

High Bifurcation of the Brachial Artery: A Cadaveric Case Series Highlighting Anatomical Variations and Clinical Implications

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Abstract

Background: The brachial artery usually ends in the cubital fossa, having divided into the radial and ulnar arteries. The variations of the origin and branching pattern, especially the high bifurcation, are of great clinical and surgical significance. This study aimed to demonstrate the four cases of the high bifurcation of the brachial artery according to the Rodríguez-Niedenfuhr classification. **Material and Methods:** The anatomical variation study was performed on 40 limbs dissected from 20 formaldehyde-fixed upper limbs. The standard neurovascular dissection of the upper limbs, cubital fossa and forearm was performed. The morphological measurements of the variation specimens were taken in situ using a digital vernier caliper. Measurements included the distance from the bifurcation point to selected anatomical landmarks and the external diameter of the arteries at their origin. **Results:** In total, four cases (cadavers) of high bifurcation of the brachial artery were discovered in twenty cadavers dissected during the research. Thus, the prevalence rate appeared to be 20%. Out of these four cases, three cases (75%) were found on the unilateral side, and one case (25%) – on the bilateral sides. In other words, 5 out of 40 dissected limbs showed variation anatomy in relation to this branching pattern, or 12.5%. Based on the Rodríguez-Niedenfuhr classification, in all four cases, a brachioradial and brachioulnar arterial pattern were identified. **Conclusion:** High-level bifurcation of the brachial artery was a frequent finding in this study. Moreover, this variation was associated with the alteration of the usual relationships of the brachial artery with the surrounding structures.

Keywords: Anatomical variation; Clinical anatomy; Upper limb; Vascular anatomy; Cadaveric anatomy.

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INTRODUCTION

The brachial artery (BA) is the continuation of axillary artery beyond the lower border of the teres major muscle. In the anterior cubital region, it divides into radial and ulnar arteries. Variations in the upper limb arteries have been frequently encountered. Most of these variations occur in the radial artery (RA) followed by the ulnar artery (UA),^[1] though brachial artery variations are less common.^[2] Accurate knowledge of muscular and neurovascular variations is of much importance for both surgeons and radiologists and may prevent diagnostic errors.^[3-5] The most frequent origin of the radial artery is in the cubital fossa at the level of the neck of the radius. The artery may have a high origin from the brachial artery or even from the axillary artery.^[6-8] Knowledge of such variations improves the safety of invasive procedures, including arterial blood sampling, catheterization, bypass graft harvest, and flap surgery. It also decreases the risk of accidental arterial injury during venipuncture or orthopedic fixation and facilitates accurate interpretation of angiographic images. This case series describes unilateral and bilateral high bifurcation of the brachial artery identified during routine cadaveric dissections, highlighting their anatomical features, embryological basis, and clinical

significance.^[9-14]

MATERIALS AND METHODS

Study Design and Sample Parameters: An anatomical, cross-sectional cadaveric study was conducted in the Department of Anatomy, Government Medical College, Srinagar over five years, from March 2021 to January 2026. The study was performed on forty arms from twenty embalmed cadavers (male and female) offered for undergraduate teaching and dissection during the said period. The inclusion criteria comprised intact specimens with no history of surgery or peripheral vascular disease and no significant deformity of the shoulder, arm, cubital fossa, or

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forearm. The exclusion criteria included a limb with severe degeneration, contracture, or surgery that compromised the dissection of the brachial neurovascular bundle.

Specimen preservation: The specimen was preserved by standard arterial washout by gravity through the femoral artery. The preservative solution used was formaldehyde solution in water with glycerin, phenol, ethanol, and sodium borate added to obtain the most appropriate consistency for good preservation and easy dissection of the arteries.

Dissection procedure: The dissection was performed following the standard anatomical landmarks as described in Cunningham's manual of practical anatomy and laboratory instructions and the steps below: Firstly, the superficial anatomical landmarks were identified and marked as the acromioclavicular joint, clavicle, coracoid process, deltoid tuberosity, medial and lateral epicondyles of the humerus, and olecranon process. Then standard incisions were made over the anterior aspect of the arm from the anterior aspect of the acromioclavicular joint down to the cubital fossa and upper forearm. The skin with superficial fat was reflected laterally to expose the deep fascia of the arm. The arm fascia was incised along the medial side of the biceps brachii, and the intermuscular septa were dissected to reach the bicipital aponeurosis. The latter was cut to access the cubital fossa.

The axillary artery was exposed from the lateral margin of the first rib to the lower border of the teres major muscle from which it continues as the brachial artery. The main trunk of the brachial artery and its collateral branches, including profunda brachii and superior/inferior ulnar collateral arteries, were dissected. Particular care was taken to highlight the variations of the arterial trunk and its relationship with the terminal branches of the brachial artery. The vascular structures were cleared of the surrounding connective tissues. The study was completed with the classification of the variants of the brachial artery following the classification proposed by Rodríguez-Niedenführ et al. A digital camera was used to capture the pictures of the selected specimen indicating the identified anatomical variants and morphometric data.

Morphometric assessment: The linear measurements were made in situ to prevent any additional vascular displacement after the completion of dissection. The distance from the bifurcation of the brachial artery to the following anatomical landmarks was measured in cm:

- The lower border of the teres major muscle
- The tip of the coracoid process
- The medial and lateral epicondyles of the humerus
- The diameter of the vessels at the origin of their main trunk and branches was measured using a digital vernier caliper and a standard ruler as well.

Ethics: The bodies used for the dissection were donated by their owners to the body donation program for science, education, and research. The dissection was performed following standard ethical guidelines and protocols for human body donation, and the body of the donor was respected throughout the procedure.

CASES:

Case 1 (Right upper limb)

The present sample was a male cadaver fixed with formalin. The right brachial artery had a high bifurcation located in mid-arm, 11.5 cm distal to the tip of the coracoid process and 17.0 cm proximal to the medial epicondyle of the humerus.

- Arterial pattern (according to Rodríguez-Niedenführ): Bifurcation of the brachial trunk into brachioradial artery and major ulnar trunk.

Course and relations:

- Median nerve descended superficial to both arterial trunks in the mid-arm, but then ran between them in the cubital fossa. The brachioradial artery progressed deep to the median nerve to the lateral forearm compartment. The ulnar trunk took a usual course along the medial side of the forearm.
- The left upper limb typically demonstrated the right brachial artery pattern.

Case 2 (Left upper limb):

The sample was a female cadaver fixed with formalin. Left brachial artery presented with a high bifurcation in the proximal third of the arm, 2.0 cm distal to the inferior border of the teres major muscle.

- Arterial pattern (according to Rodríguez-Niedenführ): High division of the brachial trunk into brachioradial and brachioulnar arteries.

Course and relations:

- **Brachioradial artery:** Progressed along the anterior-lateral side of the brachialis muscle, passed with the radial nerve through the cubital fossa, and entered the forearm deep to the brachioradialis muscle.
- **Brachioulnar artery:** Passed medial to the median nerve, which superficially crossed it from lateral to medial. In the cubital fossa, the brachioulnar artery gave off an anomalous common interosseous artery (CIA). Then it ran deep to the deep head of the pronator teres muscle.
- The right upper limb demonstrated a typical arterial pattern.

Case 3 (Bilateral upper limbs):

The present sample was a male cadaver fixed with formalin. Symmetrical bifurcations of the brachial arteries were found in the proximal third of the upper limbs.

- Arterial pattern (according to Rodríguez-Niedenführ): High origin of the brachioradial artery and brachioulnar artery (superficial ulnar artery).

Course and relations:

- The trunk of the brachial artery, prior to division, was located lateral to the median nerve. The brachioradial artery was larger in size than the ulnar one; it descended along the lateral side of the nerve. Common interosseous artery (CIA) was seen to originate from the brachioradial artery, while typically it is a branch of the ulnar arterial trunk.
- The brachioulnar artery (superficial ulnar artery) progressed down the medial side of the median nerve. It remained superficial in the forearm, running over the flexor muscles (except for the palmaris longus tendon), and finally ended in the superficial palmar arch.

Case 4 (Right upper limb):

The sample was a male cadaver fixed with formalin. The right brachial artery in this specimen exhibited an early bifurcation,

7.5 cm distal to the inferior border of the teres major muscle.

- Arterial pattern (according to Rodríguez-Niedenführ): High division of the brachial trunk into brachioradial artery and brachioulnar artery.

Course and relations:

- **Brachioradial artery:** Entered the anterior compartment of the arm, crossed the cubital fossa, and finally passed deep to the brachioradialis muscle in the forearm alongside the radial nerve.
- **Brachioulnar artery:** Continued as the main branch of the brachial artery, passing deep to the deep head of the pronator teres muscle.
- **Nerves:** In the proximal arm, the trunk of the brachial artery was located medial to the ulnar nerve. However, in the middle third of the arm, the median nerve crossed the artery trunk superficially, from lateral to medial.
- The left upper limb had a normal arterial pattern.

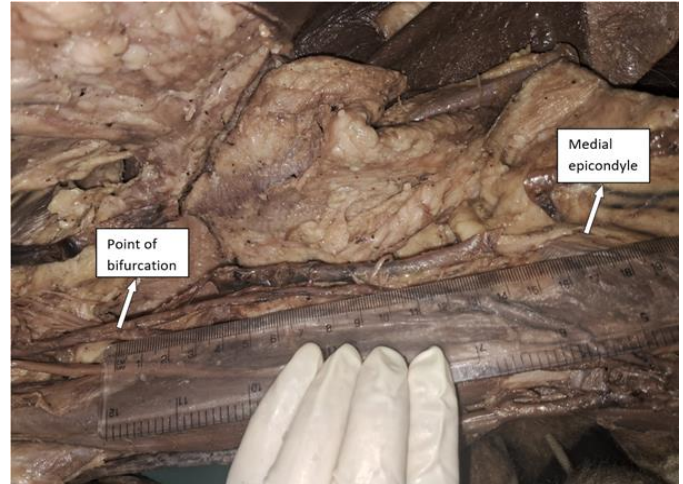


Figure 3: The level of bifurcation was found 17.0 cm proximal to the medial epicondyle (ME) of the humerus.



Figure 1: Dissection of the right anterior arm (case 1) reveals high division of the brachial artery (BA) into the brachioradial (BRA) and brachioulnar (BUA) arteries.

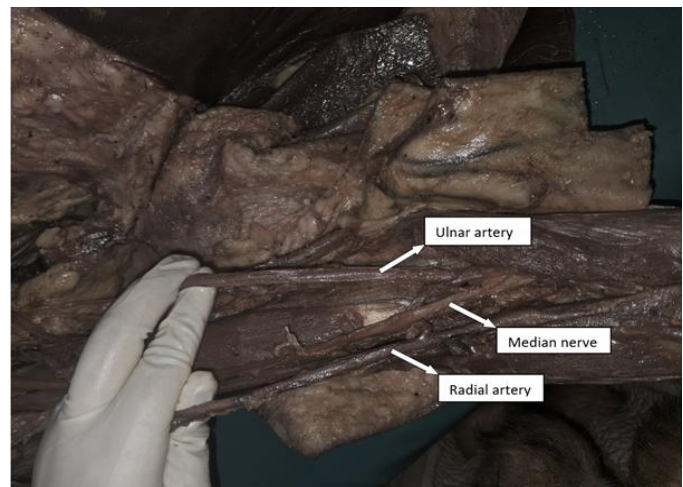


Figure 4: The relation of the median nerve (MN) to the brachioradial and brachioulnar arteries in the cubital fossa (case 1).



Figure 2: The measurement of the dissection site shows high level of bifurcation, 11.5 cm distally from the tip of the coracoid process (CP).



Figure 5: Dissection of the contralateral arm (case 1) demonstrates the absence of high-level division of the brachial artery.

RESULTS

Starting in March 2021, we conducted 40 upper-limb dissections at the Anatomy Department of our institution. I was directly involved in 10 of these dissections, with the

faculty taking the lead on approximately 30. During this series, we observed variations in the branching pattern and course of the brachial artery, including its terminal branches, in the upper limbs of four cadavers.

Table 1: showing summary of Observed Variations

Case	Sex / Side	Rodríguez-Niedenführ Classification	Level & Distance of Bifurcation from Coracoid Process	Origin Diameters	Course & Atypical Branching	Median Nerve Relationship	Laterality
Case 1	Male / Right	Brachioradial + Brachioulnar artery	Mid-arm; 11.5 cm distal to coracoid process	Brachioradial: 3.0 mm; Brachioulnar: 2.5 mm	Standard terminal distribution in forearm	MN superficial to both branches in mid-arm; deep to brachioradial artery in cubital fossa	Unilateral; contralateral limb normal
Case 2	Female / Left	Brachioradial + Brachioulnar artery	Proximal one-third of arm; 10.0 cm distal to coracoid process	Brachioradial: 3.0 mm; Brachioulnar: 3.0 mm	Common interosseous artery (CIA) arises from brachioulnar artery in cubital fossa	MN crosses brachioulnar artery superficially from lateral to medial	Unilateral; contralateral limb normal
Case 3	Male / Bilateral	Brachioradial + Superficial brachioulnar artery	Proximal one-third of arm; Right: 9.5 cm; Left: 10.0 cm distal to coracoid process	Brachioradial: 3.8 mm; Brachioulnar: 2.5 mm	CIA arises atypically from brachioradial artery; brachioulnar artery descends superficial to forearm flexors	Main trunk lateral to MN; brachioulnar artery medial to MN	Bilateral; symmetrical variation
Case 4	Male / Right	Brachioradial + Brachioulnar artery	Upper arm; 9.5 cm distal to coracoid process	Brachioradial: 3.1 mm; Brachioulnar: 2.8 mm	Brachioradial artery courses superficial to brachialis; brachioulnar artery forms main axial trunk	MN crosses brachial trunk superficially from lateral to medial in mid-arm	Unilateral; contralateral limb normal

Abbreviations: MN, Median Nerve; CIA, Common Interosseous Artery.

DISCUSSION

Arterial variations of the upper limb are common; however, their frequency differs among different populations and even among different series of cadavers. In the present study, we found high bifurcation of the brachial artery on 5 out of 40 dissected upper limbs, or 12.5%. This is probably a reasonable number for arterial variation, which is frequently reported in the literature. For example, Ozcan et al,^[21] estimated a frequency of arterial variations of the upper limb from 4.4 to 8.3% while high origin of the radial artery occurred in 12.5% of cases.^[21] In contrast, low origin of the radial artery was found to be rare (0.2%).^[21,22] Thus, the frequency found in our study (12.5%) may be similar to the frequency of high origin of the radial artery. However, in our study, we found a high bifurcation of the brachial artery, rather than a high origin of the radial artery. Compared to the previously reported arterial variation,

absence of the radial artery is even more rare, being found in only 0.03% of cases.^[23] According to Sargon et al,^[24] high origin of the radial artery from the medial superior aspect of the brachial artery was found 16.7 cm distal to the coracoid process. From this point, the artery crossed anterior to the brachial artery and ran laterally to it descending on the forearm over the bicipital aponeurosis.^[24] In our study, the distance from the coracoid process to the bifurcation of the brachial artery varied from 9.5 to 11.5 cm with the mean distance being 10.5 cm. Thus, the bifurcation points found in our study were more proximal than the one described by Sargon et al.^[24] However, the variation found in our study was not unique. On the contrary, the use of the coracoid process as the distal border for measuring allowed us to perform a reliable comparison to find out how different in different cases the bifurcation points of the brachial artery can be.

Table 2: showing Comparison with Sargon et al.^[24]

Case	Present Case: Distance from Coracoid Process	Sargon et al. ^[24]	Difference
Case 1	11.5 cm	16.7 cm	5.2 cm proximal
Case 2	10.0 cm	16.7 cm	6.7 cm proximal
Case3- right	9.5 cm	16.7 cm	7.2 cm proximal
Case3- left	10.0 cm	16.7 cm	6.7 cm proximal
Case 4	9.5 cm	16.7 cm	7.2 cm proximal

The level of high brachial artery bifurcation in the present series was measured off the coracoid process for comparison purposes. The distance from the coracoid process to the level of bifurcation was 11.5 cm in Case 1, 10 cm in Case 2, 9.5 cm on the right and 10 cm on the left in Case 3, and 9.5 cm in Case 4. All of these measurements were proximal to the 16.7 cm level reported by Sargon et al,^[24] for high origin of the radial artery. Thus, the present series confirms significant variability not only in patterns of arterial branching but also in levels of high bifurcation, and emphasizes the importance of reporting this level.

Sargon et al. report a high origin of the radial artery, while present cases demonstrate high bifurcation of the brachial artery into brachioradial and brachioulnar arteries. Therefore, while these measurements can be compared to theirs as a morphometric data, present cases represent the different anatomical variation as those described by Sargon et al.

According to the research conducted by McCormack et al,^[1] on 750 cadavers, the prevalence of upper limb arterial

variation was 18.53%. The researchers also found that unilateral and bilateral variations occurred at 24.45% and 6.32%, respectively.^[1] In addition, they found that right sides had higher prevalence of anatomical variations than the left sides did. In this research, high brachial artery bifurcation was found in 4 out of 20 cadavers (20%), which accounted for 5 of 40 upper limbs (12.5%). Unilateral variation was observed in only 3 out of 20 cadavers (15%), while bilateral variation was found in 1 out of 20 cadavers (5%). The right side was affected in 3 of 5 upper limbs with variation, while the left side was affected in 2 of them. Thus, 5% of cadavers had bilateral variation, 15% of cadavers had unilateral variation, and 20% of cadavers had variation in the high brachial artery bifurcation. This prevalence is comparable to the one of upper-limb arterial variation in general (18.53%) found by McCormack et al.^[1] It should be noted that this study investigates only high brachial artery bifurcation, while the study by McCormack et al,^[1] includes all possible variation.

Table 3: showing comparison with McCormack et al.^[1]

Parameter	McCormack et al. ^[1]	Present study
Cadavers	750	20
Upper limbs	1500	40
Overall arterial variation	18.53%	20% of cadavers
Unilateral variation	24.45%*	15% of cadavers
Bilateral variation	6.32%*	5% of cadavers
Right-sided predominance	Reported	3 right vs. 2 left affected limbs

Bidarkotimath et al,^[22] studied arterial patterns of the upper limb in 50 cadavers (100 limbs) and reported two cases of high division of the brachial artery in which the brachial artery bifurcated in the middle of the arm into radial and ulnar arteries. In our present series of study, we found 4 (out of 20) cadavers to be positive and 5 (out of 40) upper limbs for high brachial artery bifurcation. Thus, the prevalence rate recorded in our case series is higher than the prevalence rate reported by Bidarkotimath et al.^[22] However, while comparing the prevalence rates, caution must be exercised as our study was done keeping high brachial artery bifurcation as inclusion criterion and it was bilateral but the series by Bidarkotimath et al. described the wide range of variation. The published article by Bidarkotimath et al,^[22] shows inconsistent data regarding the number of cadavers and limbs in methods and discussion. While talking about methods, it says “in 50 cadavers (100 limbs)” but later in the discussion section it talks about three different variations of the brachial artery in 60 limbs. So, we compared only those two cases which they clearly mentioned in the result section.

Morphologically, the origin of the common interosseous artery (CIA) from the brachioulnar artery (Case 2) or directly from the brachioradial artery (Case 3) represents a crucial anatomical departure from standard textbook anatomy, where the CIA arises as a branch of the ulnar artery distal to the apex of the cubital fossa. Furthermore, the variable topographical relationship between the variant arterial trunks and the median nerve—such as the median nerve crossing the brachioulnar artery superficially in Cases 2 and 4, or riding deep to the early bifurcation in Case 1—underscores the positional

plasticity of neurovascular development in the arm.

Embryological Basis

Developmental theories related to the arterial development of the upper limb are controversial. However, studies related to embryos with the aid of 3-dimensional reconstructive imaging along with molecular and genetic studies have provided an overview of arterial development. Vasculogenesis initiates the development of the blood vessel through the action of signaling pathways, which activate hemangioblasts and endothelial cells to form a primitive tubular network. The cells involved differentiate into arterial and venous endothelial cells to form the main capillary plexus. This plexus undergoes angiogenesis, which is a remodeling and sprouting process controlled by the balance of the activators and inhibitors involved in the signaling pathways. Capillary plexus extends in the upper limb by the 28th day of embryonic development.

Capillary maturation proceeds in a proximodistal pattern of differentiation where segments of the capillary plexus are either maintained, enlarged, or pruned according to the tissues' needs. Oxygenation and nutrient availability affect maturation. The axillary and brachial arteries have developed up to the 41st day. The forearm arteries have developed with their branches up to the 44th day, except for the distal radial artery. The presence of variant forearm arteries suggests that vessel formation has been disrupted between the 41st and 44th days of embryonic development.^[4]

Understanding the clinical variations of BA requires referring to the development of upper limb vessels in embryogenesis. Each of the embryo's upper limbs is provided by an axis

artery derived from a seventh intersegmental artery. The ventral axial line along which the axis artery grows distally terminates in a palmar capillary plexus. Axillary artery, brachial artery, anterior interosseous artery, and deep palmar arch are derived from the main trunk of the axis artery.^[10-12]

Clinical significance of the BA

Clinically, the BA is important in the measurement of blood pressure, since it is always in the region of the cubital fossa where the stethoscope is placed during measurement of auscultatory blood pressure. This is directly related to the superficial position of the artery relative to the skin. The BA also participates in the measurement of oscillometric pressure whereby the blood pressure cuff is placed on the distal and medial part of the arm circling the space between the biceps brachii and triceps brachii.

The hand has a complex and rich vascular network, and its most important arterial supply comes from the two terminal branches of the BA. Since both RA and UA contribute to the superficial and deep palmar arch, the occlusion of one of these arteries does not obstruct the blood supply of the hand completely. The Allen test is used to assess collateral blood flow to the hands and it is particularly useful in preparing for a procedure that may interrupt blood flow in either the radial or the ulnar artery.^[6] The Allen test can easily be performed and may be done with just a clinician's hands: the hand is exsanguinated by having the patient squeeze their fist tightly. The UA and RA are occluded by manual pressure, the patient relaxes the hand, and the pressure over the UA is released. Time required for the return of normal coloration of skin is measured to assess collateral flow. A return time less than 5 s indicates good collateral flow, a return between 5-10 s is an equivocal test, and a return of longer than 10 s indicates poor collateral circulation of the blood.^[7]

The elbow cubital anastomosis or the peri-articular arterial anastomoses of the elbow is an anatomical structure in the nature of vessels. This network is supplied with arterial blood from the superior and inferior ulnar collateral arteries, branches from the DBA, branches from the RA (radial recurrent artery) and branches from the UA (ulnar recurrent artery).^[5] The cubital anastomosis of the elbow is responsible for supplying the elbow joint and its supporting structures. A network of arterial vessels allows oxygenated blood to circulate around the elbow joint no matter which position the joint is in. It provides proper nutrition to the structures of the ligaments and joint capsule, thus minimalizing the risk of insufficient vascularization.

Supracondylar fractures of the humerus are seen in children. It has been reported that fully displaced supracondylar fractures in children have vascular injuries in 12% of cases, with injuries of the brachial artery predominating. Brachial artery occlusion is a significant vascular complication occurring with this injury; subsequently, the risk of loss of the limb is possible. Limb claudication can also be considered as another vascular complication, which may result from either the dislodgment of a thrombus at the site of restricted flow or incomplete repair of the brachial artery.^[8,9] Superficially placed radial or ulnar arteries may also be mistaken for veins, increasing the risk of accidental arterial injection.

CONCLUSION

A comprehensive understanding of the vascular anatomy of the upper limb, including its variations, is vital for anatomists, surgeons, radiologists, and other clinicians. Such knowledge helps to avoid mistakes in diagnosis and complications during surgery. Regularly recognizing these patterns during dissection exercises and in clinical settings emphasizes the need for anatomical training that emphasizes variation as a fundamental aspect, rather than focusing solely on idealized, standard models.

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Conflicts of interest

There are no conflicts of interest.

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