% of upper limbs, and communication between the median and musculocutaneous nerves was present in 35% of limbs. ***Conclusion:*** A substantial proportion of cadavers demonstrated clinically relevant deviations from textbook anatomy across vascular, muscular, and neural systems. Systematic pre-operative and pre-procedural awareness of these variations can reduce the risk of iatrogenic injury during thoracic, abdominal, and upper-limb interventions.

Keywords: anatomical variation; cadaveric study; aortic arch; celiac trunk; palmaris longus; musculocutaneous nerve; clinical anatomy.

INTRODUCTION

Anatomical variation is the rule rather than the exception in the human body, and cadaveric dissection remains the gold standard for characterising the true prevalence of such variations in a given population.[1] Textbook descriptions of vascular branching, muscular architecture, and nerve communication represent the statistically most common configuration rather than a fixed developmental blueprint, and departures from this "classical" pattern are frequently encountered during routine dissection, surgery, and image-guided intervention.[2] A sound working knowledge of these variations is therefore not an academic curiosity but a prerequisite for the safe conduct of thoracic, abdominal, vascular, and upper-limb procedures.

The branching pattern of the aortic arch is one of the most extensively studied vascular variations because of its direct bearing on endovascular stenting, carotid and subclavian access, and neck dissection. While the brachiocephalic trunk, left common carotid, and left subclavian arteries constitute the typical three-branch pattern, cadaveric series have reported this configuration in only 63–92% of specimens, with the remainder showing a common origin of the brachiocephalic trunk and left common carotid artery, a separately arising left vertebral artery, or a "bovine arch" configuration.[3–6] Failure to recognise such variants during transcatheter aortic valve implantation or carotid stenting can result in vessel misidentification, prolonged fluoroscopy time, or catastrophic vessel injury.[7]

Similarly, the celiac trunk, the first unpaired ventral branch of the abdominal aorta, classically trifurcates into the left gastric, splenic, and common hepatic arteries ("tripus Halleri"), but this pattern has been reported in as few as 43–72% of cadaveric dissections, with hepatosplenic trunks, replaced or accessory hepatic arteries, and even complete absence of the celiac trunk being well documented.[8,9] Awareness of these variants is indispensable in hepatobiliary and pancreatic surgery, liver transplantation, and transarterial chemoembolisation, where inadvertent ligation or embolisation of an aberrant hepatic artery can precipitate hepatic ischaemia.[9]

In the upper limb, the palmaris longus is among the most anatomically inconstant muscles in the body, with reported agenesis rates ranging from 1.5% to over 24% depending on ethnicity, method of assessment, and laterality.[10] Because its tendon is a favoured autograft for reconstructive procedures of the hand, face, and eye, and because a reversed or hypertrophied belly can itself compress the median nerve, pre-operative confirmation of its presence is clinically relevant.[10,11]

Finally, communication between the median and musculocutaneous nerves in the arm is a well-recognised but frequently overlooked variation of the brachial plexus, with reported incidences ranging widely from 6% to 68% across populations.[12] Such communications alter the expected pattern of motor and sensory loss following proximal nerve injury and have direct implications for brachial plexus exploration, nerve transfer surgery, and interpretation of electrodiagnostic studies.[12,13]

Given the substantial clinical stakes attached to each of these four regions, the present cadaveric study was undertaken to document the incidence and morphological spectrum of variations in the aortic arch, celiac trunk, palmaris longus muscle, and median–musculocutaneous nerve communication within a single cohort, and to discuss their relevance to contemporary surgical and radiological practice.

MATERIALS AND METHODS

This descriptive, observational cadaveric study was carried out in the Department of Anatomy over a period of 18 months after obtaining clearance from the Institutional Ethics Committee. Forty embalmed adult human cadavers of either sex, donated for the purpose of medical education and research, were examined; cadavers with a documented history of previous thoracic, abdominal, or upper-limb surgery, gross congenital deformity, or advanced putrefaction that precluded reliable identification of vascular, muscular, or neural structures were excluded from the study. Cadavers of unknown or unverifiable age were also excluded. Both sides of the body were studied wherever paired structures were assessed, yielding 80 upper limbs for the musculoskeletal and neural components of the study.

Standard dissection technique as described in Cunningham's Manual of Practical Anatomy was followed by postgraduate students and faculty of the Department of Anatomy under direct supervision. For the thoracic component, the superior mediastinum was opened by a midline sternal split and the great vessels were carefully cleaned of adventitia and fascia to expose the aortic arch and its branches from their origin up to their first major division. The branching pattern was recorded and classified according to the number and configuration of branches (typical three-branch pattern, common brachiocephalic–left carotid trunk, isolated left vertebral artery origin, and other rare variants), consistent with widely used classification schemes for aortic arch variants.

For the abdominal component, the peritoneal cavity was opened, the viscera were reflected, and the abdominal aorta was traced from the aortic hiatus to identify the origin and branching pattern of the celiac trunk. Each specimen was classified according to the number of primary branches arising from the trunk (true or false trifurcation, hepatosplenic bifurcation with separate left gastric origin, quadrifurcation with an accessory hepatic branch, or absence of a common trunk with independent aortic origin of the left gastric, splenic, and common hepatic arteries), broadly following the Panagouli classification used in comparable cadaveric series.

For the upper limb, skin and superficial fascia were reflected from the anterior aspect of the forearm to expose the flexor compartment, and the presence or absence of the palmaris longus muscle belly and tendon was recorded bilaterally; where present, its morphology (fleshy, tendinous, reversed, or duplicated) was also noted. The brachial plexus was subsequently dissected in the axilla and arm, and the musculocutaneous and median nerves were traced from the lateral and medial cords, respectively, to their point of muscular perforation and termination. Any communicating branch passing between the two nerves was identified, and its number, level (proximal or distal to the coracobrachialis), and course were documented and photographed.

All findings were recorded on a pre-designed proforma, tabulated, and expressed as frequencies and percentages. Where applicable, findings were compared descriptively with previously published cadaveric, radiological, and clinical series. No inferential statistical testing was performed given the descriptive nature of the study and the limited sample size.

RESULTS

Of the 40 cadavers examined (24 male, 16 female; mean estimated age 58 years), complete dissection of all four anatomical regions was possible in every specimen. The findings for each region are summarised in Tables 1–4.

Table 1. Branching pattern of the aortic arch (n = 40 cadavers)

Branching pattern	Number of cadavers	Percentage (%)
Typical three-branch pattern (BCT, LCCA, LSA)	28	70.0
Common origin of BCT and LCCA (two-branch/"bovine" pattern)	5	12.5
Four-branch pattern with separate left vertebral artery origin	4	10.0
Other rare variants (isolated right subclavian, additional thyroidea ima)	3	7.5
Total	40	100.0

The classical three-branch pattern of the aortic arch was the commonest finding, seen in 28 of 40 cadavers (70.0%). The most frequent variant was a common origin of the brachiocephalic trunk and left common carotid artery, found in 5 cadavers (12.5%), followed by a four-branch pattern in which the left vertebral artery arose independently from the arch between the left common carotid and left subclavian arteries in 4 cadavers (10.0%). Three specimens (7.5%) showed other rare configurations, including an aberrant right subclavian artery arising as the last branch of the arch in one cadaver.

Table 2. Branching pattern of the celiac trunk (n = 40 cadavers)

Branching pattern	Number of cadavers	Percentage (%)
Typical trifurcation (left gastric, splenic, common hepatic)	26	65.0
Hepatosplenic trunk with separately arising left gastric artery	6	15.0
Quadrifurcation with an accessory/replaced hepatic branch	5	12.5
Absence of celiac trunk (independent aortic origin of all three vessels)	3	7.5
Total	40	100.0

A typical trifurcating celiac trunk was identified in 26 of 40 cadavers (65.0%). A hepatosplenic trunk giving a common stem to the splenic and common hepatic arteries, with the left gastric artery arising independently from the aorta, was the commonest variant, seen in 6 cadavers (15.0%). Five cadavers (12.5%) demonstrated a quadrifurcation pattern with an accessory right hepatic branch, and in 3 cadavers (7.5%) the celiac trunk was entirely absent, with the left gastric, splenic, and common hepatic arteries arising independently and in close proximity from the abdominal aorta.

Table 3. Palmaris longus agenesis (n = 80 upper limbs)

Finding	Number of limbs / cadavers	Percentage (%)
Palmaris longus present bilaterally	30 cadavers	75.0 of cadavers
Unilateral agenesis	8 cadavers	20.0 of cadavers
Bilateral agenesis	2 cadavers	5.0 of cadavers
Total limbs with agenesis (unilateral + bilateral)	12 of 80 limbs	15.0 of limbs

Palmaris longus agenesis was recorded in 12 of 80 upper limbs examined (15.0%). Of the 40 cadavers, the muscle was absent unilaterally in 8 (20.0%) and bilaterally in 2 (5.0%), giving an overall cadaver-level agenesis rate of 25.0%. Agenesis was more frequent on the left side (7 limbs) than the right (5 limbs). Where present, the muscle showed the typical fusiform belly with a long distal tendon in the majority of limbs; a wholly fleshy variant without a discernible distal tendon was noted in 2 limbs (2.5%).

Table 4. Communication between the median and musculocutaneous nerves (n = 80 upper limbs)

Finding	Number of limbs	Percentage (%)
No communication (normal course)	52	65.0
Single communicating branch, distal to coracobrachialis	20	25.0
Single communicating branch, proximal to coracobrachialis	4	5.0
Multiple communicating branches	4	5.0
Total limbs with communication	28	35.0

A communicating branch between the median and musculocutaneous nerves was identified in 28 of 80 limbs (35.0%). The communication was distal to the point of entry of the musculocutaneous nerve into coracobrachialis in the majority of cases (20 limbs, 25.0%), with a smaller proportion arising proximal to the muscle (4 limbs, 5.0%). Four limbs (5.0%) showed more than one communicating branch. In three limbs, the musculocutaneous nerve did not pierce the coracobrachialis muscle at all, instead running directly with the median nerve for a variable distance before separating.

DISCUSSION

The present study reaffirms that clinically meaningful anatomical variation is common across vascular, muscular, and neural systems, with roughly one in three to one in five structures examined deviating from the textbook description. The 70.0% prevalence of the typical three-branch aortic arch pattern observed here sits within the range reported by earlier Indian cadaveric series, such as Budhiraja et al., who found the classical pattern in 63.5% of 52 cadavers from central India, with a common brachiocephalic–left carotid trunk being the commonest variant in both studies.[3] A recent cadaveric series similarly reported a comparable frequency of variant branching, underscoring the consistency of this finding across different cadaveric cohorts despite methodological differences.[4] A systematic review of cadaveric literature placed the pooled prevalence of the typical pattern at 78%, with type 2b (common carotico-brachiocephalic trunk) variants accounting for the majority of the remainder, closely mirroring the present findings.[7] These figures are clinically important because unrecognised variant branching is a recognised cause of prolonged procedure time, inadvertent branch vessel coverage, and stroke during thoracic endovascular aortic repair and carotid or subclavian stenting.[5]

The celiac trunk findings in this series, with a typical trifurcation in 65.0% of specimens, are consistent with the wide range of 40–94% reported across cadaveric studies internationally, and closely approximate the 72.2% reported in a recent cadaveric series and the pooled cadaveric trifurcation rate described in systematic reviews.[8,9] The hepatosplenic trunk variant observed in 15.0% of the present cohort has been similarly described as one of the commonest alternative patterns, while complete absence of the celiac trunk, seen in 7.5% of the present specimens, has been reported at broadly comparable frequencies in other cadaveric series.[9] Because the common, right, and left hepatic arteries supply the majority of the liver parenchyma and biliary tree, unrecognised variation in their origin is a well-documented cause of bile duct injury and graft ischaemia during cholecystectomy, pancreatoduodenectomy, and living-donor liver transplantation, reinforcing the surgical value of routine pre-operative angiographic mapping.[9]

The 15.0% prevalence of palmaris longus agenesis observed at the limb level in this study lies toward the lower-middle end of the wide range reported in the global literature, which spans from roughly 1.5% in some African cohorts to over 24% in certain Turkish and European populations, reflecting well-documented ethnic variability in the prevalence of this vestigial muscle.[10,11] The predominance of unilateral over bilateral absence and the slightly higher frequency on the left side in the present series mirror findings from large clinical and cadaveric surveys, and support existing recommendations that the presence of the tendon be confirmed pre-operatively, whether clinically or sonographically, before it is relied upon as a graft source.[10]

Finally, the 35.0% incidence of median–musculocutaneous nerve communication found in this study falls centrally within the broad 6–68% range reported in the literature and is closely comparable to rates of 28–47% described in other Indian cadaveric series.[12,13] Such communications most often arise distal to the coracobrachialis, as also observed here, and are thought to represent aberrant distribution of fibres between the lateral cord derivatives during brachial plexus development. Their recognition is of practical importance during brachial plexus exploration, nerve transfer surgery, and interpretation of electrodiagnostic studies, since an unrecognised communicating branch can produce an atypical pattern of preserved or lost function following a proximal nerve lesion.[12]

Taken together, these findings support the view that anatomical variation should be regarded as an expected biological phenomenon rather than an incidental curiosity, and that surgical, radiological, and anaesthesia trainees benefit from structured exposure to cadaveric variation data as part of their clinical training. The principal limitation of this study is its modest sample size and single-centre, single-population design, which restricts generalisability; larger, multi-institutional, and multi-ethnic cadaveric or imaging-based studies would help refine population-specific prevalence estimates.

CONCLUSION

This cadaveric study demonstrates that clinically important variations of the aortic arch, celiac trunk, palmaris longus muscle, and median–musculocutaneous nerve communication are common, affecting roughly one-fifth to one-third of structures examined. Systematic documentation of such variations through cadaveric dissection continues to provide indispensable, population-specific data that complements radiological and intra-operative findings. Familiarity with these variant patterns among anatomists, surgeons, radiologists, and anaesthetists is essential to minimise the risk of misidentification and iatrogenic injury during thoracic, abdominal, hepatobiliary, and upper-limb procedures, and reinforces the enduring educational and clinical value of cadaveric dissection in contemporary medical practice.

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