Health & Research Journal

Vol 8, No 2 (2022)

Volume 8 Issue 2 April - June 2022

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doi: 10.12681/healthresj.30133

HEALTH AND RESEARCH JOURNAL
E-ISSN:2459-3192

(2022), Volume 8, Issue 2

REVIEW

ANATOMICAL VARIATIONS OF FOREARM ARTERIES: A LITERATURE REVIEW

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Abstract

Introduction: The formation of the arterial system of the upper limb takes place in several stages during embryonic development. Several arterial variations in the branching pattern are observed and studied. It is suggested that arterial variants of the arm and forearm arise through the persistence, enlargement and differentiation of parts of the initial arterial network which would normally remain as capillaries or even regress. The present review aims at the anatomical approach of the arm and forearm with special reference to the variations of the arteries in these anatomical areas.

Methods: We conducted a search of reviews using the PubMed Database and the Book of Radiology by Wacker F. et al (2017) referring to the anatomical variants of the forearm and their frequency in the general population.

Results: Regular hematosis of the forearm (with the presence of the radial, the ulnar and the interosseous artery) was studied in 81 out of 100 bodies at the Laboratory of the Descriptive Anatomy of the Medical School, University of Athens. All the forearm's arteries ramify from the brachial artery at 68%. All the forearm's arteries ramify from the superficial brachial artery at 7%. Forearm's superficial arteries are present in 10%. Presence of the median artery (embryo remnant) is found at a rate of 9%.

Conclusions: The anatomical variants of the arteries of the arm and forearm are related to the clinical practice. The deeper knowledge of the above anatomical variants of the arteries is especially important for surgeons, when they perform invasive procedures, such as the elevation of radial forearm flap or dermal flap. It is also of great importance for radiologists and orthopaedic and plastic surgeons for the proper design of surgical procedures involving the arteries of the upper limb. Finally, the peripheral branch pattern of the brachial artery is important for vascular surgeons.

Keywords: Anatomical variation, arterial variation, arm, forearm, artery.

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Cite as: Chrysoglou, C-L., Michalis, I., Goula, M., Troupis, T. (2022). Anatomical variations of forearm arteries: a literature review. Health and Research Journal,8(2),80-89. https://ejournals.epublishing.ekt.gr/index.php/HealthResJ

INTRODUCTION

The formation of the arterial system of the upper limb takes place in several stages during the embryonic development. It is suggested that the arteries of the upper limb are originated from a central vascular trunk, forming a common interosseous artery and a median artery associated with the median nerve. The median artery sustains the main blood supply, as the interosseous artery regresses. As the development continues, the capillaries of the ulnar and the radial side of the forearm enlarge, in order to form the ulnar and radial arteries and replace the median artery. In some cases, the interosseous and the median artery remain in the adult life.[1]

The variations of the arteries of the upper limb are very common. Their existence range from 10 to 55%. It is suggested that they arise from the persistence of arteries which normally regress during the embryonic development. However, little is known about how or when during development these variations arise.[2, 3, 4, 5]

There are several anatomical variations of the main arteries of the forearm. They are named after topographic criteria (brachial, radial, ulnar) and their course in the arm (superficial etc.).

Below is a brief presentation of each arterial variation, its origin and course.[5]

There are two main variations of the brachial artery:

1) Superficial brachial artery:

It is a brachial artery coursing superficially in front of the median nerve. It crosses the median nerve roots above in 36% and below them in 63% of cases. It gives a small branch which remains behind the median nerve and provides collateral branches to the biceps brachii muscle. After adopting its superficial course, at the level of the elbow it branches into the radial and ulnar arteries.[5]

2) Accessory brachial artery:

It originates from the upper third of the brachial artery. It crosses anterior to the median nerve and rejoins the brachial artery at the level of the elbow, before its division to the forearm arteries.[5]

The variations of the arteries at the area of the brachium-antebrachium are the following:

1) Brachioradial artery:

It is a radial artery with high origin. It originates in 23% from the axillary artery and in 77% from the brachial artery (from the upper third of the brachial artery in 65,4%, the middle third in 7,7% and the lower third in 3,9% of cases). It courses superficially to the median nerve. In 64% it passes posterior to the bicipital aponeurosis at the elbow and in 36% it passes anterior to the aponeurosis. In some cases the brachioradial artery anastomoses with the deep brachial artery at the elbow.[5]

2) Superficial brachioulnar artery:

Is an ulnar artery with high origin. In some cases it originates from the axillary artery. In other cases it is originated from the brachial artery. It crosses the median nerve and continues superficially to it. It can pass posterior to the bicipital aponeurosis, anterior to it or even pierce it. In the forearm, it passes beneath the deep fascia and between the superficial forearm flexor muscles and adopts its final course to the ulnar side of the forearm.[5]

3) Brachioulnar artery:

Is an ulnar artery with high origin. It can originate from the axillary artery. It crosses the median nerve in the arm, passes behind the bicipital aponeurosis and continues a normal course of the ulnar artery in the forearm and hand.[5]

4) Superficial brachioulnoradial artery:

It is a superficial brachial artery which branches into ulnar and radial arteries at the level of the elbow and coexists with the normal brachial artery.[5]

The arterial variations that are located exclusively in the antebrachium:

1) Superficial radial artery:

It is defined as radial artery with normal origin which crosses over the tendons which define the snuffbox at the level of the wrist. It is a very rare finding.[5]

2) Duplication of the radial artery:

The proximal radial artery originates from the brachial and provides blood supply to the upper third of the forearm and the distal radial artery, which originates from the anterior interosseous artery, supplies the lower forearm and hand.[5]

3) Absence of the radial artery:

In this case the blood supply is provided from the anterior interosseous artery or the median artery.[5]

4) Duplication of the ulnar artery:

It usually co exists with the superficial brachioulnar artery.[5]

5) Absence of the ulnar artery:

In this case the blood circulation is replaced by the radial or the interosseous artery.[5]

6) Median artery:

It is present during early embryonic life and normally regresses the second embryonic month. This reverse may take place latter during embryonic development, leaving branches of the median artery that persist in adult life. There are two types of the median artery, the antebrachial and the palmar type. The antebrachial type represents a median artery with partial regression, thus it is short and terminates before the wrist. On the contrary, the palmar type is long, large and reaches the palm. The antebrachial type most frequently originates from the anterior interosseous artery. The palmar type originates from the caudal angle between the ulnar and the common interosseous artery. Other possible origins for both patterns is the ulnar artery or the common interosseous artery.[5, 6]

MATERIALS AND METHODS

We conducted a search of reviews referring to the anatomical variants of the forearm and their frequency in the general population in the PubMed Database and the Book of Radiology by Wacker F. et al (2017). Inclusion criteria were relevance to the subject and thorough examination of multiple anatomical variations in cadavers or embryos. We included a total of 14 studies and the Book of Radiology by Wacker F. et al.

RESULTS

1. Superficial Brachial Artery (SBA)

In the study of *Kachlik et al*, 130 preparations of upper limbs of the cadaverous material (Czech population, Caucasian race, 44-89 years old, 61 males, 69 females) were included. The incidence of the superficial brachial artery was 5% of cases.[7]

Hee-Jun Yang et al found an SBA of axillary origin in 12.2% of cadaveric arms. Unilateral occurrence was detected in 16 cadavers and bilateral in 10. SBAs gave rise to radial and ulnar arteries in the cubital fossa (8.9%), continued in the forearm as the radial artery (2.3%), or ended in the upper arm (1.0%). The SBA ended as ulnar artery was not found in any of the cadavers. The bifurcation of the SBA into the radial and ulnar arteries, presence of an SBA that ends in the upper arm, and the lack of continuation as the ulnar artery are characteristics of SBAs in Korean cadavers.[8]

The study of *Rodríguez-Niedenführ et al* in human cadavers showed that the superficial brachial artery variant was found in 10 male cadavers (11%), one case bilaterally and 9 cases unilaterally (5 right, 4 left) and in 8 female cadavers (7.9%) unilaterally (5 right, 3 left). The total incidence of the SBA was 18 of 192 cadavers (9.4%) or 19 of 384 upper limbs (4.9%). There was no statistically significant difference between males and females or right and left sides. In this study, the brachial artery adopted its course superficial to the median nerve, crossing above the median nerve roots in 7 cases (36.8%) and below them in 12 (63.2%).[5]

Rodríguez-Niedenführ et al found that the SBA, where the course of the brachial artery was anterior rather than posterior to the median nerve was observed in 7.7% of a total of 168 upper limbs (13 human embryos).[9]

2. Accessory Brachial Artery

In the study of *Chakravarthi et al* with 140 upper limb specimens of 70 cadavers (35 males and 35 females) the accessory brachial artery was noted in eight female cadavers (11.43%). Out of eight cadavers in three cadavers (4.29%) an unusual bilateral accessory brachial artery arising from the axillary artery and it is continuing in the forearm as superficial accessory ulnar artery was noted. Rare unusual variant unilateral accessory brachial artery and its reunion with the main brachial artery in the cubital fossa and its variable course in relation to the musculocutaneous nerve and median nerve were also noted in five cadavers (7.14%). No anatomical variations were found in male cadavers.[10]

The study of *Rodríguez-Niedenführ et al* in human cadavers found only one male cadaver with an accessory brachial artery unilaterally. The total incidence of this variation was 1 in 192 (0.52%) or 1 in 384 upper limbs (0.26%).[5]

In the study of *Rodríguez-Niedenführ et al* in human embryos the accessory brachial artery, where a second brachial artery originates from the axillary, coursing in front of the median

nerve and rejoining the brachial artery before reaching the elbow was observed in 1 out of 168 upper limbs (0.6%).[9]

3. Brachioradial Artery

Haladaj et al observed that the radial artery was found to have a high origin in 9.2% of total number of the limbs: two cases from the axillary artery and nine cases from the brachial artery. Anastomosis between the brachioradial and "normal" brachial arteries in the cubital fossa was also frequently observed (54.6%). The anastomosis was dominant in one case, balanced in three cases, minimal in two cases, and absent in five cases.[11]

McCormack et al observed that the brachioradial artery was found in 110 out of 750 upper limbs (14.6%), 59 on the right side and 51 on the left side.[12]

Natsis et al found two cases of anatomical variations of the brachioradial artery out of 48 upper limbs (4.17%).[13]

In the study of *Rodríguez-Niedenführ et al* in 192 human cadavers the brachioradial artery was present in 15 male cadavers, unilaterally in 10 cases and bilaterally in 5 cases and in 24 female cadavers, unilaterally in 15 and bilaterally in 9. The total incidence of the brachioradial artery was 39 out of 192 cadavers (20.3%) and 53 out of 384 upper limbs (13.8%). There was no statistically significant difference between males and females or right and left sides. [5]

In the study of *Rodríguez-Niedenführ et al* in human embryos the brachioradial artery was present in 21 of 150 upper limbs (14%). The brachioradial artery originated from the axillary artery in 5 (24%) cases and from the brachial artery in 16 (76%) cases.[9]

4. Superficial Brachioulnar Artery

Rodríguez-Niedenführ et al observed the presence of the superficial brachioulnar artery in 5 male cadavers, 4 unilaterally and 1 bilaterally and in 5 female cadavers, all 5 cases being bilateral. The total incidence was 10 of 192 cadavers (5.2%) and 16 of 384 upper limbs (4.2%). There was no statistically significant difference between males and females or right and left sides.[5]

Rodríguez-Niedenführ et al found 7 cases of the superficial brachioulnar artery in 150 upper limbs from human embryos (4.7%). In 3 (43%) cases it originated from the axillary, while in 4 (57%) it originated from the brachial artery.[9]

5. Brachioulnar Artery

The brachioulnar artery was found in only one male cadaver in the study of *Rodríguez-Niedenführ et al*. Therefore, the incidence was 1 in 192 cadavers (0.52%) or 1 of 384 upper limbs (0.26%).[5]

6. Superficial Branchio-ulno-radial Artery

The superficial branchio-ulno-radial artery was observed in one male and one female cadaver unilaterally in the study of *Rodríguez-Niedenführ et al*. The incidence was 2 of 192 cadavers (1.04%) and 2 of 384 upper limbs (0.52%).[5]

7. Superficial Radial Artery

Natsis et al reported the presence of the superficial radial artery in 3 cases unilaterally and 1 case bilaterally out of 96 cadavers and 192 upper limbs.[14]

Another study by *Natsis et al* found that the superficial radial artery existed in 2 cases out of 66 cadavers, both of them unilaterally.[15]

Rodríguez-Niedenführ et al reported that this arterial pattern was observed in one male cadaver bilaterally. The incidence was 1 of 192 cadavers (0.52%) or 2 of 384 upper limbs (0.52%).[5]

According to *Lappas et al* the superficial radial artery in addition to a normal radial artery was found in 1% of 100 cadavers.[16]

8. Duplication of Radial Artery

A real duplication has only been reported in once (Kadanoff & Balkansky, 1966). This variation was not found in any of the 192 cadavers in the study of Rodríguez-*Niedenführ et al*.[5]

9. Absence of radial Artery

The radial artery has been rarely reported as being totally absent, with an estimated incidence of less than 0.03%. It is a rare anatomical variant, no case were found according to *Rodríguez-Niedenführ et al*.[5]

10. Duplication of Ulnar Artery

No cases were found in 192 cadavers as reported by *Rodríguez-Niedenführ et al*.[5]

11. Absence of Ulnar Artery

Not even studies based on very large samples found it, so its incidence may be considered as lower than 0.015%. No cases were found in 192 cadavers as reported by *Rodríguez-Niedenführ et al*.[5]

12. Median Artery

In the study of *Cheruiyot et al* median arteries were observed in 37 (59.7%) cases of 62 upper limbs. Of these, the palmar type comprised 12 (32.4%) and antebrachial type 25 (67.6%) cases. It occurred bilaterally in 14 (45.2%) cases.[17]

The study of *Patnaik et al* found that the incidence of the median artery in 100 upper limbs (from 50 cadavers) was 9%. Three cases were unilateral and three cases were bilateral.[18]

In the study of *Rodríguez-Niedenführ et al* in human embryos the median artery was observed in 28 of the 150 upper limbs (18.7%).[9]

According to *Rodríguez-Niedenführ et al* the median artery may persist in adult life in 2 different patterns, palmar and antebrachial. The palmar type, which represents the embryonic pattern, is large, long and reaches the palm. The antebrachial type, which represents a partial regression of the embryonic artery is slender, short, and terminates before reaching the wrist. These 2 arterial patterns appear with a different incidence. The palmar pattern was studied in the whole sample (120 cadavers) and had an incidence of 20%, being more frequent in females than in males (1.3:1), occurring more often unilaterally. The antebrachial pattern was studied in 79 cadavers and had an incidence of 76%, being more frequent in females than in males (1.6:1); it was commoner unilaterally.[6]

Lappas et al reported that the frequency of the median artery was found to be 9% in 100 cadavers. It originated from the ulnar artery proximal or with the common interosseous artery in 3% of cases, from the ulnar artery distal to the common interosseous artery in 2%, from the common interosseous artery in 2% and from the radial artery in 2% of cases.[16]

The frequency of these variations is presented in the following tables (*Table 1*), which include the results of 11 anatomical studies and the Book of Radiology by *Wacker F. et al* as well as the percentage of the occurrence of each variation.

The results of the Book of Radiology by *Wacker F. et al* were very similar to the ones described in the study of *Lappas et al* in 100 bodies, as presented in *Table 2*.[19, 16]

DISCUSSION

The most common arterial variations according to the studies described above are the brachioradial artery with an incidence ranging from 4.17% to 14.6%, the SBA with an incidence ranging from 4.9% to 12.2% in 986 upper limbs and the median artery with an incidence from 9% to 59.7% in a total of 552 upper limbs.

The median artery may persist into adult life as 2 different patterns, palmar and antebrachial. The median artery has been considered in to different functional roles: (1) as a nutrient artery for the median nerve or (2) as an arteria comitans (satellite) chiefly concerned with the supply of structures other than the median nerve rather than as a true nutrient artery.[6]

According to Natsis et al, radial artery variations consist the largest group of arterial variations in the literature. More specifically, the high origin of the radial artery is the most common arterial variation in the upper limb. This finding is confirmed by our study wish demonstrates that the brachioradial artery is among the three most frequently reported upper limb vascular variations. This variant artery often arises from the proximal third of the brachial artery and less frequently from the axillary artery. In the forearm, the radial artery of high origin follows the course of a normal radial artery.[13]

As far as the SBA is concerned, its decreasing incidence in comparison to older studies can be attributed to new specification guidelines, classification of the variations and melioration in study methods, which have been improved thanks to the conclusions of the previous findings and observations.[7]

Arterial variations, especially those that occur more frequently, have a great clinical significance in the everyday practice of several medical specialties, such as radiologists and surgeons.

Their superficial course in the forearm makes them vulnerable to trauma. Due to their close proximity to the superficial veins, they can be catheterized by mistake. It has also been reported intra-arterial injection, with severe consequences, such as drug poisoning, occlusion and finger gangrene.

The knowledge of the arteries of the forearm and their variations has a great impact in the surgical field. More specifically, in vascular surgery the radial artery is used as graft for coronary bypass.

The superficial brachioradial and superficial brachioulnar artery may be encountered during raising a radial forearm flap, in

order to cover large skin deficits of the hand in plastic and reconstructive surgery.

Thus, it is necessary for surgeons who plan and conduct surgeries of the upper limb, firstly to determine the vascular network of the forearm with the use of Color Doppler ultrasonography or angiography.

CONCLUSIONS

The anatomical variants of the arteries of the arm and forearm are frequent and should always be taken in consideration. The deeper knowledge of the above anatomical variants of the arteries is especially important for surgeons, when conducting procedures, such as the elevation of radial forearm flap or dermal flap. It is also of great importance for radiologists, orthopaedic and plastic surgeons for the proper design of surgical procedures involving the arteries of the upper limb. Most importantly, the peripheral branch pattern of the brachial artery is crucial for vascular surgeons.

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ANNEX

TABLE 1. Arterial variations of the arm.

Variation	Authors	Year	Sample	Study	Country/population	Unilateral (R/L)	Bilateral	Male	Female
Superficial Brachial Artery	David Kachlik et al.	2011	130 upper limbs	cadavers	Czech	4 (1R / 2L)			3
	Hee-Jun Yang et al.	2008	304 upper limbs	(154) cadavers	Korean	16	10	16.1%R 8.6% L	13.6% R 10.2% L
	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		17 (10R/ 7L)	1	10 (11%)	8 (7.9%)
	M.Rodríguez-Niedenführ et al.	2001	168 upper limbs	embryos		13 (7.7%)			
Accessory Brachial Artery	Kosuri Kalyan Chakravarthi et al.	2014	140 upper limbs	(70) cadavers		5 (7.14%) (1R/4L)	3 (4.29%)		8 (11.43%)
	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadaver		1 (0.26%)			
	M.Rodríguez-Niedenführ et al.	2001	168 upper limbs	embryos		1 (0.6%)			

TABLE 1. Arterial variations of the arm and forearm.

Variation	Authors	Year	Sample	Study	Country/population	Unilateral (R/L)	Bilateral	Male	Female
Brachioradial Artery	Robert Haładaj et al.	2018	120 upper limbs	cadavers		11 (9.2%) (6R/5L)		6 (9.2%)	5 (9.1%)
	McCormack L. J. et al	1953	750 upper limbs	cadavers		110 (14.6%) (59R/51 L)			
	Natsis K. et al.	2009	48 upper limbs	cadavers	Caucasian	2 (4.17%) (1R/1L)		1	1
	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		25 (16R/9L)	14	15 (16.5%)	24 (23%)
	M.Rodríguez-Niedenführ et al.	2001	150 upper limbs	embryos		21 (14%)			
Superficial Brachioulnar Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		4 (2R/2L)	6	5 (5.5%)	5 (4.9%)
	M.Rodríguez-Niedenführ et al.	2001	150 upper limbs	embryos		7 (4.7%)			
Brachioulnar Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		1 (0.26%) (1R)		1 (1.1%)	
Superficial Brachio-ulno-radial Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		2 (0.52%) (2L)		1 (1.1%)	1 (0.99%)

TABLE 1. Arterial variations of the arm and forearm.

Variation	Authors	Year	Sample	Study	Country/population	Unilateral (R/L)	Bilateral	Male	Female
Superficial Radial Artery	Natsis K. et al.	2017	192 upper limbs	(96) cadavers		3 (2R/1L)	1		
	Natsis K. et al.	2007	132 upper limbs	(66) cadavers		2 (1R/1L)		1	1
	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers			1 (0.52%)		
	Lappas et al.	2018		(100) cadavers		1%			
Duplication of Radial Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		0 (<0.26%)			
Absence of Radial Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		0 (<0.26%)			
Duplication of Ulnar Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		0 (<0.26%)			
Absence of Ulnar Artery	M.Rodríguez-Niedenführ et al.	2001	384 upper limbs	(192) cadavers		0 (<0.26%)			
Median Artery	Isaac Cheruiyot et al.	2017	62 upper limbs	(31) cadavers	black Kenyan	9 (6R/3L)	14 (37.8%)		
	Madhumita Patnaik et al.	2016	100 upper limbs	(50) cadavers		3 (6%)	3		
	M.Rodríguez-Niedenführ et al.	2001	150 upper limbs	embryos		28 (18.7%)			
	M.Rodríguez-Niedenführ et al.	1999	240 upper limbs	(120) cadavers		55 (30R/25L)	29	29	55
	Lappas et al.	2018		(100) cadavers		9%			

TABLE 2. Normal arterial pattern and variations of the forearm.

	Lappas et al (2018)	*Wacker et al (2017)*
Normal arterial pattern of the forearm	81%	84%
All arteries of the forearm branch from the branchial artery	68%	70%
All arteries of the forearm ramify from the superficial brachial artery	7%	6%
The radial artery originates from the superficial brachial artery, and the ulnar and interosseous artery from the brachial artery	4%	5%
All arteries of the forearm ramify from the superficial brachial artery, with a large anastomosis of the brachial and the radial arteries in the cubital region	2%	3%