Variations of the arterial pattern in the upper limb revisited: a morphological and statistical study, with a review of the literature

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ABSTRACT

A total of 192 embalmed cadavers were examined in order to present a detailed study of arterial variations in the upper limb and a meta-analysis of them. The variable terminology previously used was unified into a homogenous and complete classification, with 12 categories covering all the previously reported variant patterns of the arm and forearm.

Key words: Brachial artery; radial artery; ulnar artery; median artery; interosseous artery; arterial variations; upper limb.

INTRODUCTION

Variations of the arterial patterns in the upper limb have been the subject of many anatomical studies due to their high incidence. However, some important aspects have until now remained confused or unstudied, due to the use of different terminologies (Table 1), and of different criteria for classifying and/or subclassifying them (Schwalbe, 1898; Breme, 1899; Müller, 1903; Adachi, 1928; Skopakoff, 1959; Wankoff, 1962; Fuss et al. 1985).

Furthermore, although several large-sample studies have statistically analysed the existence of arterial variations in the upper limb, most of them have included nonhomogeneous samples or incomplete extremities, and failed to describe the related morphological features of each of the separate patterns throughout their whole length in the arm and forearm (Quain, 1844; Krause, 1867; Schwalbe & Pfitzner, 1889, 1891, 1894; Stieda, 1910, 1916; Rodríguez-Cadarso, 1925; Skopakoff, 1959; Keen, 1961; Wankoff, 1962; Fuss et al. 1985, 1988; Bergman et al. 1988, 2000; Matula et al. 1990; Rodríguez-Baeza et al. 1995). It is also surprising that in such large-sample studies, there are only a few references to sex and laterality (Quain, 1844; Gruber, 1867; Hazlett, 1949; Fuss et al. 1985).

Other studies have presented accurate detailed morphological descriptions but have been unable to present the corresponding statistical data (Ramsay, 1812; Von Haller, 1813; Struthers, 1848, Gruber, 1867; Oeffinger, 1867; Pye-Smith et al. 1870; Davies-Colley et al. 1872–73; Nunn, 1874; Baker, 1883; Dunn et al. 1890; Smith, 1895; Bertacchini, 1896; Bartels 1900; Fontan & Lhereux, 1911; Fischer, 1926; Singer, 1933; Moncayo-Marques, 1941; Bianchi, 1943; Loetzke & Kleinau, 1968; Pabst & Lippert, 1968; Milani, 1975; Poteat, 1986; Fuss, 1988; Cox & Griswold, 1991; Gonzalez-Compta, 1991; Golan et al. 1994; Ozan et al. 1994; Sargon & Celik, 1994; Anil et al. 1996; Celik et al. 1996; Fadel & Amonoo-Kuofi, 1996; Içten et al. 1996; Nakatani et al. 1996, 1998*a*, *b*; Sargon et al. 1996; Diz et al. 1998; Görmüs et al. 1998; Brown et al. 1999; Yazar et al. 1999; Yuksel et al. 1999; Melling et al. 2000).

The purpose of this study, therefore, was to review the literature on arterial variations in the upper limb in order to simplify previous classifications, and to unify the terminology and morphological descriptions. The review data were then compared with

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Table 1. *Previous terminology used to define upper limb arterial variations*

Superficial brachial artery
type 3 (Fuss et al. 1985)
type II (Wankoff, 1962)
Accessory brachial artery (McCormack et al. 1953)
Inselbildung (Ruge, 1884)
high bifurcation and reunion of brachial arteries (Herrington, 1905).
Superficial brachioulnar artery (Bianchi, 1943)
arteria antebrachialis superficialis ulnaris
high origin of the ulnar artery
superficial ulnar artery
superficial brachial artery continuing as ulnar artery
superficial brachial artery continuing as superficial ulnar artery
brachial anterior continuing as ulnar artery
type 2, 4 and 7 (Fuss et al. 1985)
type IV, V and IX (Wankoff, 1962)
superficial ulnar artery with high origin
type B2 (Anagnostopoulou & Venieratos, 1999)
Brachioulnar artery
high origin of ulnar artery
superficial ulnar artery
superficial brachial artery continuing as ulnar artery
Brachioradial artery (Barkow, 1869)
a. brachialis superficialis continuing as radial artery
high origin of the radial artery
type 5 (Fuss et al. 1985)
type III, IX, XII, XIV and XV (Wankoff, 1962)
type B1 (Anagnostopoulou & Venieratos, 1999)
superficial radial artery
Superficial brachioradial artery
Brachiointerosseous artery
superficial brachial artery continuing as common interosseous artery
vas aberrans flowing into anterior interosseous
Superficial brachiomedian
arteriae brachii superficialis, antibrachii superficialis et mediana
superficial median artery
Superficial brachioulnoradial artery (Moncayo-Marques 1941).
high origin of the interosseous artery (Cruveilhier, 1851)
radioulnar trunk
type VI and X (Wankoff (1962)
type 6 (Fuss et al. 1985)
type B4 (Anagnostopoulou & Venieratos, 1999)
Superficial radial artery (Sachs, 1987)
antebrachialis dorsalis superficialis
ramus dorsalis of the radial artery
a. dorsalis radialis superficialis
Absence of the radial artery
Absence of the ulnar artery

the results of our new survey on a large and statistically reliable sample of human cadavers, to present a clear, detailed morphological and statistical analysis of the arterial variations reported in the arm and forearm.

MATERIALS AND METHODS

A total of 192 embalmed cadavers (384 upper limbs) were examined. There were 91 males and 101 females, and the age of death ranged from 56 to 103 y.

The limbs had been partially dissected by Cambridge or Cornell preclinical medical students, and then further dissected by the authors using magnification. Statistical comparisons between percentages were performed by the Chi-squared test. $P < 0.05$ was regarded as statistically significant.

RESULTS

Our results show 7 different arterial variations of the major arteries of the upper limb. They were named according to topographical criteria, based on the region/s in which they were located (brachial, radial, ulnar, or a combination of these), and also whether or not the variant vessel had a superficial course.

Table 2. *Sex and side distribution of the brachioradial, superficial brachioulnar and superficial brachial artery in 384 upper limbs*

	Brachioradial		Superficial brachioulnar		Superficial brachial	
	Left	Right	Left	Right	Left	Right
Male ($n = 91$)	9 (9.9%)	11 (12.1%)	3 (3.3%)	3 (3.3%)	5 (5.5%)	6 (6.6%)
Female ($n = 101$)	14 (13.9%)	19 (18.8%)	5 (4.9%)	5 (4.9%)	3 (3.0%)	5 (5.0%)
Total ($n = 192$)	23 (12%)	30 (15.6%)	8 (4.2%)	8 (4.2%)	8 (4.2%)	11 (5.7%)

Table 3. *Incidence of variations of the radial artery in the present study compared with the results of previous reports adapted to our criteria. The total row values are based only on the reports that made specific mention of a variation*

	Sample	BR	SBR	SR	Duplication	Absence
Quain (1844)	429	53 (12%)	1 (0.23%)	3 (0.69%)	0 (< 0.23%)	0 (< 0.23%)
Müller (1903)	300	41 (13.7%)	—	—	0 (< 0.33%)	0 (< 0.33%)
Adachi (1928)	—	29/410 (7%)	1/698 (0.14%)	7/698 (1%)	0 (< 0.24%)	0 (< 0.24%)
McCormack (1953)	750	107 (14.3%)	1 (0.13%)	5 (0.7%)	0 (< 0.13%)	0 (< 0.13%)
Weathersby (1956*a*)	408	64 (15.6%)	—	—	0 (< 0.25%)	0 (< 0.25%)
Skopakoff (1959)	610	55 (9%)	—	—	0 (< 0.16%)	—
Keen (1961)	284	17 (5.9%)	0 (< 0.35%)	3 (1%)	0 (< 0.35%)	0 (< 0.35%)
Wankoff (1962)	800	78 (9.7%)	—	—	0 (< 0.125%)	—
Rodríguez-Baeza (1995)	150	6 (4%)	0 (< 0.67%)	0 (< 0.67%)	0 (< 0.67%)	0 (< 0.67%)
Our results (2000)	384	53 (13.8%)	0 (< 0.26%)	2 (0.52%)	0 (< 0.26%)	0 (< 0.26%)
Total		504/4525 (11.1%)	3/2695 (0.24%)	20/2695 (0.74%)	0/4525 (< 0.02%)	0/3115 (< 0.03%)

BR, brachioradial artery; SBR, superficial brachioradial artery; SR, superficial radial artery.

Each of the variations found in the present study are analysed separately below.

1. Superficial brachial artery (Fig. 1*a*). This is a brachial artery coursing in front of rather than behind the median nerve.

In our sample this variant was found in 10 male cadavers (11%), 1 case bilaterally and 9 cases unilaterally (5 right, 4 left). It was also found in 8 female cadavers (7.9%), all *cases* unilaterally (5 right, 3 left). Consequently the total incidence of the superficial brachial artery was 18 of 192 cadavers (9.4%), or 19 of 384 upper limbs (4.9%) (table 2). The Chi-squared test did not show statistically significant differences between males and females ($\chi^2 = 0.8837$, $P > 0.05$), or right and left sides ($\chi^2 = 0.4983$; $P > 0.05$).

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%).

The superficial brachial artery gives off a small branch which remains behind the median nerve and provides collateral branches to the biceps brachii muscle.

After adopting its superficial course, the superficial brachial artery does not show relevant morphological details, and at the level of the elbow it branches into the forearm arteries.

2. Accessory brachial artery (Fig. 1*b*). This originates above the elbow level from the upper third of the brachial artery. It crosses anterior to the median nerve to rejoin proximal to the elbow with the brachial artery, before its division into ulnar and radial arteries.

In our sample this was found in only 1 male cadaver (1.1%), unilaterally on the right side. Consequently the total incidence of this variation was 1 of 192 cadavers (0.52%), or 1 of 384 upper limbs (0.26%).

3. Brachioradial artery (Figs 2, 3). This is defined as a radial artery with a high origin.

We found this in 15 male cadavers (16.5%), unilaterally in 10 cases (6 right, 4 left) and bilaterally in 5. It was found in 24 female cadavers (23.8%), with 15 cases unilateral (10 right, 5 left) and 9 bilateral. Consequently, the total incidence of the brachioradial artery was 39 out of 192 cadavers (20.3%) or 53 out of 384 upper limbs (13.8%) (Tables 2, 3). The Chi-squared test did not show statistically significant differences between males and females ($\chi^2 = 2.3012$, $P > 0.05$), or right and left sides ($\chi^2 = 1.0725$, $P > 0.05$).

The brachioradial artery originated from the axillary artery (Fig. 2) in 12 cases (23%), the upper third of the brachial (Fig. 3*a*, *b*) in 34 (65.4%), the middle third of the brachial (Fig. 3*c*) in 4 (7.7%) and

Table 4. *Origins of brachioradial artery in the present study compared with previous reports based on large samples. The total row values are based only on those studies that made specific mention of the origin*

	Cases	Axilar	Brachial	Upper 1/3	Middle 1/3	Inferior 1/3	SB
Quain (1844)	53	16 (30%)	37 (70%)	19 (35.9%)	13 (24.6%)	5 (9.5%)	0
Müller (1903)	31	8 (25.8%)	23 (74.2%)	22 (71%)	1 (3.2%)	0	0
Adachi (1928)	29	9 (31%)	20 (69%)	—	—	—	—
McCormack (1953)	107	16 (15%)	91 (85%)	—	—	—	—
Weathersby (1956*a*)	64	16 (25%)	48 (75%)	—	—	—	—
Skopakoff (1959)	—	—	—	—	—	—	3
Wankoff (1962)	—	—	—	—	—	—	—
Karlsson (1982)	8	1 (12.5%)	7 (87.5%)	5 (62.5%)	2 (25%)	0	—
Uglietta (1989)	8	1 (12.5%)	7 (87.5%)	2 (25%)	2 (25%)	3 (37.5%)	—
Rodríguez-Baeza (1995)	6	1 (16.7%)	5 (83.3%)	3 (50%)	1 (16.65%)	1 (16.65%)	0
Our results (2000)	52	12 (23%)	40 (77%)	34 (65.4%)	4 (7.7%)	2 (3.9%)	0
Total results	358	80/358 (22.3%)	278/358 (77.7%)	85/119 (71.5%)	23/119 (19.3%)	11/119 (9.2%)	—

SB, superficial brachial artery.

Table 5. *Incidence of variations of the ulnar artery in the present study compred with previous reports adapted to our criteria*

	Sample	SBU (%)	BU (%)	Duplication (%)	Absence (%)
Quain (1844)	429	30 (7%)	1 (0.23%)	0 (< 0.23%)	0 (< 0.23%)
Gruber (1867)	—	20/700 (2.9%)	—	2/1200 (0.17%)	0 (< 0.08%)
Breme (1899)	388	7 (1.8%)	3 (0.8%)	1 (0.25%)	0 (< 0.25%)
Müller (1903)	100	2 (2%)	0 (< 1%)	0 (< 1%)	0 (< 1%)
Adachi (1828)	1198	8 (0.7%)	0 (< 0.25%)	0 (< 0.25%)	0 (< 0.25%)
McCormack (1953)	750	12 (1.6%)	5 (0.7%)	0 (< 0.13%)	0 (< 0.13%)
Weathersby (1956*a*)	408	10 (2.5%)	5 (1.2%)	0 (< 0.25%)	0 (< 0.25%)
Skopakoff (1959)	610	21 (3.4%)	1 (0.16%)	0 (< 0.16%)	0 (< 0.16%)
Keen (1961)	284	8 (2.8%)	0 (< 0.35%)	0 (< 0.35%)	0 (< 0.35%)
Wankoff (1962)	600	24 (4%)	1 (0.12%)	0 (< 0.12%)	0 (< 0.12%)
Fuss et al. (1985)	200	3 (1.5%)	0 (< 1.2%)	0 (< 1.2%)	0 (< 1.22%)
Rodríguez-Baeza (1995)	150	7 (4.6%)	1 (0.7%)	0 (< 0.67%)	0 (< 0.67%)
Our results (2000)	384	16 (4.2%)	1 (0.26%)	0 (< 0.26%)	0 (< 0.26%)
Total		168/6201 (2.7%)	18/5501 (0.33%)	3/6701 (0.045%)	0/6701 (< 0.015%)

SBU, superficial brachioulnoradial artery; BU, brachioulnoradial artery.

the lower third of the brachial artery in 2 (3.9%) (Table 4). In 1 case, its origin could not be determined.

The brachioradial artery runs superficial to the median nerve along the arm. In our sample, at the elbow fossa it passed anterior to the bicipital aponeurosis in 18 cases (36%) (Fig. 2*a*) and posterior to it in 32 cases (64%) (Fig. 2*b*); we could not obtain data in 3 cases.

At the elbow fossa the brachioradial artery anastomosed with the deep brachial artery in 14 cases (26.4%). This anastomosis adopted a rectilinear form in 4 cases (2 in front of and 2 behind the bicipital tendon) and a sling-like loop morphology in 10 cases (6 in front of and 4 behind the bicipital tendon). In the latter cases, the caliber before the anastomosis was smaller than after it (Figs. 2 & 3*a*).

When a brachioradial artery was present, the radial recurrent artery originated from it in 23 cases (46%) (Fig. 3*b*), from the deep brachial artery in 17 cases (34%), and from the anastomosis between those vessels in 10 cases (20%) (Fig. 2*a*, *b*). In 3 cases the origin of the radial recurrent artery could not be recorded due to previous preclinical student dissection. A second radial recurrent artery was present in 12 cases (22.6%), passing behind the bicipital tendon.

In the forearm, the brachioradial artery adopted the morphology of a normal radial artery.

In 1 case (0.26% of upper limbs), a large median artery originated from the lower third of the brachioradial artery and joined the median nerve to course with it through the carpal tunnel (Fig. 3*b*).

4. Superficial radial artery. This is defined as a radial artery with a normal origin, which at the wrist level crosses over the tendons which define the snuffbox. In 1 case in our sample, before crossing

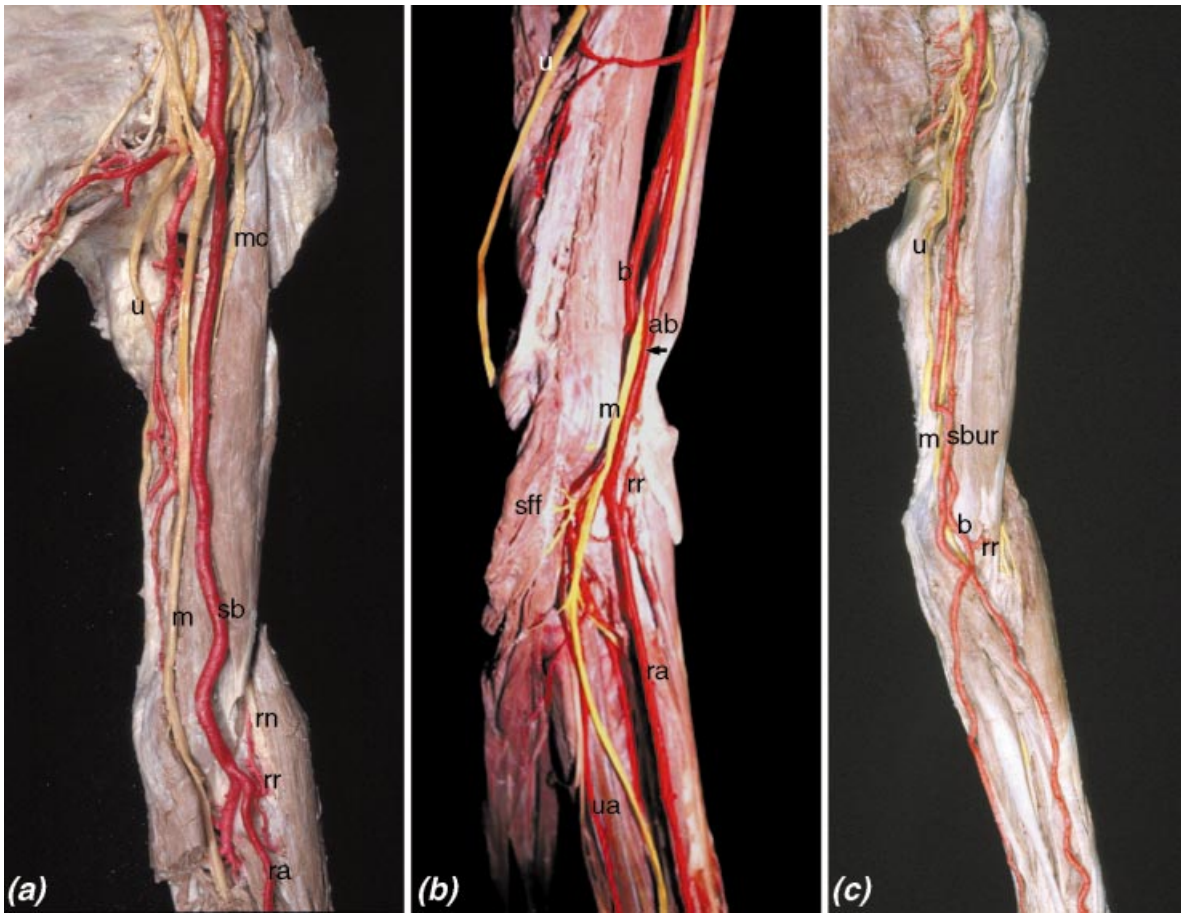

Fig. 1. Variations in the course and numbers of the brachial artery. (*a*) Superficial brachial artery (ab). Note the arrow indicating the point where the accessory brachial and the brachial (b) arteries rejoin. (*b*) Accessory brachial artery. (*c*) Superficial brachioulnoradial artery (sbur). Ra, radial artery; rr, radial recurrent artery; ua, ulnar artery; m, median nerve; u, ulnar nerve; mc, musculocutaneous nerve; rn, radial nerve; sff, superficial forearm flexor mucles.

those tendons it gave off a median artery that joined the median nerve to pass through the carpal tunnel.

This arterial pattern was observed in 1 male cadaver (1.1%), bilaterally. Consequently, its incidence was 1 of 192 cadavers (0.52%) or 2 of 384 upper limbs (0.52%) (Table 3).

5. *Superficial brachioulnar artery* (*SBU*) (Figs 4–6). This is defined as an ulnar artery with a high origin, and which courses over the superficial forearm flexor muscles. This was found in 5 male cadavers (5.5%), in 4 cases unilaterally (2 right, 2 left) and in 1 case bilaterally. It was also found in 5 female cadavers (4.9%), all 5 cases being bilateral. Therefore its total incidence was 10 of 192 cadavers (5.2%) or 16 of 384 upper limbs (4.2%) (Tables 2, 5). The Chi-squared test did not show statistically significant differences between males and females ($\chi^2 = 0.6559$, $P > 0.05$), or right and left sides ($\chi^2 = 0$, $P > 0.05$).

The SBU arose from the axillary artery (Fig. 4*a*) in 4 of the 16 examples with this pattern (25%), the upper third of the brachial (Fig. 5*a*) in 6 (37.5%), and the lower third of the brachial (Fig. 5*b*) in 3 (18.75%). In 3 of the specimens (18.75%), it originated from the lower third of a superficial brachial artery (Fig. 6*a*) (Table 6).

After its origin at the axillary artery, the SBU continues superficially crossing the median nerve roots to follow a course superficial to the median nerve along the arm (Fig. 4*a*); in cases originating from the brachial artery, it also crosses the median nerve to run superficial to it along the arm (Fig. 5*a*). In all cases it runs under the brachial fascia.

The SBU at the elbow passed deep to the bicipital aponeurosis in 9 of the 16 cases (56.25%) and superficial to it in 6 (37.5%). In 1 specimen (6.25%), the variant artery pierced the bicipital aponeurosis (Fig. 6*b*).

In the forearm of all the cases, the artery adopted a course beneath the deep fascia and then ran between the superficial forearm flexor muscles and the deep antebrachial fascia to lie alongside the flexor carpi ulnaris muscle and eventually adopt its usual position on the lateral aspect of the ulnar nerve in the middle third of the forearm (Fig. 4*a*).

Table 6. *Origins of the superficial brachioulnar artery in the present study compared with previous reports based on large samples. The total row values are based only on those studies which made specific mention about the origin*

	Cases	Axilar	Brachial	Upper 1/3	Middle 1/3	Inferior 1/3	SB
Quain (1844)	31	8 (25.8%)	23 (74.2%)	6 (19.4%)	1 (3.2%)	16 (51.6%)	0
Gruber (1867)	20	4 (20%)	16 (80%)	—	—	—	—
Breme (1899)	7	1 (14.3%)	6 (85.7%)	1 (14.3%)	0	5 (71.4%)	0
Müller (1903)	2	1 (50%)	1 (50%)	0	0	1 (50%)	0
McCormack (1953)	17	7 (41.2%)	10 (58.8%)	—	—	—	—
Fuß et al. (1985)	3	1 (33.3%)	2 (66.7%)	0	0	0	2 (66.7%)
Rodríguez-Baeza (1995)	8	2 (25%)	6 (75%)	3 (37.5%)	2 (25%)	1 (12.5%)	0
Our results (2000)	16	4 (25%)	12 (75%)	6 (37.5%)	0	3 (18.75)	3 (18.75)
Total	104	28/104 (26.9%)	76/104 (73.1%)	16/50 (32%)	3/50 (6%)	26/50 (52%)	5/50 (10%)

SB, superficial brachial artery.

The brachial artery divides at its normal level into the radial artery and the interosseous trunk, the latter sending off the recurrent ulnar artery.

6. Brachioulnar artery (Fig. 4*b*). This is defined as an ulnar artery with a high origin and a normal course along the forearm and hand.

This was found in only 1 male cadaver (1.1%), unilaterally on the right side. Therefore the total incidence was 1 of 192 cadavers (0.52%), or 1 of 384 upper limbs (0.26%) (Table 5).

In this case, it originated from the axillary artery above the elbow (Fig. 4*b*), then crossed the median nerve roots to take a superficial course alongside it. At the elbow, after passing below the bicipital aponeurosis, the brachioulnar artery regained the usual course of the ulnar artery in the forearm. At the elbow it also anastomosed with the normal brachial artery (Fig. 4*b*).

7. Superficial brachioulnoradial artery (Fig. 1*c*). This is defined as a superficial brachial artery branching at elbow level into radial and ulnar arteries and coexisting with a normal brachial artery that continues as the common interosseous trunk. This variation was found in 1 male (1.1%), and 1 female cadaver (0.99%), unilaterally on the left side in both cases. The total incidence was 2 of 192 cadavers (1.04%), or 2 of 384 upper limbs (0.52%).

In both cases the superficial brachioulnoradial artery originated from the axillary artery above the median nerve roots, then coursed superficially until it was anterior to the median nerve along the arm but under the brachial fascia. At the elbow fossa it pierced the bicipital aponeurosis in 1 case and passed superficial to the bicipital aponeurosis in the other case.

Also at the elbow, in 1 case, there was an anastomosis behind the bicipital tendon connecting the deep brachial artery with the radial artery (branch of the superficial brachioulnoradial artery).

Distal to the origin of the variant artery, the deep or normal brachial artery, coursed in its normal position along the arm, continuing in the forearm as the common interosseous trunk which gave off the radial recurrent and ulnar recurrent arteries and then split into the anterior and posterior interosseous arteries. In 1 case a median artery was associated; it originated from the common interosseous trunk, adopting an antebrachial pattern which passed anterior to the anterior interosseous nerve, and ended in the middle third of the forearm.

DISCUSSION

Variations of the normal arterial pattern in the upper limb occur frequently (McCormack et al. 1953; Wankoff, 1962). The most frequent are those involving a second artery in the arm, which continues into the forearm, and they have therefore attracted more attention than variations affecting only the forearm arteries. Many of these reports have failed to take account of previous ones, resulting in a great diversity of terminology which makes any comparison of the results difficult if not impossible (Table 1).

Some authors have applied topographic criteria, and have considered the arteries regionally. Thus a second artery in the arm may have been given the name brachialis superficialis, but once it crossed the elbow it was renamed according to its course, either radial, ulnar, superficial ulnar or interosseous (Adachi, 1928; Skopakoff, 1959; Wankoff, 1962). Therefore the brachialis superficialis and the variations of the radial and ulnar arteries were analysed separately. Consequently the information about those variant arteries within the arm and forearm was repeated in different chapters, with overlapping results and the omission of some important information (Quain, 1844; Adachi, 1928; Skopakoff, 1959). Similarly, when the origin of the brachialis superficialis was analysed, its continuation

in the forearm was omitted (Skopakoff, 1959), and when a variant artery was detected in the forearm, its detailed origin was not described.

Other terms employed to describe the origin of the variant artery in the arm included superior and inferior (Schwalbe, 1898, Breme, 1899), superior, media and inferior (Adachi, 1928; Fuss et al. 1985) and superior, media, inferior and ima (Müller, 1903). These terms were used not only to characterise the origin from the axillary or brachial artery, but also to relate the origin of the artery to variations of the brachial plexus, such as a second median nerve root (Michel, 1855; Müller, 1903; Adachi, 1928). However, as Miller stated (1939), combinations of nerve and arterial variations are extremely difficult to analyse or classify.

In later attempts to simplify and unify, subsequent authors have considered the variant artery as a complete entity in the arm and forearm, and have therefore kept the same name in both the arm and forearm (McCormack et al. 1953). Thus authors grouped together information about the origin of the artery in the arm with information about its course in the forearm, and no overlapping of results occurred. Authors proposed different terms such as superficial radial, superficial ulnar, high origin of the radial or high origin of ulnar (Table 1). But these names are inappropriate, as in the arm there are no radial or ulnar regions (Schwalbe, 1898).

We considered that these terminological problems can be clarified by combining the term 'brachio' with the corresponding region in the forearm (i.e. brachioradial, brachioulnar, brachiointerosseous, brachiomedian or a combination of these), and depending on whether these latter arteries adopted a normal or superficial course in the forearm, the term superficial was added. Similar criteria were used by 2 previous authors when reporting a brachioradial artery (Barkow, 1869) and a superficial brachioulnar artery (Bianchi, 1943).

The proposed terminology is simple, avoids the used of additional terms (Schwalbe, 1898, Breme, 1899; Adachi, 1928; Fuss et al. 1985; Müller, 1903) and follows the criteria proposed by other authors (Barkow, 1869; Bianchi, 1943). It considers the variation as an entity along its extension (McCormack et al. 1953), and respects the topographical criteria (Adachi, 1928; Skopakoff, 1959) but does not use inappropriate names to refer to the vessel when it courses in different regions (McCormack et al. 1953).

We have therefore unified previous descriptions in a total of 12 different arterial variations in the upper limb (Table 1).

For the sake of clarity the morphological details of each different variation are discussed separately: first those variations located exclusively in the arm (superficial and accessory brachial arteries), then the arterial variants located in the arm and forearm regions (brachioradial, brachioulnar, brachiointerosseous, brachiomedian arteries, superficial brachioradial,superficialbrachioulnar,superficialbrachioulnoradial arteries), and then those located exclusively in the forearm (superficial radial artery, absence of ulnar artery, absence of radial artery). Finally we analyse the arterial patterns of the upper limb based on the presence the different types of arterial variations.

Variations located exclusively in the arm

Superficial brachial artery. This is a brachial artery coursing in front of rather than behind the median nerve. This arterial variation has not been considered in many studies of upper-limb arterial variations, which have only dealt with those cases where two arteries were present (McCormack et al. 1953; Weathersby, 1956*a*). This pattern has been classified into different types depending on the forearm branching pattern (Wankoff, 1962; Fuss et al. 1985). However, we have not subclassified the superficial brachial artery because we consider that the variations of the arteries originating from it are to be studied together with the forearm arteries (either the radial or ulnar; see below). The incidence of the superficial brachial artery (combining our results with data reclassified from previous studies) varies from 3.6% to 9.6% (Keen, 1961; Wankoff, 1962; Fuss et al. 1985, 1988; Matula et al. 1990). Only 1 previous report (Fuss et al. 1985) gave data on sex and laterality reporting this arterial pattern more frequently in males and on the right side; although these differences were not statistically significant; our results supported their findings. However, Fuss and colleagues did not analyse unilateral or bilateral presence, as has been done in this report, which finds unilateral presence to be more common.

Fuss et al. (1985) found that the superficial brachial artery usually adopts its superficial course above the median nerve roots, varying from our findings and those of previous studies (Lippert & Pabst, 1985) which show the superficial brachial artery adopting its superficial course more frequently below these roots. Depending on whether the superficial brachial artery crossed the median nerve on its anterior or posterior face, it was subclassified by previous authors as brachialis superficialis medialis or lateralis (Adachi,

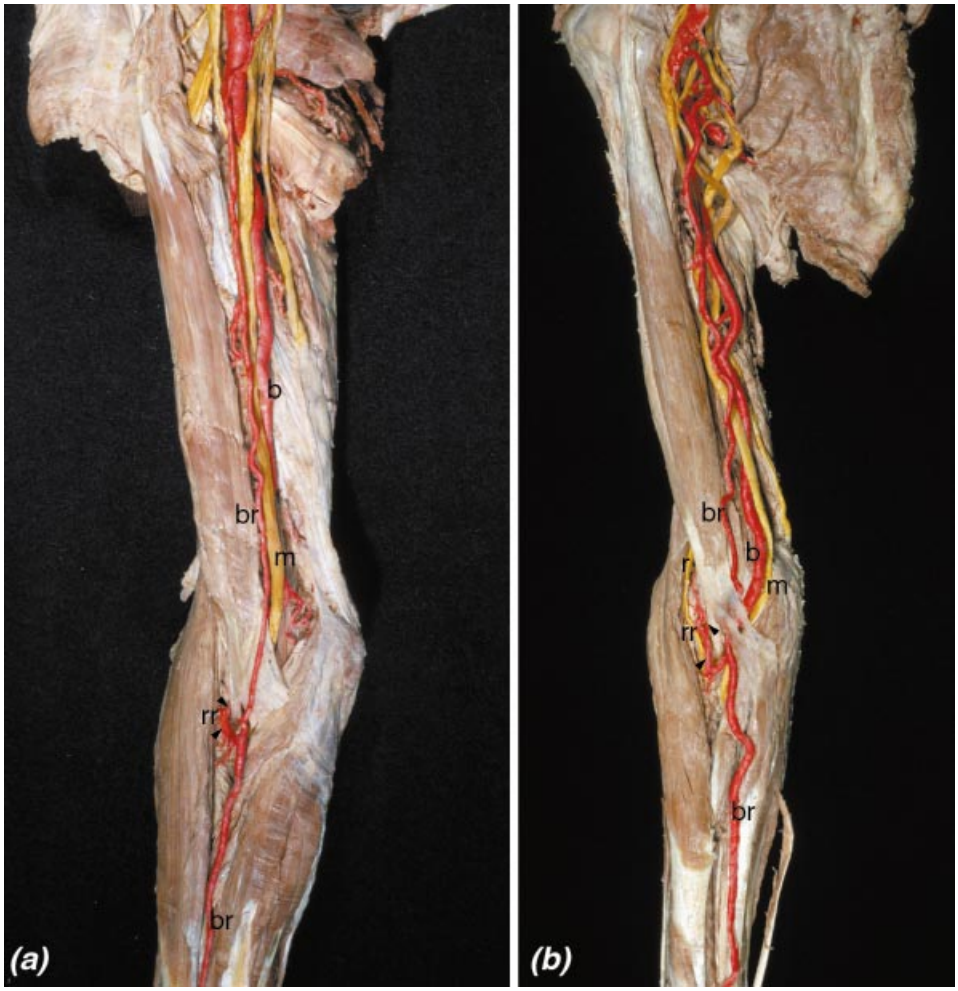

Fig. 2. Origin of the brachioradial (br) from the axillary artery. Note in both cases the sling-like loop anastomosis (arrowheads) behind the bicipital tendon and the radial recurrent artery (rr) originating from the anastomosis. (*a*) Brachioradial artery passing in front of the bicipital aponeurosis. (*b*) Brachioradial passing behind the bicipital aponeurosis. b, brachial artery; m, median nerve.

1928), but we have not differentiated this morphological feature.

At the point where the superficial brachial artery adopts its superficial course, it sends a branch posteriorly, providing the normal branches of the brachial artery (profunda brachii, anterior or posterior humeral circumflex, superior ulnar collateral, etc.) (Adachi, 1928; Fuss et al. 1985). This has been reported as a small branch which, reaching the elbow, anastomoses with the ulno-interosseous trunk or the radial artery by its posterior surface (Adachi, 1928; Çavdar et al. 2000). However, this morphological feature was not found in our study and has not been reported by other authors, as the branch coursing behind the median nerve is so small that special attention has to be paid to detect it (Adachi, 1928).

After adopting its superficial course, this variation does not present any further deviation from the norm. As already mentioned, at the elbow it branches into all the forearm arteries; and although some authors have subclassified them if the forearm arteries presented variations (Fuss et al. 1985), we have not done so. The existence of a superficial brachial artery has been explained in comparative anatomy studies as the retention of a primitive pattern (Bayer, 1893; Göppert, 1904).

Accessory brachial artery. This is defined as the coexistence of 2 brachial arteries that rejoin before branching into the antebrachial arteries. This rare variant appeared in 0.26% of upper limbs, an incidence similar to that in some previous reports (Quain 1844; McCormack et al. 1953; Keen, 1961), though slightly lower than that found by Rodríguez-Baeza et al. (1995).

Its origin has always been found at the brachial artery, and it rejoins the latter in the distal third of the arm before the division of the latter into the normal forearm arteries (Quain, 184, McCormack et al. 1953; Keen, 1961; Rodríguez-Baeza et al. 1995). The median nerve passes through both arteries, and therefore some previous authors here compared this pattern with an island and consequently named it *inselbildung*

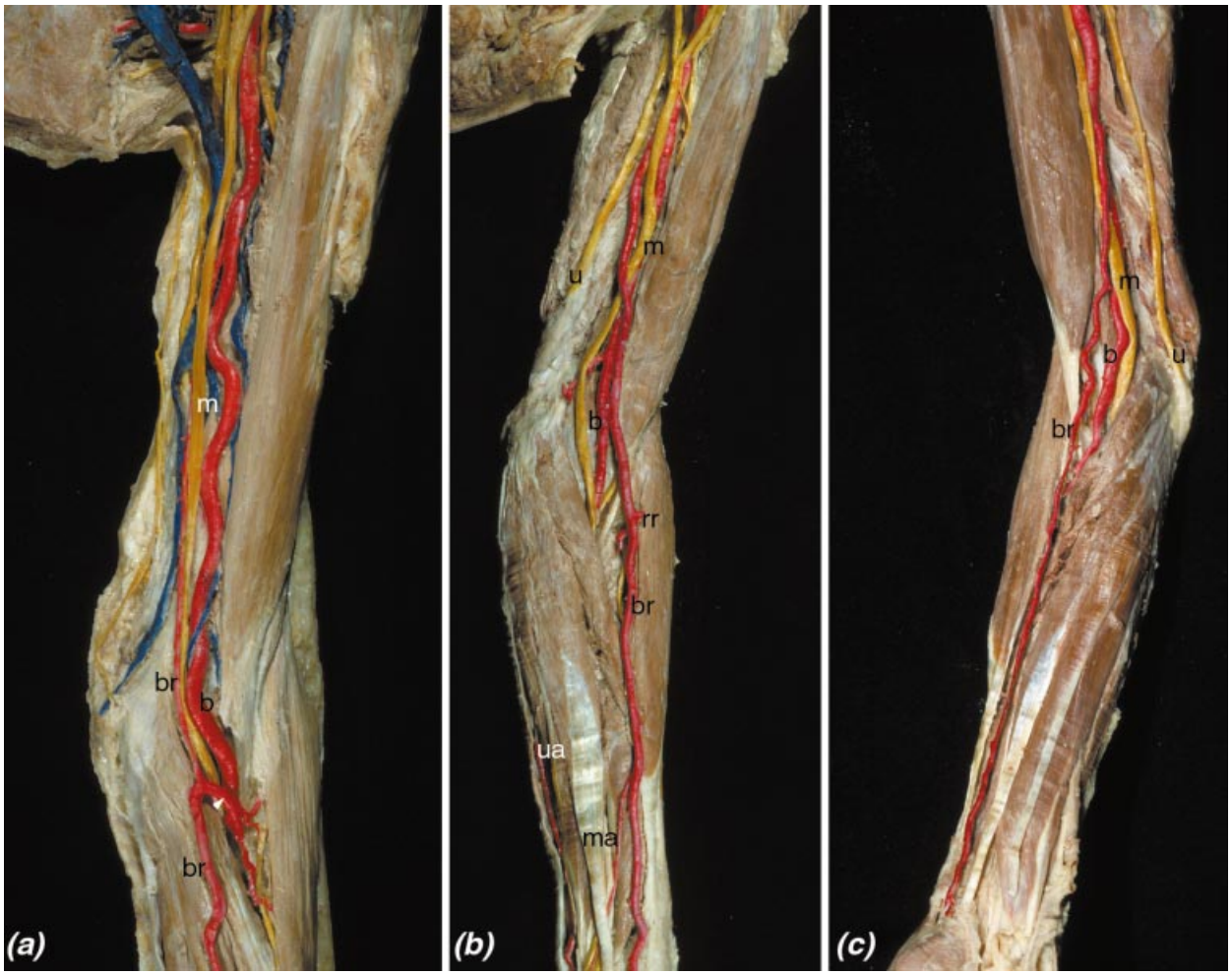

Fig. 3. Origin of the brachioradial (br) from the brachial artery (b). (*a*) Origin from the upper third with sling-like loop anastomosis at the elbow (arrowheads). (*b*) Origin from the upper third. Note the median artery (ma) at the distal third of the forearm. (*c*) Origin from the middle third. rr, radial recurrent artery; m, median nerve; u, ulnar nerve; ua, ulnar artery.

('islandformation') (Ruge, 1884). The previously reported cases do not differ from the one observed in the present report.

Arterial variations located along the arm and forearm

Brachioradial artery (*BR*). This is defined as a high origin of the radial artery coexisting in the whole arterial pattern of the limb with a brachial or superficial brachial artery that branches into ulnar and common interosseous trunk.

This brachioradial artery has been described as the most frequent finding (Tables 2, 3). We agree with previous authors in finding it unilaterally more frequently than bilaterally (Gruber, 1867; Keen, 1961; Rodríguez-Baeza et al. 1995). There are few references to laterality and sex distribution in previous reports, and therefore it is not possible to make full comparisons. However, we found it more frequently in females and on the right side, unlike previous authors who found it more frequently in males and with no side differences (Fuss et al. 1985), although these differences were not statistically significant.

Our results confirm earlier findings, that the brachioradial artery originates more frequently from the brachial than the axillary and specifically from the upper third of the brachial, followed by the middle and inferior thirds respectively (Table 4).

The brachioradial, after its origin, crosses the median nerve and adopts an anterior, superficial position to it along the arm, while the brachial artery is in its normal position behind the median nerve or occasionally in front of the median nerve, and is therefore named the superficial brachial artery (Adachi, 1928). Although in all our cases the brachioradial artery was located deep to the brachial fascia, a subcutaneous course over the brachial fascia has also been reported (Kumaris & Sclavunos, 1903).

At the antecubital fossa, our results show that the brachioradial artery passes posterior to the bicipital aponeurosis more often than anterior to it. This relationship has previously only been considered in

case reports (Içten et al. 1996; Gonzalez-Compta, 1991; Sargon et al. 1996; Melling et al. 2000), and not in large samples (Weathersby, 1956*a*; Skopakoff, 1959; Keen, 1961; Wankoff, 1962), which makes statistical comparison impossible. A piercing of the bicipital aponeurosis has also been reported (Gonzalez-Compta, 1991), although we have observed no such case.

At the antecubital fossa, the brachioradial artery may anastomose with the brachial artery through a vessel with a sling-like loop or a rectilinear form (Quain, 1844; Cruveilhier, 1851; Baader, 1866; Charles, 1873, 1875; Müller, 1903; Pohlman, 1908; Forster, 1917; Michelsson, 1920; Poynter, 1920; Ljubomudroff, 1927; Adachi, 1928; McCormack et al. 1953; Weathersby, 1956*a*; Skopakoff, 1959; Wankoff, 1962; Chouéki-Guttenbrunner et al. 1990; Rodríguez-Baeza et al. 1995; Rodríguez-Niedenführ et al. 2000). Similar to the results of this study, the anastomosis has previously been observed in 19–50 % of upper limbs where a brachioradial artery was present (Quain, 1844; Müller, 1903; Adachi, 1828; McCormack et al. 1953; Weathersby, 1956*a*; Wankoff, 1962) findings comparable with our own and its morphological details have been analysed in specific studies (Ljubomudroff, 1927; Rodríguez-Niedenführ et al. 2000).

The origin of the radial recurrent artery when a brachioradial artery is present has not been reported by the authors of large-sample studies (Quain, 1844; Müller, 1903; Adachi, 1928; McCormack et al. 1953; Weathersby, 1956*a*; Keen, 1961; Fuss et al. 1985; Rodríguez-Baeza et al. 1995). We found that it originated most commonly from the brachioradial, followed by the brachial and finally from the anastomosis between both vessels. However, like previous authors, we found that when an anastomosis between a brachioradial and a brachial artery is present, the radial recurrent arose more frequently from it (McCormack et al. 1953; Rodríguez-Niedenführ et al. 2000).

In the forearm, a rare anastomosis between the brachioradial and the median (Schwalbe, 1898; Schwyzer & De Garis, 1935; McCormack et al. 1953; Wankoff, 1962) or the anterior interosseous artery (Meckel, 1816; Schwalbe, 1898) has been previously reported but not found in the present report.

Although the coexistence of a brachioradial and a median artery is normally expected, due to the high incidence of the latter (Rodríguez-Niedenführ et al. 1999), the origin of a median artery in the distal third of the forearm from the brachioradial, as seen in this study and by Müller (1903), is rare. This association may be explained by the close relationship between the radial and median arteries by means of anastomosis at different levels of the forearm (Baader, 1866; Müller, 1903). Therefore the pattern observed in our case may be seen as an enlargement of the anastomosis in the distal third of the forearm, together with the atrophy of the proximal part of the median artery (Müller, 1903).

Superficial brachioradial artery (*SBR*). This is defined as a high origin of the radial artery coursing over the brachioradialis muscle or tendons which define the snuffbox, and coexisting in the whole arterial pattern with a brachial artery that usually branches into ulnar and interosseous, or occasionally into the radial and ulnar, and is described as a duplication of the radial artery (Kadanoff & Balkansky, 1966).

The association of a radial artery originating above the elbow and superficial course in the forearm was not found in the present report, although it has been reported as being frequent (Meckel, 1816; Adachi, 1928). Adachi (1928) made this statement based on the finding of 3 out of his 8 cases of a superficial course originating from the arm. However, if the total number of brachioradial arteries and their superficial courses are considered, the incidences are very low, and consequently Adachi's statement may not be correct (Table 3). It is noteworthy that several reports based on large samples have only analysed the presence of 2 arteries in the arm and have not reported its course in the forearm, making it impossible to detect such variations or to compare further incidences (Skopakoff, 1959; Wankoff, 1962; Fuss et al. 1985).

The superficial brachioradial, like the brachioradial, arises from the axillary (Meckel, 1816) or the brachial artery (Quain, 1844; McCormack et al. 1953) and does not show morphological differences to the brachioradial until reaching the forearm.

The superficial brachioradial artery adopts its superficial course in the proximal (Meckel, 1816), middle (Quain, 1844) or distal third of the forearm (McCormack et al. 1953), and ends like the superficial radial artery, passing through the first intermetacarpal space to form the deep palmar arch (Adachi, 1928).

The duplication of the radial artery, superficial brachioradial and radial arteries coexisting has only been reported once (Kadanoff & Balkansky, 1966), being the rarest of radial artery variations, with an estimated incidence of less than 0.02 %. The brachioradial originated from the axillary and coexisted with a normal radial arising from the brachial. At the elbow, the brachioradial and the radial arteries

anastomosed and continued separately to the wrist (Kadanoff & Balkansky, 1966).

Superficial brachioulnar artery (*SBU*). This is defined as a high origin of the ulnar artery coursing over the forearm flexor muscles and coexisting in the whole arterial pattern, with a brachial or superficial brachial artery which branches into the radial and common interosseous trunk, or more infrequently into the radial and ulnar arteries. This latter case has been described as duplication of the ulnar artery (Gruber, 1867).

The SBU has been reported as being more common unilaterally than bilaterally (Gruber, 1867; Hazlett, 1949), but our findings contradicted this. Similarly, our results, which show an equal left-right distribution, do not support previous reports of higher incidence of the SBU on the right side (Quain 1844; Gruber, 1867; Hazlett, 1949), although, these differences were not statistically significant.

It is surprising that, in our study, occurrences in female cadavers were bilateral, while almost all variations in male cadavers were unilateral. This was not considered in previous studies (Fuss et al. 1985).

According to previous authors and our own results, the SBU artery originates from the proximal third of the brachial artery more often than elsewhere (Table 6). Some authors have found the superficial brachial artery to be the most frequent origin (Fuss et al. 1985), but this difference could be explained statistically by differences in sample size, as the latter study was based on a smaller sample than others (Table 6). We did not find any cases where it originated from the middle third of the brachial artery, as has been noted previously (Quain, 1844; Fuß, 1988; Rodríguez-Baeza et al. 1995).

After its origin, the artery ran along the arm in front of the median nerve and deep to the brachial fascia in all our cases and also in previous ones (McCormack et al. 1953). Occasionally the artery, after piercing the brachial fascia, coursed subcutaneously in the arm (Richmond, 1879; Hale White et al. 1886; Kumaris & Sclavunos, 1903; Fadel & Amonoo-Kuofi, 1996).

There are statistical data about the relation of the SBU to the bicipital aponeurosis, our results confirm previous findings showing that the SBU is more likely to pass posterior to the bicipital aponeurosis (McCormack et al. 1853) than anterior to it, and only rarely pierced it (Gruber, 1871; Breme, 1899; Adachi, 1928; Nakatani et al. 1996).

At the elbow, the superficial brachioulnar artery may present an anastomosis with the brachial artery and, although we did not find examples of this anastomosis, we have based our interpretations on previous reports. In the adult, around 4% of cases of SBU show this anastomosis, but a higher incidence (up to 20%) was observed in fetal specimens. This difference is explained mainly by the differences in sample size (Wankoff, 1962).

After crossing the elbow, the SBU artery usually passed under the antebrachial fascia (Cruveilhier, 1851; Gruber, 1867; Quain, 1844; Müller, 1903, 1905; Adachi, 1928; Hazlett, 1949; McCormack, et al. 1953; Rodríguez-Baeza et al. 1995; Anil et al. 1996), and we found this too, but there have also been reports of a subcutaneous course over the antebrachial fascia (Quain, 1844; Cruveilhier, 1851; Schwyzer & de Garis, 1935; Hazlett, 1949) and crossed over by the median cubital vein (Fadel & Amonoo-Kuofi, 1996).

The SBU artery reached the lateral border of the flexor carpi ulnaris at mid-forearm level (McCormack et al. 1953) or in the distal third of the forearm, close to the wrist joint (Schwalbe, 1898; Müller, 1903). During its course in the forearm, the artery adopts a position superficial or deep to the palmaris longus, if present (Schwalbe, 1898; Schwyzer & de Garis, 1935; Hazlet, 1949; Weathersby, 1956*a*). We did not observe this variation, as all our cases coursed over all the flexor muscles and adopted a normal position in the middle third of the forearm. Recently a superficial brachioulnar artery passing between the radial and common interosseous trunk has been represented diagrammatically as a common variant (Anagnostopoulou & Venieratos, 1999), although such a case has not been found in the available literature.

The SBU artery has been observed together with other arterial variations: median artery (Müller, 1903; Schwyzer & de Garis, 1935; Weathersby, 1956*b*; Pabst & Lippert, 1968; Rodríguez-Baeza et al. 1995), superficial median originating from the SBU, namely antibrachii superficialis mediano-ulnaris (Schwalbe, 1898; Müller, 1903; Adachi, 1928; Lippert & Pabst, 1985), and absence of the radial artery (Poteat, 1986). The latter 2 patterns are rare and were not been found in the present study, while the coexistence of a median artery has already mentioned as a normal feature.

Another rare morphological feature not found in the present study is the presence of anastomosis in the forearm with other arteries such as the anterior interosseous (Gruber, 1867; Quain, 1844; Sañudo et al. 1998) or the median artery (Wankoff, 1962).

The coexistence of an SBU and a normal ulnar artery (duplication of the ulnar artery) is a very rare arterial pattern of the upper limb. It has been described as having an incidence of 0.16% (Gruber,

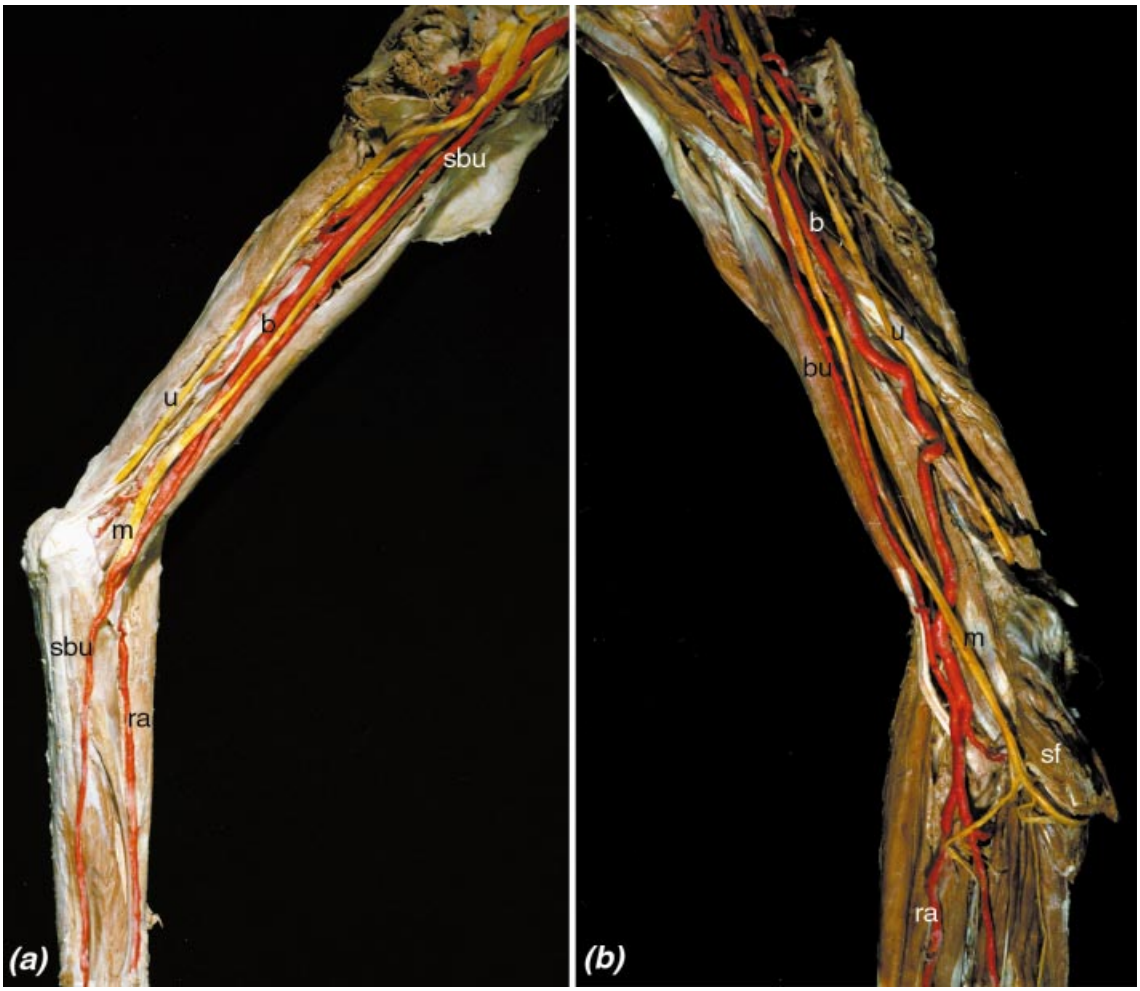

Fig. 4. (*a*) Anterior view of a left upper limb. Origin of the superficial brachioulnar (sbu) from the axillary artery. Note the course over the superficial forearm flexor muscles. (*b*) Anterior view of a right upper limb. Brachioulnar (bu) originating from the axillary artery and coursing deep to the superficial forearm flexor muscles (sf). Note the anastomosis at the elbow. b, brachial artery; ra, radial artery; m, median nerve; u, ulnar nerve.

1867), the SBU originating from the axillary (Theile, 1841; Hyrtl, 1860; Gruber, 1867) or brachial artery (Gruber, 1871).

The SBU and the normal ulnar artery may run separately until the hand (Gruber, 1867; Gruber, 1871) or the SBU may flow into the normal ulnar artery in the middle-distal third of the forearm (Hyrtl, 1860; Wankoff, 1962; Lippert & Pabst, 1985).

Brachioulnar artery. This is defined as a high origin of the ulnar artery coexisting in the whole arterial pattern of the limb, with a brachial artery which branches into the radial and common interosseous trunk.

This pattern is less frequent than the former (Table 5), and no references have been made to laterality or sex distribution as it was almost always a casual finding. The statistical analysis therefore has little significance.

The origin of the brachioulnar artery has been described as being at the upper third of the brachial artery (Rodríguez-Baeza et al. 1995; Aharinejad et al. 1997) or, as we found it, the axillary artery (Meckel, 1816). As most previous authors with large samples considered the brachioulnar as a variation of the superficial brachioulnar or did not even differentiate them, there are insufficient statistical data about the origin of the former to make comparisons (McCormack et al. 1953; Skopakoff, 1959; Rodríguez-Baeza et al. 1995).

The course of the brachioulnar artery in the arm was anterior to the median nerve and beneath the brachial fascia in our and previous cases (Aharinejad et al. 1997). In our case, the artery passed under the bicipital aponeurosis to regain the normal course of the ulnar artery, a course superficial to the bicipital aponeurosis has not yet been reported. However, no specific descriptions of this morphological relationship exist and therefore no significant statistical data

Fig. 5. Origin of the superficial brachioulnar (sbu) from the brachial artery. (*a*) Origin from the upper third (*b*) Origin from the lower third. b, brachial artery; ra, radial artery; m, median nerve; u, ulnar nerve.

(Weathersby, 1956*a*, *b*; Rodríguez-Baeza et al. 1995; Aharinejad et al. 1997).

Our case, at the elbow, anastomosed with the brachial artery as has already been observed by other authors (Ljubomudroff, 1927), but no statistical data about this morphological detail are available as the brachioulnar artery was always found as a casual finding. In a previous study where the brachioulnar and superficial brachioulnar arteries were not differentiated, the incidence of this anastomosis was established in 13% of the total number of arterial variations (Rodríguez-Niedenführ et al. 2000) but, if the former patterns are differentiated, then no statistical data are available.

The course and relationships of the brachioulnar artery in the forearm are the same as in that of a normal ulnar artery, sending off the ulnar recurrent artery and ending in the hand (Aharinejad et al. 1997).

Superficial brachioulnoradial artery. This is defined as a superficial brachial artery branching at the elbow level into the radial and ulnar arteries coursing over the superficial forearm flexors, and coexisting in the whole arterial pattern of the limb with a normal brachial artery that continues as the common interosseous trunk.

Its incidence has been confirmed as being lower than the brachioradial or superficial brachioulnar arteries, and ranging from 0.14% to 1.3% (Gruber, 1867; Quain, 1844; Fuss et al. 1985; Rodríguez-Baeza et al. 1995).

Few reports give data about laterality or sex distribution, therefore statistical comparison has little value. However, we found it in 1 male and 1 female, while Fuss et al. (1985) found it in 2 male cadavers, although their sample comprised almost twice as female cadavers as males. With regard to laterality, their results revealed an equal left-right distribution, while we only found it on the left side.

The origin of the superficial brachioulnoradial artery has been reported from the axillary, as in both our cases, or more frequently from the brachial artery with a 1:2.5 ratio (Quain, 1844). After its origin in the

arm it coursed in front of the median nerve but under the brachial fascia. However, there has been a report of a piercing of the brachial fascia and a subcutaneous course over the brachial and antebrachial fascia as far as the hand (Jurjus et al. 1986).

It has also been variably described as passing in front of or behind the bicipital aponeurosis, or even as piercing it (Schwyzer & De Garis, 1935).

At the elbow, an anastomosis between the deep or normal brachial and the radial artery, as a branch of the superficial brachioulnoradial artery, has been reported previously (Schwalbe, 1898; Pabst & Lippert, 1968), we found a case in our sample too.

The radial recurrent and ulnar recurrent arteries arose from the interosseous trunk in our sample, as well as in previous cases (Cruveilhier, 1851; Schwalbe, 1898).

The coexistence of this variation with a median artery, as mentioned above, is not a surprising finding due to the high incidence of the latter (Rodríguez-Niedenführ et al. 1999).

Brachiointerosseous artery. This is defined as a high origin of the interosseous artery coexisting in the whole arterial pattern of the limb with a brachial artery that branches into radial and ulnar arteries. It is a rare variation which has been reported mainly as a casual finding (Lauth, 1830; Carrington et al. 1883; Nakatani et al. 1997). Its incidence has not yet been established and, as it was not found in the present report, its incidence may be considered as being less than 0.26% (1/384).

The origin of this artery was reported as taking place from above the median nerve roots (Carrington et al. 1883; Nakatani et al. 1997).

This artery may present an anastomosis in the forearm connecting it to the brachial artery (Lauth, 1830; Carrington et al. 1883). In the forearm, no departures from the normal morphology of the anterior interosseous artery were cited (Lauth, 1830; Carrington et al. 1883; Nakatani, 1997).

Superficial brachiomedian artery. This is defined as a high origin of the median artery coursing over the superficial flexor muscles and coexisting in the whole arterial pattern of the limb, with a brachial artery that branches into radial and ulnar arteries.

The superficial course of a median artery in the forearm has been reported with an incidence of 1% (Lippert & Pabst, 1985; Nakatani et al. 1999), although it has not been found in some previous studies based on larger samples (McCormack et al. 1953; Rodríguez-Niedenführ et al. 1999). However, its origin from above the elbow is rarer and its incidence was established as being close to 0.5% (Quain, 1844; Adachi, 1928) although again it was not found in this or in some previous studies (McCormack et al. 1953).

The origin of the superficial brachiomedian artery has been found at either the axillary or the brachial arteries (Quain, 1844; Schwalbe, 1898; Hoskins, 1914; Adachi, 1928). At the elbow it passes behind the bicipital aponeurosis (Adachi, 1928), and in the forearm it courses superficial to the pronator teres and flexor carpi radialis muscles and ocassionally crosses behind the palmaris longus tendon to join the median nerve in the distal third of the forearm and then to enter the palm through the carpal tunnel as a normal median artery (Quain, 1844; Adachi, 1928).

Arterial variations located exclusively in the forearm

Superficial radial artery (*SR*). This is a radial artery coursing over the tendons defining the snuffbox. This is a rare finding, with an incidence $\sim 0.5\%$ of the upper limbs (Table 3). Few references about laterality or sex distribution exist, as the incidence is estimated to be the same in males and females (Adachi, 1928; Sachs, 1987). Furthermore, it has been reported as more frequent unilaterally (Sachs, 1987), without side differences (Adachi, 1928; Keen, 1961), if it has been reported at all (McCormack et al. 1953). The statistical comparison of these results, therefore, has little significance.

The superficial radial artery may adopt its superficial course at different levels of the forearm (Schwalbe, 1898; Breme, 1899; Adachi 1928; McCormack et al. 1953; Keen, 1961; Loetzke & Kleinau, 1968; Sachs, 1987), the distal superficial course, as in the present report, being considered the most frequent one (Adachi, 1928; McCormack et al. 1953). The superficial radial artery has also been described as arising above the elbow (Meckel, 1816; Adachi, 1928; McCormack et al. 1953), being considered in this report as a separate pattern due to its course in the arm (superficial brachioradial).

The superficial radial artery has usually been reported as piercing the antebrachial fascia and coursing subcutaneously along the superficial branch of the radial nerve (Meckel, 1816; Gruber, 1864, 1870*c*; Loetzke & Kleinau, 1968).

The superficial radial artery may end as a single branch passing through the first intermetacarpal space (Adachi, 1928; McCormack et al. 1953) or as a double branch (Schwalbe, 1898; Adachi, 1928). In this latter case, one artery coursed above the snuffbox delimiting tendons and crossed through the first intermetacarpal space, while the second artery passed under them and

Table 7. *Arteries classified by a topographical criteria*

	Arterial patterns	Our findings	Reviews
Arm			
1 artery	Brachial	76.06%	—
	Superficial brachial	4.9%	7.28%
2 arteries	Brachial and accessory brachial	0.26%	0.25%
	Brachial and brachioradial	13.8%	11.1%
	Brachial and superficial brachioradial	< 0.26%	0.24%
	Brachial and brachioulnar	0.26%	0.33%
	Brachial and superficial brachioulnar	4.2%	2.7%
	Brachial and superficial brachioulnoradial	0.52%	0.48%
	Brachial and superficial brachiomedian	< 0.26%	—
	Brachial and brachiointerosseus	< 0.26%	—
Forearm			
1 artery	Ulnar and radial absent	< 0.26%	< 0.03%
	Radial and ulnar absent	< 0.26%	< 0.015%
2 arteries	Ulnar and radial	81.22%	—
	Ulnar and brachioradial	13.8%	11.1%
	Ulnar and superficial brachioradial	< 0.26%	0.24%
	Ulnar and superficial radial	0.52%	0.74%
	Radial and brachioulnar	0.26%	0.33%
	Radial and superficial brachioulnar	4.2%	2.7%
3 arteries	Ulnar and radial and brachiomedian	< 0.26%	
	Ulnar, radial and superficial brachioradial (radial duplication)	< 0.26%	< 0.02%
	Radial, ulnar and superficial brachioulnar (ulnar duplication)	< 0.26%	0.045%

formed the dorsal carpal network together with the posterior interosseous artery (Schwalbe, 1898).

This pattern has not been explained embryologically (De Vriese, 1902; Müller, 1903), but rather by comparative anatomy (Schwalbe, 1895; Müller, 1905; Manners-Smith, 1910, 1911). In other primates the radial artery divides into a volar branch representing the human radiopalmar branch, and a dorsal branch that represents the normal radial artery. The dorsal branch in other primates, however, branches again into superficial and deep branches. The former courses above the tendons of the snuffbox to reach the first intermetacarpal space, and the latter courses below the tendons of the snuffbox to reach the second and third intermetacarpal spaces (Schwalbe, 1895; Müller, 1905; Manners-Smith, 1910, 1911). Therefore the presence of a superficial radial artery in humans may be explained as homologous (vestigial) to the superficial division of the dorsal branch of the radial artery in primates (Schwalbe, 1895; Wood et al. 1997).

Finally, there has been a single report of a superficial radial artery, with a median artery originating from it (Wood et al. 1997). This association, as already mentioned for the brachioradial artery, is explained by the close relationships by means of anastomosis at different levels of the forearm between the median and radial territories (Baader, 1866; Müller, 1903). So a low origin of the median from the radial artery may be explained by the enlargement of the anastomosis at the distal end of the forearm together with and atrophy of the proximal part (Müller, 1903).

Duplication of the radial artery. As mentioned previously with relation to the BR, a real duplication has only been reported once (Kadanoff & Balkansky, 1966). Other patterns considered as duplication are unusual cases in which 2 radial arteries are present, each one supplying a different territory (Sankott, 1919, 1920). A proximal radial artery originating from the brachial supplies the upper third of the forearm, while a distal radial originating from the anterior interosseous supplied the normal branches of the radial in the distal third of the forearm and hand (Kadyi, 1881; Sankott, 1919, 1920). However, the proximal artery may be considered as the radial recurrent, and the distal one a substitute for the absent radial artery (Thomson, 1883). Due to the similarities shown between these cases and those of radial artery absence, we consider the latter cases as better matching the following pattern.

Absence of the radial artery. The radial artery has been rarely reported as being totally absent (Charles, 1894; Schwalbe, 1898; Kadanoff & Balkansky, 1966; Poteat, 1986) with an estimated incidence of less than 0.03% (Table 3).

In these cases, the radial blood supply territory was provided by the anterior interosseous (Gruber, 1864; Kadanoff & Balkansky, 1966; Poteat, 1986) or the median artery and described as a. mediano-radialis

Fig. 6. (*a*) Superficial brachioulnar (sbu) originating from the superficial brachial artery (sb). (*b*) Superficial brachioulnar artery piercing the bicipital aponeurosis. b, brachial artery; ra, radial artery; m, median nerve; u, ulnar nerve.

(Schwalbe, 1898). The former cases show similar morphological features to those described above as radial artery duplication (Sankott, 1919, 1920).

The radial artery has also been reported as rudimentary with a great reduction of its calibre (Gruber, 1864, 1870*b*; Kadyi, 1881; Schwalbe, 1898) where it may appear as having simultaneous origin from 3 different levels of the arm to form a single thin artery (Gruber, 1870*a*). However, rather than considering 3 different origins, we regard this latter pattern as a radial artery with arterial anastomosis at different levels as was previously considered and supported by morphological findings (Baader, 1866; Kadyi, 1881; Schwalbe, 1898; Müller, 1903).

This rudimentary vessel may also receive an anastomosis from the anterior interosseous artery at wrist level, enlarging its calibre distal to it (Calori, 1868; Thomson, 1883; Schwalbe, 1898).

The partial absence of the radial artery with the described anastomosis may be explained as a transitional form between its complete absence in some animals and its normal development in humans (Zuckerkandl, 1895).

Duplication of the ulnar artery. A real pattern of duplication of the ulnar artery includes the existence of an SBU as mentioned in the discussion. However, partial duplications of the ulnar artery have been described, with the SBU reaching the palm and the normal one sending off the ulnar recurrent and the common interosseous arteries before ending up as small muscular branches to the forearm flexor muscles (Richmond, 1879; Walsham, 1880; Breme, 1899). This variation has been considered as frequent by Gruber (1867), who mentioned that when an SBU is present, a rudimentary normal ulnar artery as described above is also usually present. Many authors who reported an SBU artery have observed the origin of the ulnar recurrent artery from the interosseous trunk; however, they did not consider it as a duplication (Quain, 1844; Collins, 1886; Schwalbe, 1898; Fuss, 1988, Ozan et al. 1994; Devansh, 1996; Nakatani et al. 1996) as neither do we.

Furthermore, a very infrequent division of the normal ulnar artery into 2 branches in the distal third of the forearm has also been described as a duplication of the ulnar artery (Oeffinger, 1867). The laterally placed artery has been named a. volaris radialis superficialis ex ulnaris (Breme, 1899). However, the fact that this supposed ulnar artery has been reported coursing in the carpal tunnel together with the median nerve (Oeffinger, 1867, Breme 1899), makes it more appropriated to consider it as a median artery rather than as an ulnar artery. So this case, rather than being a duplication of the ulnar, should be considered as a median artery originating in the distal third of the forearm from the ulnar artery, resembling the a. antibrachii superficialis mediano-ulnaris (Schwalbe, 1898; Adachi, 1928), with the difference to the median artery originates from a normal ulnar rather than from an SBU.

Absence of the ulnar artery. The absence of the ulnar artery is a rare variation. Not even studies based on very large samples found it (Gruber 1867; McCormack et al. 1953; Wankoff, 1962), so its incidence may be considered as lower than 0.015% (Table 5). Furthermore, in the available literature only 2 anatomical reports described an ulnar artery which ended up as the ulnar recurrent and interosseous branches, a large median artery taking its place (Calori, 1868; Bankart et al. 1869). In a recently reported clinical case, the absence of the ulnar artery was compensated by the radial and interosseous rather than by the median artery (Nunoo-Mensah, 1998).

The complete or partial absence of the ulnar artery has been explained in comparative anatomy studies as the transition from its total absence in some lower animals to its complete development in humans (Zuckerkandl, 1894, 1895; Schwalbe, 1895).

The arterial patterns expected to be found in the upper limb, based on the existence of the major arterial variations mentioned above, could be classified based on a topographical criteria in 10 for the arm and in 11 for the forearm (Table 7).

A common morphological detail in all the variations described is the possible coexistence of a median artery in the forearm (Schwalbe, 1898; Müller, 1903; Dubreuil-Chambardel, 1922; McCormack et al. 1953, Rodríguez-Baeza et al. 1995). However, this coexistence should be expected as a normal feature because the median artery has been previously described as having a high incidence (Rodríguez-Niedenführ et al. 1999). Therefore we have not included it in the classification by patterns.

The information by patterns and incidence (Table 7) could be especially important for clinicians and surgeons when performing invasive procedures in order to know the arteries they might expect when approaching a particular area (arm and forearm).

The arterial variations of the upper limb have been implicated in different clinical situations. The superficial brachioradial and superficial brachioulnar arteries have been encountered during elevation of the radial forearm flap (Fatah et al. 1985; Thoma & Young, 1992; Heden & Gylbert, 1990; Funk et al. 1995; Yuksel et al. 1999). Furthermore, the superficial brachioulnar artery has also been suggested as a basis for a skin flap (Devansh, 1996).

Possible intra-arterial injection of drugs due to the proximity of normal vein puncture sites has also been reported (Cohen, 1948; Hazlett, 1949; Deligonul et al. 1988; Thomas & Newell, 1995), as well as possible arteriographic misinterpretations when the contrast dye is injected distal to the origin of these variant arteries (Keller et al. 1980; Karlsson & Niechajev, 1982; Uglietta & Kadir, 1989).

The existence of a superficial radial artery implies the absence of the normal radial pulse at wrist level (Sachs, 1987; Diz et al. 1998). It has also been reported as producing problems in cannulation for operation monitoring (Diz et al. 1998) and as a symptomatic presence that required surgical treatment (Brown et al. 1999).

Finally, in a recently reported clinical case, the absence of the ulnar artery was responsible for hand ischaemia after radial artery grafting for coronary bypass (Nunoo-Mensah, 1998).

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