J. Anat. (1995) 187, pp. 473–479, with 6 figures Printed in Great Britain

An anatomical study and ontogenetic explanation of 23 cases with variations in the main pattern of the human brachio–antebrachial arteries

A. RODRÍGUEZ-BAEZA, J. NEBOT, B. FERREIRA, F. REINA, J. PÉREZ, J. R. SAÑUDO AND M. ROIG

Department of Morphological Sciences (Anatomy and Embryology Unit), Faculty of Medicine, Autonomous University of Barcelona, Bellaterra, Spain

(*Accepted 11 April 1995*)

ABSTRACT

Twenty-three cases with variations in the brachio–antebrachial arterial pattern of the human upper limb are reported. According to the artery which showed a variation, 4 groups were recognised: (1) isolated persistence of the median artery; (2) high origin of the ulnar artery; (3) high origin of the radial artery; and (4) duplication of the brachial artery, either with or without anastomosis at the cubital fossa. In addition, in groups 2, 3 and 4 the median artery may have persisted. Based on these arterial variations an anatomical and embryological correlation was established from a morphogenetic pattern which is proposed as being normal. Thus the terminal branches of the superficial brachial artery take part in the development of the radial, ulnar and median arteries, joining with the trunks of deep origin of these arteries in the primitive axial artery. Regression of the superficial arterial segments located proximal to this anastomosis gives rise to the definitive arterial pattern. Either the total or partial persistence of the superficial arterial segments explains those cases of high origin of either the radial or ulnar arteries as well as the duplications of the brachial artery. We postulate that the persistence of the median artery is independent of the presence or absence of any other variation in the arterial pattern.

Key words: Vasculature; anatomical variation; brachio–antebrachial arterial system.

INTRODUCTION

Variations in the arterial pattern of the upper limb have been observed frequently, either in routine dissections or in clinical practice (Lippert & Pabst, 1985). Anatomy textbooks make reference to 'vas aberrans' in the main brachio–antebrachial arterial pattern (Shäfer & Thane, 1894; Testut & Latarjet, 1981; Williams & Warwick, 1985), whereas Adachi (1928), McCormack et al. (1953), Skopakoff (1959), Fuss et al. (1985) and Tountas & Bergman (1993) described these arterial variations in more detail.

Explanations for arterial variations in the human upper limb have generally been based on the classical outlines of arterial development (Singer, 1933; Carlson, 1994). However, the anatomical and embryological correlation in recent publications (Jurjus et al. 1986; Poteat, 1986; González-Compta, 1991) shows that it may differ from the classical descriptions. Accordingly, we have studied a series of variations observed in the main pattern of the human brachio–antebrachial arteries in order to provide an embryological explanation.

MATERIALS AND METHODS

A total of 150 routine dissections of the upper limb from adult cadavers and 10 from full-term fetuses were performed. In the adult cadavers, the brachial and the anterior antebrachial regions were dissected. In those cases in which a variation in the arterial pattern of the limb was observed, dissection was focused on the brachio–antebrachial arterial axis. In

Correspondence to Dr Alfonso Rodríguez-Baeza, Departamento de Ciencias Morfológicas, Unidad de Anatomía y Embriología, Facultad de Medicina, Universidad Autónoma de Barcelona, 08193 Bellaterra (Barcelona), Spain.

the fetuses, arterial injections of coloured material (natural latex, barium sulphate or Araldite) were undertaken. The arterial patterns in these upper limbs were then identified by means of dissection using a surgical microscope, angiography or corrosion by hydrochloric acid. In order to locate easily the origin of the arterial variation into the brachial artery, the arm was divided topographically into 3 equal segments (Fig. 1) (Bergman et al. 1984; Jurjus et al. 1986).

RESULTS

Twenty-three upper limbs showing variations in the pattern of the brachio–antebrachial arteries were found: 17 showed unilateral variations (14 adult cadavers, 3 fetuses) whereas in the other 6 upper limbs they were bilateral (2 adult cadavers, 1 fetus). Based on the artery of the brachio–antebrachial axis presenting variations, 4 groups were recognised (see Fig. 1).

Isolated persistence of the median artery

In all cases the terminal branches of the brachial artery (the radial artery and the median-interosseous–ulnar arterial trunk) arose at the cubital fossa. Two types of terminal division of the median-interosseous–ulnar arterial trunk were observed: (1) bifurcation into ulnar artery and median-interosseous arterial trunk (case 2, Fig. 2; cases 3, 4); or (2) division into 3 branches: the ulnar artery, the common interosseous artery and the median artery (case 1). In case 3, the median nerve was split by the median artery.

High origin of the ulnar artery

These cases were grouped depending on whether a median artery was present or not.

Presence of a median artery (2 cases). Both upper limbs (cases 5, 6) belonged to the same cadaver and showed a bilaterally symmetric arterial variation. The ulnar artery arose from the axillary artery, crossed the median nerve and, at the elbow, ran superficial to the epitrochlear muscles. The brachial artery divided into 2 terminal branches at the cubital fossa: the radial and the median-interosseous trunk arteries. In both cases, the median nerve was split by the median artery.

Absence of a median artery (6 cases). The origin of the ulnar artery varied, occurring in the upper third (cases 7–9), the middle third (cases 10, 11) or the lower third (case 12) of the brachial artery. In 5 of these cases (cases 7, 8, 10–12) the ulnar artery ran superficial to the epitrochlear muscles (Fig. 3). In case 7, the diameter of the ulnar artery was substantially smaller than that of the brachial artery (Fig. 3).

High origin of the radial artery

These cases were also divided into 2 groups depending on whether a median artery was present or not.

Presence of a median artery (3 cases). The origin of the radial artery differed for each case, being in the upper third (case 13), the middle third (case 14) or the lower third (case 15) of the brachial artery. At the elbow, the brachial artery either bifurcated into the ulnar artery and the median-interosseous arterial trunk (case 14), or divided into 3 terminal branches: the ulnar artery, the common interosseous artery and the median artery, which arose at the same level (case 13, Fig. 4*a*, *b*; case 15). Cases 13 (Fig. 4*a*) and 14 showed the median nerve split by the median artery.

Absence of a median artery (4 cases). Two of these cases belonged to the same cadaver (cases 16, 17). In case 16, the radial artery arose from the axillary artery, whereas in the others (cases 17–19) it arose from the upper third of the brachial artery. In all cases the brachial artery divided into 2 branches at the elbow, the ulnar artery and the common interosseous artery. In case 16, the diameter of the radial artery was considerably larger than that of the brachial artery. Case 19 (upper limb from a fetus) showed an anastomosis at the cubital fossa between the brachial artery and the radial recurrent artery, which arose from the superficial brachial artery.

Duplication of the brachial artery

In 4 cases 2 brachial arteries were present, one superficial and another deep to the median nerve. In 2 of these cases the superficial brachial artery ended in an anastomosis at the cubital fossa, whereas in the other 2 cases it continued to the antebrachial region. Hence, 2 groups could be identified.

Cases with anastomosis (2 cases). In case 20, the superficial brachial artery arose from the upper third of the brachial artery and ended anastomosing at the lower third of it. The terminal division of the brachial artery followed a regular pattern. In case 21 (upper limb from a fetus), the superficial brachial artery arose from the distal third of the axillary artery and ended by anastomosing with the radial artery at the elbow (Fig. 5*b*). The brachial artery divided into 2 branches

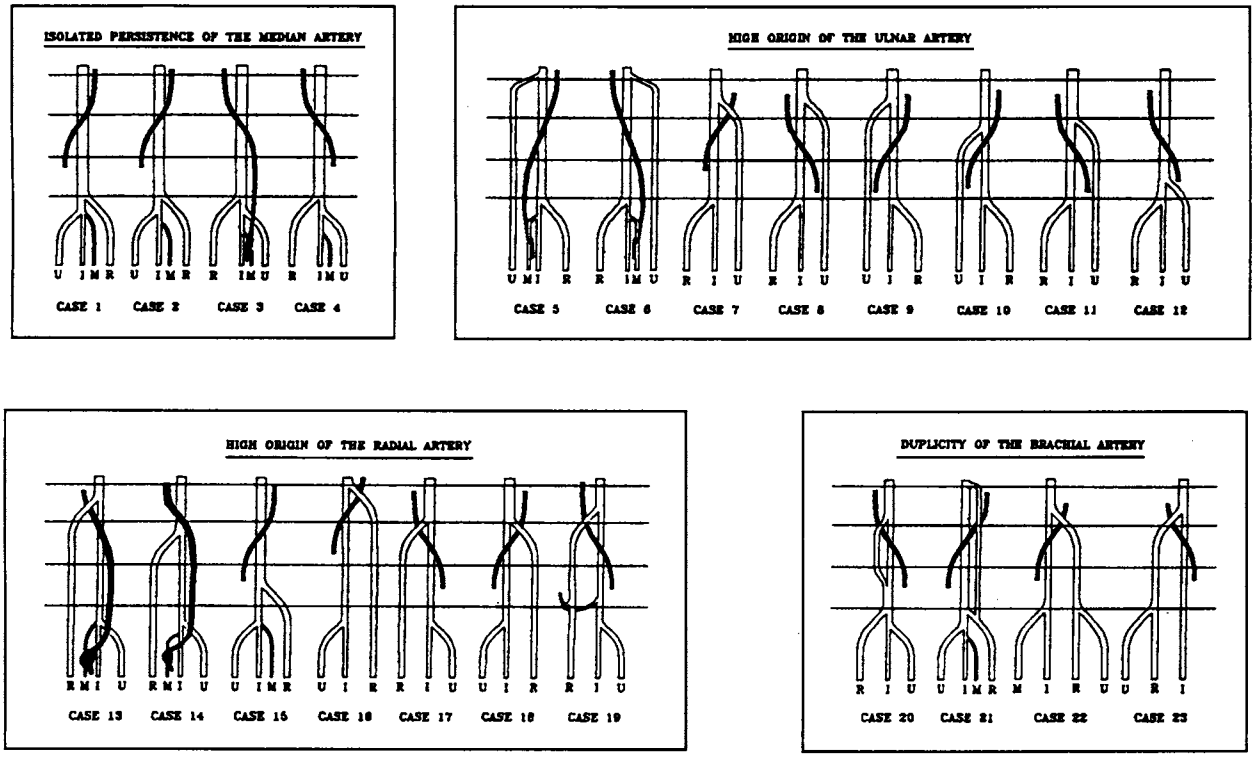

Fig. 1. Diagram showing all cases with variations in the main brachio–antebrachial arterial pattern. The arm region is divided topographically by horizontal lines into three equal segments: upper third, middle third and lower third. The black area represents the median nerve. I, common interosseous artery; M, median artery; R, radial artery; U, ulnar artery.

at the cubital fossa, the radial artery and the median-interosseous–ulnar arterial trunk.

Cases without anastomosis (2 cases). In both, the superficial brachial artery arose from the upper third of the arm and divided into the radial and ulnar arteries at the elbow. The ulnar artery ran superficial to the epitrochlear muscles (Fig. 5*a*). In case 22 (Fig. 5*a*) the brachial artery divided into the common interosseous artery and the median artery at the elbow, whereas in case 23 it continued into the forearm as the interosseous artery.

DISCUSSION

Variations in the number and/or course of the arteries of the upper limb have clinical and surgical significance (Cohen, 1948; Hazlett, 1949; McCormack et al. 1953; Seldinger, 1964; Jurjus et al. 1986; Tountas & Bergman, 1993). The prevalence of right side variations (2:1) observed by Lanz & Wachsmuth (1959) does not coincide either with that found by McCormack et al. (1953) or with that observed in the present study of 1.2:1. Bilateral variations have been noticed in 35% of our cases, being considerably higher than the 6.33% referred by McCormack et al. (1953).

The primitive axial artery and the superficial brachial artery have been implicated in the normal morphogenesis of the arteries of the upper limb (Müller, 1903; Senior, 1926; Singer, 1933; Schwyzer & De Garis, 1935). Briefly, the axillary, brachial and interosseous arteries derive from the primitive axial artery. Transiently, the median artery arises as a branch of the interosseous artery (Singer's Stage (SS) II; Singer, 1933). This artery has a major haemodynamic function during the SS III and SS IV (~ Carnegie's stage (CS) 19–20; O'Rahilly et al. 1981), and begins to regress at the SS V (~ CS 21), remaining as a residual artery: the commitans artery of the median nerve (Mrazková, 1973, 1989). The superficial brachial artery, identified by Müller (1903) in the 11.7 mm crown–rump length (CRL) embryo (~ CS 17) and by Senior (1926) in the 21 mm CRL embryo (~ CS 20), joins the axillary and brachial segments of the primitive axial artery by means of several trunks of origin. Müller (1903) also observed a superficial antebrachial artery joined to the superficial brachial artery in the same embryo. The superficial brachial artery anastomoses with the distal segment of the brachial artery in the 23 mm CRL embryo (~ CS 21) (Senior, 1926). Such an anastomosis plays an increasing haemodynamic role that leads to

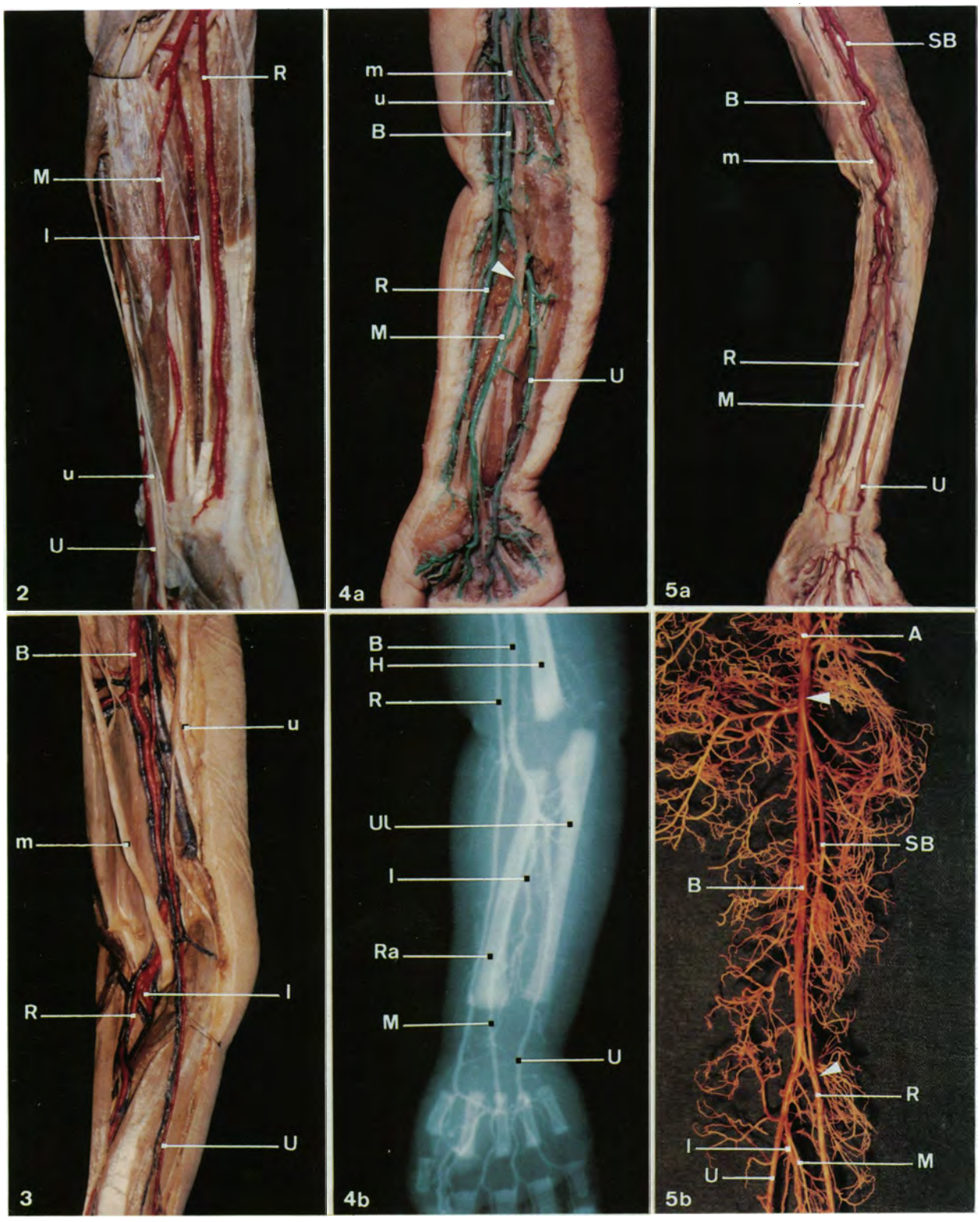

Fig. 2. Dissection of the anterior region of the forearm from an adult cadaver (case 2), showing persistence of the median artery. I, interosseous artery; M, median artery; R, radial artery; U, ulnar artery; u, ulnar nerve.

Fig. 3. Dissection of the anterior region of the arm and the forearm from an adult cadaver (case 7) showing a high origin of the ulnar artery. B, brachial artery; I, common interosseous artery; m, median nerve; R, radial artery; U, ulnar artery; u, ulnar nerve.

Fig. 4. (*a*) Dissection of the anterior region of the arm and the forearm from a full-term fetus (case 13) showing a high origin of the radial artery. The median nerve is split by the median artery (arrowhead). (*b*) Angiography showing the arterial pattern in the same case. B, brachial artery; H, humerus; I, interosseous artery; M, median artery; m, median nerve; R, radial artery; Ra, radius; U, ulnar artery; u, ulnar nerve; Ul, ulna.

involution of the proximal segment of the superficial brachial artery. This may represent the origin of the radial artery (Senior, 1926; Singer, 1933). The ulnar artery would arise directly from the axial artery in the 14 mm CRL embryo (~ CS 17–18) (Mrazková, 1973, 1989) or the 18 mm CRL embryo (SS III ~ CS 19–20). However, Poteat (1986) considered that it followed a similar development to that of the superficial brachial–radial system where a superficial ulnar artery, present at the SS II, anastomosed with the brachial artery (SS III ~ CS 19–20), determining involution of the proximal segment of the superficial ulnar artery.

The global analysis of these morphogenetic facts together with cases of variations previously published may suggest some changes in understanding of normal formation of the upper limb arteries.

1. The superficial brachial artery is a consistent embryonic vessel that plays an important role in the normal arterial morphogenesis of the upper limb. Persistence of this artery in the adult (Tountas & Bergman, 1993), coexisting or not with the brachial artery, was found in 17% of subjects by Fuss et al. (1985), 22% by Lippert & Pabst (1985), and 25% by Lanz & Wachsmuth (1959).

2. The superficial brachial artery has 2 terminal branches (Müller, 1903; Vancov, 1961): a medial one which is the superficial antebrachial artery and a lateral one that continues in the forearm as a part of the definitive radial artery.

3. The superficial antebrachial artery divides into 2 terminal branches: median and ulnar (Müller, 1903; Lanz & Wachsmuth, 1959; Vancov, 1961). Each of these branches anastomoses with a corresponding branch of the primitive axial artery, which are trunks in origin of the median and ulnar arteries respectively. Gradually, the trunks of deep origin obtain a haemodynamic predominance and the superficial antebrachial artery together with the preanastomotic segment of its terminal branches regress. Therefore, 2 segments can be distinguished in both the median and ulnar arteries: a proximal or deep one which corresponds to trunks of origin in the primitive axial artery, and another distal or superficial which represents postanastomotic segments of the terminal branches of the superficial antebrachial artery. Such an understanding is based on the following data.

3.1. Several cases have been described in which the superficial antebrachial artery anastomosed with the ulnar artery at the middle third of the forearm, resulting distally in an artery located in the usual position of the ulnar artery in the forearm and hand (Vancov, 1961; Lippert & Pabst, 1985). This position remained also in other cases where the superficial antebrachial artery completely replaced the ulnar artery (Lippert & Pabst, 1985; Tountas & Bergman, 1993).

3.2. Superficial median arteries have been described arising from the superficial antebrachial artery. They become satellites of the median nerve in the distal third of the forearm (Vancov, 1961; Lippert & Pabst, 1985).

3.3. The formation of the superficial antebrachial artery precedes that of the ulnar artery (Müller, 1903).

3.4. The plexiform appearance of arteries during embryonic development (De Vriese, 1902; Arey, 1963; Fitzgerald, 1978) suggests that several anastomoses take place between superficial and deep arteries in the forearm, which sometimes persist as was described by Singer (1933), Schwyzer & De Garis (1935), McCormack et al. (1953), Vancov (1961) and Pabst & Lippert (1968).

4. The radial artery usually develops similarly to the median and ulnar arteries. Thus the lateral terminal branch of the superficial brachial artery anastomoses with a trunk for the deep origin of the radial artery in the primitive axial artery. Deep haemodynamic predominance determines regression of those superficial arterial segments located proximal to the anastomosis, while the distal segments persist as a part of the radial artery. This explanation is in agreement with that given by Senior (1926) and Singer (1933). However, they defined the superficial branch of the anastomosis as the proper superficial brachial artery and not as its lateral terminal branch. This difference may be justified by the fact that once the anastomosis between the trunk for the deep origin of the radial artery and the lateral branch of the superficial brachial artery is made (SS V, 23 mm CRL embryo ~ CS 21), the definitive patterns of the median and ulnar arteries have already been established.

According to these interpretations, the morphogenetic changes in the brachio–antebrachial arterial

Fig. 5. (*a*) Dissection of the anterior region of the arm and the forearm from an adult cadaver (case 22) showing duplication of the brachial artery. The superficial brachial artery can also be seen. (*b*) Injection and corrosion displaying the brachio–antebrachial arterial pattern from a full-term fetus (case 21) showing duplication of the brachial artery. Arrowheads, origin and termination of the superficial brachial artery. A, axillary artery; B, brachial artery; I, common interosseous artery; M, median artery; m, median nerve; R, radial artery; SB, superficial brachial artery; U, ulnar artery.

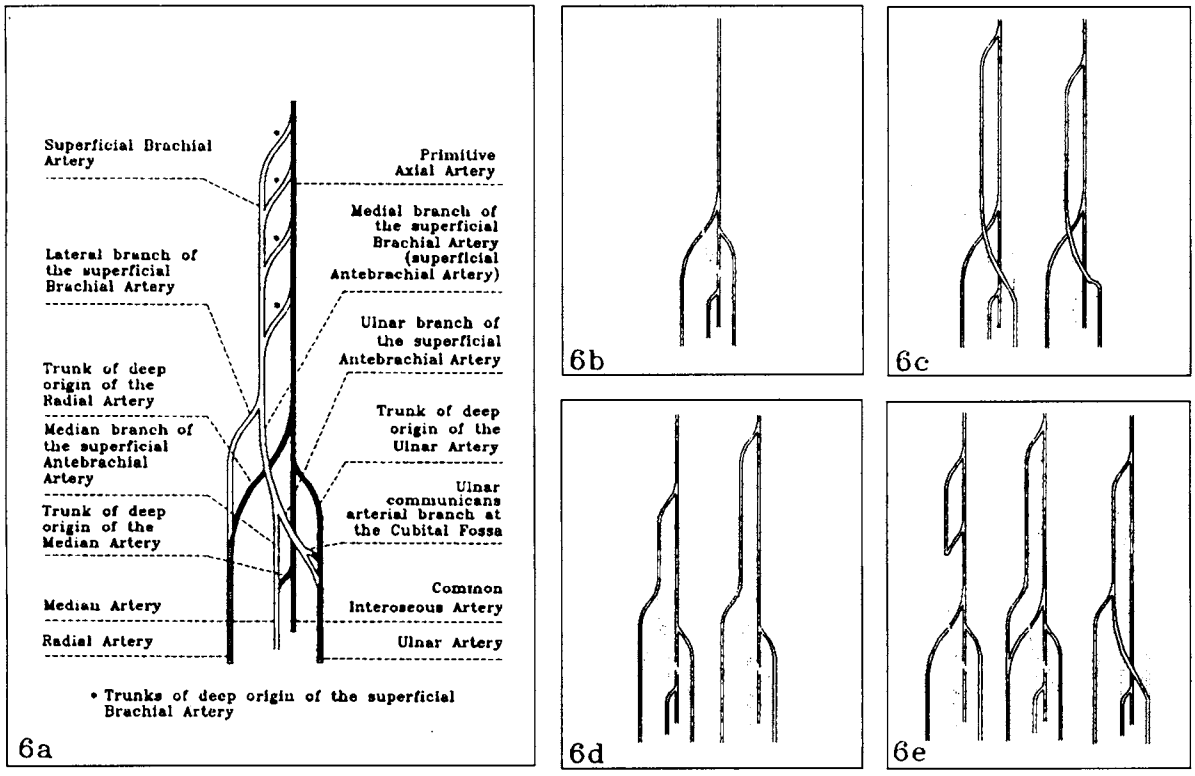

Fig. 6. Schematic diagrams showing arterial segments that are present during development of the brachio–antebrachial arterial system. (*a*) Diagram summarising all segments during normal development. The deep arterial system (black lines) remains in the definitive arterial pattern whereas only distal segments (shaded lines) of the superficial arterial system (empty lines) persist as a part of the radial and ulnar arteries. (*b–e*) Diagrams showing the proposed embryological events during development of 4 groups of brachio–antebrachial arterial variations. The arterial segments that persist are represented by empty lines whereas those segments that regress are represented by dotted lines. (*b*) Isolated persistence of the median artery that arises from the median interosseous arterial trunk. (*c*) Diagrams showing 2 different patterns with a high origin for the ulnar artery. This artery may run either superficial (on the left) or deep (on the right) to the epitrochlear muscles. In addition, the diagram on the left is also a case of persistence of the median artery. (*d*) Two patterns with a high origin for the radial artery either with (on the left) or without (on the right) persistence of the median artery. (*e*) Diagrams showing 3 different patterns of duplication of the brachial artery. On the left there are 2 trunks of deep origin of the superficial brachial artery. The central diagram shows a case with persistence of the superficial brachial artery and its lateral branch, which joins the trunk of deep origin of the radial artery. Persistence of the median artery can also be observed. The diagram on the right shows a case with persistence of the superficial brachial artery and its 2 terminal branches, as well as the median artery.

pattern that may have caused the different arterial variations observed by us are summarised in Figure 6*a*. This also shows transitional arterial segments and those that remain in the adult pattern.

Persistence of the median artery (Fig. 6b)

Persistence of the median artery in our cases is justified in section 3 of the preceding discussion. Due to its morphogenesis, this variation may be associated with several variations of the brachio–antebrachial arterial pattern (Fig. 6*c–e*).

Persistence of the superficial brachial pattern (Fig. 6c–e)

Under this designation, we have grouped those cases in which the superficial brachial embryonic system shows its primitive axial origin and persists at brachial and/or antebrachial level.

Persistence at brachial level. In these cases, 2 brachial arteries are found. One is superficial and the other deep to the median nerve. The persistence of 2 of the early trunks of origin in the superficial brachial artery explains the case in which the superficial brachial artery joins the brachial artery distally (Fig. 6*e*). In that case, in which the superficial brachial artery anastomoses with the upper third of the radial artery, a transitory phase in the radial artery formation would take place (Fig. 6*e*). Thus both the superficial brachial artery and the pre-anastomotic segment of its terminal lateral branch would persist.

Persistence at both brachial and antebrachial levels. The characteristic of these cases is that the adult arterial pattern shows a brachial or axillary origin for the radial and/or ulnar arteries (Tountas & Bergman, 1993; Fig. 6*c–e*). The high origin of either the radial

or ulnar arteries is embryologically justified by a crossed haemodynamic predominance between the deep and the superficial arterial territories of the primitive original segments of these arteries. This fact leads to the persistence of the superficial brachial artery and one of its terminal branches and, moreover, agenesis (primary or secondary to a regression) of the trunk of deep origin (Fig. 6*c*, *d*).

In a single case with a high origin of the radial artery, a loop-like formation similar to those described by Adachi (1928), McCormack et al. (1953) or Chouéki-Guttenbrunner et al. (1990), was observed. This arrangement has been related to hypotrophic persistence of the anastomosis between the primitive axial artery and the superficial brachial artery at the level of the deep origin of the radial artery.

Also in a single case, an ulnar artery with a high origin crossed deep to the epitrochlear muscles. This suggests the existence of an anastomosis between the pre-anastomotic segment of the ulnar branch of the superficial antebrachial artery and the trunk for the deep origin of the ulnar artery (ulnar communicans arterial branch of the ulnar fossa; Fig. 6*c*). It is nevertheless possible that the trunk of origin of the ulnar artery itself arises ectopically from the superficial antebrachial artery territory. In any case, this arterial bypass would have become a predominant arterial route in the primitive plexiform pattern and may justify the regression of those adjacent arterial segments that have a minor haemodynamic significance.

In those cases in which the superficial brachial artery gave rise to the definitive radial and ulnar arteries at the level of the antecubital fossa, the determining factors of the above mentioned high origin of both vessels would have coexisted as well (Fig. 6*e*). The origin of these arteries either from the axillary or brachial arteries depends on which of the early trunks of origin of the superficial brachial artery have persisted (Fuss et al. 1985).

REFERENCES

ADACHI B (1928) *Das Arteriensystem der Japaner*, vol. 1, pp. 327–374. Kyoto: Maruzen Press.

AREY LB (1963) The development of peripheral blood vessels. In *The Peripheral Blood Vessels* (ed. J. L. Orbison & D. E. Smith), pp. 1–16. Baltimore: Williams and Wilkins.

BERGMAN RA, THOMPSON SA, AFIFI AK (1984) *Catalog of Human Variation*, pp. 108–114. Baltimore: Urban & Schwarzenberg.

CARLSON BM (1994) *Human Embryology and Developmental Biology*, pp. 197–201. St Louis, MO: Mosby.

CHOUÉKI-GUTTENBRUNNER K, FUSS FK, PODESER B (1990) Die Schlingenbildung der Arteria radialis an ihrem Ursprung. *Acta Anatomica* **138**, 270–272.

COHEN SM (1948) Accidental intra-arterial injection of drugs. *Lancet* **255**, 361–371, 409–416.

DE VRIESE B (1902) Recherches sur l'évolution des vaisseaux sanguins des membres chez l'homme. *Archives de Biologie* **18**, 665–730.

FITZGERALD MJT (1978) *Human Embryology*, pp. 38–56. New York: Harper International.

FUSS FK, MATULA ChW, TSCHABITSCHER M (1985) Die Arteria brachialis superficialis. *Anatomischer Anzeiger* **160**, 285–294.

GONZÁLEZ-COMPTA X (1991) Origin of the radial artery from the axillary artery and associated hand vascular anomalies. *Journal of Hand Surgery* **16A**, 293–296.

HAZLETT JW (1949) The superficial ulnar artery with reference to accidental intra-arterial injection. *Canadian Medical Association Journal* **61**, 289–293.

JURJUS A, SFEIR R, BEZIRDJIAN R (1986) Unusual variation of the arterial pattern of the human upper limb. *Anatomical Record* **215**, 82–83.

LANZ T, WACHSMUTH W (1959) *Praktische Anatomie*, vol. 1, part 3 Arm, pp. 124–125, 144. Berlin: Springer.

LIPPERT H, PABST R (1985) *Arterial Variations in Man*, pp. 68–73. New York: Springer.

MCCORMACK LJ, CAULDWELL EW, ANSON BJ (1953) Brachial and antebrachial arterial patterns. *Surgery, Gynecology and Obstetrics* **96**, 43–54.

MRÁZKOVÁ O (1973) Ontogenesis of arterial trunks in the human forearm. *Folia Morphologica* **21**, 193–196.

MRÁZKOVÁ O (1989) Le réseau vasculaire du membre supérieur et ses relations avec les muscles pendant l'ontogénèse humaine. *Angéiologie* **41**, 41–52.

MÜLLER E (1903) Beiträge zur Morphologie des Gefässystems. I. Die Armarterien des Menschen. *Anatomischer Hefte* **22**, 377–575.

O'RAHILLY R, BOSSY J, MÜLLER F (1981) Introduction à l'étude des stades embryonnaires chez l'homme. *Bulletin de l'Association des Anatomistes* **65**, 5–98.

PABST R, LIPPERT H (1968) Beiderseitiges Vorkommen von A. brachialis superficialis, A. ulnaris superficialis und A. mediana. *Anatomischer Anzeiger* **123**, 223–226.

POTEAT WL (1986) Report of a rare human variation: absence of the radial artery. *Anatomical Record* **214**, 89–95.

SCHÄFER EA, THANE GD (1894) *Quain's Elements of Anatomy*, vol. 2, part II, *Arthrology–Myology–Angeiology*, pp. 436–453. London: Longmans, Green.

SCHWYZER AG, DE GARIS ChF (1935) Three diverse patterns of the arteria brachialis superficialis in man. *Anatomical Record* **63**, 405–416.

SELDINGER SI (1964) Arteries of the extremities. In *Handbuch Medizinischer Radiologie* (ed. L. Deithelm, O. Olsson, F. Strnad, H. Vieten & A. Zuppinger), vol. 10, part 3, pp. 400–472. Berlin: Springer.

SENIOR HD (1926) A note on the development of the radial artery. *Anatomical Record* **32**, 220–221.

SINGER E (1933) Embryological pattern persisting in the arteries of the arm. *Anatomical Record* **55**, 403–409.

SKOPAKOFF VC (1959) Über die Variabilität der Ab- und Verzweigung der A. brachialis superficialis. *Anatomischer Anzeiger* **106**, 356–368.

TESTUT L, LATARJET A (1981) *Tratado de Anatomía Humana*, vol. 2, pp. 287–307. Barcelona: Salvat.

TOUNTAS ChP, BERGMAN RA (1993) *Anatomic Variations of the Upper Extremity*, pp. 196–210. New York: Churchill Livingstone.

VANCOV V (1961) Une variété extrêmement complexe des artères du membre supérieur chez un foetus humain. *Anatomischer Anzeiger* **109**, 400–404.

WILLIAMS PL, WARWICK R (1985) *Gray Anatomía*, vol. 1, p. 663. Barcelona: Salvat.