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Anatomical variability of the superficial venous network of the upper limb and its clinical implications

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Abstract

Background: The superficial veins of the upper limb are the most frequently instrumented vessels in clinical practice, yet their configuration within the cubital fossa is inconstant between individuals. Such variability bears directly upon the safety of venipuncture, upon catheter placement, and upon selection of conduits for arteriovenous fistula construction. **Methods:** Six hundred and forty limbs from 320 adults were examined by surface mapping under cuff inflation with near-infrared transillumination. Configurations were assigned to six categories derived from an established classification. Prevalence was estimated using Wilson intervals, and associations with sex and side were examined by chi-square testing. Luminal calibre and the interval separating each vein from the median nerve were recorded. **Results:** The oblique configuration predominated, occurring in 52.5% of limbs, followed by the classical branching configuration in 24.1%. Distribution varied significantly with sex but not with side, and bilateral concordance reached only 68.1%. The median cubital vein proved the most capacious and most readily visualised channel, whereas the basilic vein lay nearest the median nerve and the cephalic vein farthest from it. **Conclusion:** Antecubital venous configuration is sufficiently variable that every limb warrants individual assessment before instrumentation, particularly where vascular access surgery is being actively contemplated.

Keywords: Cubital fossa, Median cubital vein, Venipuncture, Arteriovenous fistula, Anatomical variation

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1. Introduction

The superficial veins of the extremity lie in the subcutaneous plane between two layers of the superficial fascia, and constitute a continuous net-work, whose origin is the dorsal venous arch of the hand, and whose termination is the axillary vein. There is no similar vascular field which is as frequently instrumented. These vessels are relied upon in phlebotomy, administration of drugs and contrast medium, insertion of peripherally inserted central catheters, and creation of arteriovenous fistulae to be used in haemodialysis (Strandberg, 2016;

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Moore *et al.*, 2014). A skill in finding and choosing them is thus an everyday necessity of clinical practice and not a perfecting of descriptive anatomy.

There are three major channels identified. The cephalic vein rises at the radial side of the forearm as the lateral border of the biceps brachii and thus passes through the deltopectoral groove and ends into the axillary vein. The basilic vein rises on the ulnar and then the medial part of the limb and then penetrates the deep fascia on the mid line of the arm. In between the two, the median antebrachial vein rises. These channels are joined together in the cubital fossa with one or more oblique communications of which the median cubital vein is the most regular (Jasinski and Poradnik, 2003). Behind this vein there is the bicipital aponeurosis between the vein plane and the brachial artery and the lateral and medial antebrachial cutaneous nerves follow the cephalic and basilic veins respectively (Mikuni *et al.*, 2013; Yamada *et al.*, 2008).

The configuration of these communications is not constant. Consecutive observations dating back to the beginning of the twentieth century and the current ones gathered through inspection of living subjects, cadaveric dissection of the veins, transillumination and computed tomographic venography have continually shown interindividual variation, as well as the variation due to sex and to population (Berry and Newton, 1908; Okamoto, 1922; Charles, 1932; Del Sol *et al.*, 2012). Advances in this area have however been stalled by the emergence of classification schemes. Over time, morphologically identical patterns have been assigned various names by different authors, such that a pattern in one rightly called type A in a particular series, is type 2 or type 3 in other series, and it is dangerous to directly compare studies (Pires *et al.*, 2018; Yammine and Eric, 2017). The joint study of twenty-seven series of 9924 limbs is the largest effort at harmonizing these schemes and is the main quantitative source on the subject.

This variability has neither trivial nor uniformly appreciated clinical outcomes. The cannulated vein can influence the likelihood of the first attempt success and risk of harm to nearby tissues. Percussion of a cutaneous nerve causes lancinating pain and paraesthesia immediately followed by the penetration and paraesthesia and, unintentionally, entry into an aberrant superficial artery can lead to the ischaemic sequelae (Ramos, 2014; Shivappagoudar and George, 2013). The calibre, course and patency of the cephalic and basilic veins in vascular access surgery determine maturation and long-term functioning of fistulas and an undescribed variant could require revision of the surgical plan intraoperative (Quencer and Arici, 2015; Kumar *et al.*, 2007).

Despite a rich descriptive literature, relatively few studies have investigated venous configuration, luminal calibre and neurovascular proximity at the same time, therefore, the morphological and the procedural sides of the issue have been presented separately. The current work was created to fill in that gap. It aimed to find out what proportion each arrangement of the antecubital venous system, whether or not this arrangement is connected with the sex or with the side and to what degree, whether configuration is related to venipuncture, catheter insertion, and vascular access surgery.

2. Materials and methods

2.1. Design and cohort

A cross-sectional analysis (descriptive) was carried out on 320 adults with 640 upper limbs being analyzed. The sample consisted of 168 males and 152 females with a mean age of 34.6 years with a standard deviation of 11.2 years and a minimum of 18 years and a maximum of 64 years. They were all evaluated on both limbs and the unit of measurement was the individual limb unless bilateral concordance was being evaluated. Limbs were avoided in which a history of a previous operative procedure, traumas, venous thrombosis, or prior arteriovenous access existed, as fibrosis in these limbs distorts the superficial venous map and renders these limbs unreliable to classify.

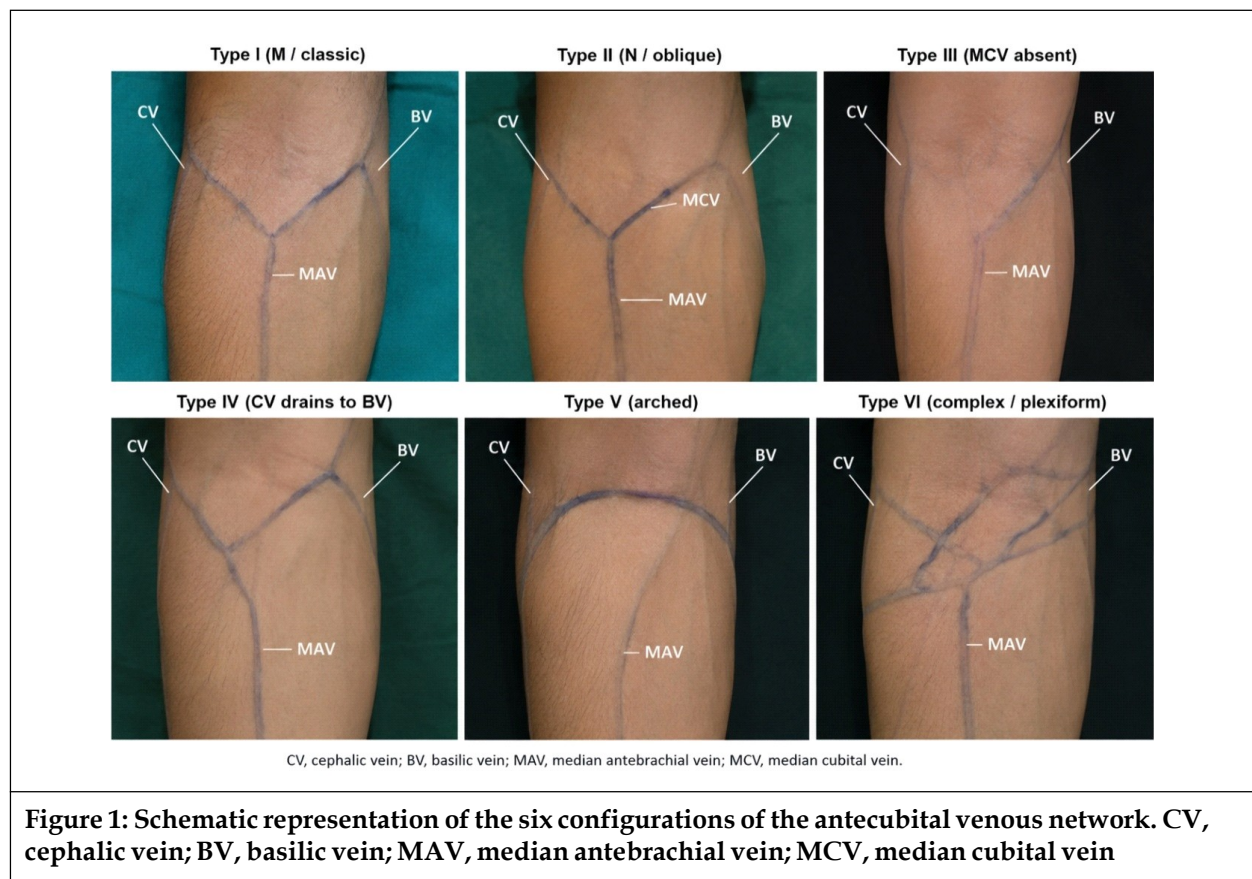
2.2. Visualisation and measurement

All the limbs were tested in extension and supination. Pneumatic cuff was used to distend the superficial veins by placing a pneumatic cuff on the arm and inflating the cuff to reach the subdiastolic pressure. Tracing of the venous course on the skin was followed by confirmation by near-infrared transillumination; a method that clears subcutaneous channels with reasonable fidelity, and without recourse to dissection (Lee *et al.*, 2015). In all the limbs that had them, the cephalic, basilic, median and cubital veins of the forearms were found.

The luminal calibre was measured and the space between each vein and the underlying median nerve has been measured following the inflation of the cuff as per the protocol that has been observed in previous ultrasonography studies ([Mukai et al., 2020](#)).

2.3. Classification

The configurations were grouped into six categories based on the scheme that was confirmed in the pooled analysis and modified to assess the surfaces. Figure 1 shows these. Type I refers to the classical division pattern, where the median antebrachial vein separates into median cephalic and median basilic tributaries and is an M or Y form. Type II refers to the oblique type where a single median cubital vein drains upwards and medially between the cephalic and basilic veins and takes in the median antebrachial vein- an N-type. Type III refers to loss of the median cubital vein, with the cephalic and basilic systems independent of each other in the fossa. Type IV: The basilic vein has termination of the cephalic vein without any residual proximal cephalic vein. Type V refers to a proximal concavity arched communication. The residual complex and plexiform arrangements are in Type VI. Each limb was classified using a five-point scale by two observers and the few discrepancies were conflict resolved by consensus.



2.4. Statistical analysis

Categorical variables are given in the form of absolute frequencies and corresponding percentages. The Wilson score method was used to obtain ninety-five percent confidence intervals and the method has satisfactory coverage when the proportion is close to parameter space limits. The Pearson chi-square test was used to determine association between configuration and sex, and configuration and side. Bilateral concordance was determined as the percentage of the subjects with the same configuration on both limbs. Continuous variables are reported in terms of arithmetic mean and standard deviation. A probability less than 0.05 was taken as a sign of statistical significance.

3. Results

3.1. Configuration of the antecubital venous network

A definite configuration was assignable in all 640 limbs. The oblique Type II arrangement predominated,

being identified in 336 limbs, corresponding to 52.5% of the cohort, with a 95% confidence interval of 48.6 to 56.3%. The classical Type I arrangement followed, present in 154 limbs or 24.1%. Absence of the median cubital vein, designated Type III, was recorded in 66 limbs or 10.3%, and Type IV in 45 limbs or 7.0%. The arched Type V and the plexiform Type VI arrangements were infrequent, accounting for 3.4% and 2.7% of limbs respectively. Together the two commonest configurations therefore accounted for slightly more than three quarters of the cohort (Table 1).

3.2. *Distribution according to sex*

Configuration was associated with sex, the chi-square statistic being 15.0 upon five degrees of freedom with a corresponding probability of 0.010. The classical Type I arrangement occurred more often in men, accounting for 28.6% of male limbs as against 19.1% of female limbs. Absence of the median cubital vein was correspondingly more frequent in women, at 13.8% of female limbs as against 7.1% of male limbs. The predominant Type II arrangement was distributed almost equally between the sexes, at 53.0% and 52.0% respectively, so that the observed association derived principally from the less frequent configurations (Figure 2).

Table 1: Distribution of antecubital venous configurations in 640 upper limbs, with 95% Wilson confidence intervals				
Configuration	Morphological description	Limbs (n)	Prevalence (%)	95% CI (%)
Type I	Classical branching, M or Y form	154	24.1	20.9 to 27.5
Type II	Oblique median cubital vein, N form	336	52.5	48.6 to 56.3
Type III	Median cubital vein absent	66	10.3	8.2 to 12.9
Type IV	Cephalic vein terminating in basilic vein	45	7.0	5.3 to 9.3
Type V	Arched communication	22	3.4	2.3 to 5.1
Type VI	Complex or plexiform	17	2.7	1.7 to 4.2
Total		640	100.0	

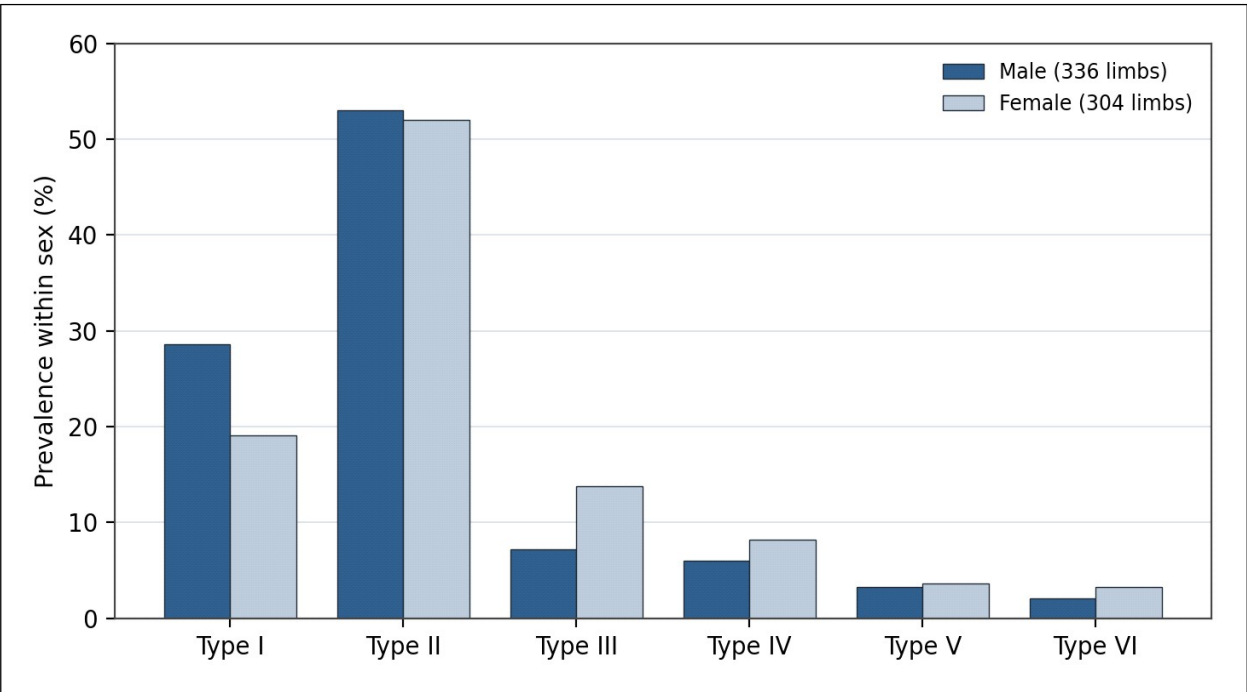


Figure 2: Distribution of venous configuration according to sex

3.3. Laterality and bilateral concordance

No association was demonstrable between configuration and side, the chi-square statistic being 0.66 upon five degrees of freedom with a probability of 0.985. An identical configuration was present in both limbs of 218 of the 320 participants, yielding a bilateral concordance of 68.1% with a 95% confidence interval of 62.8 to 73.0%. Approximately one participant in three therefore exhibited dissimilar arrangements on the two sides (Table 2).

Table 2: Distribution of antecubital venous configurations according to body side (n = 640 limbs)

Configuration	Right (n = 320)	Left (n = 320)	Total (n)
Type I	77	77	154
Type II	168	168	336
Type III	33	33	66
Type IV	22	23	45
Type V	11	11	22
Type VI	9	8	17
Chi-square (χ^2)			0.66
Degrees of freedom (df)			5
P-value			0.985

3.4. Luminal calibre, visibility and relation to the median nerve

Among the communicating channels the median cubital vein possessed the greatest calibre after cuff inflation, with a mean diameter of 3.8 millimetres. The largest single measurement was obtained from the cephalic vein within the deltopectoral groove, at 4.1 millimetres, consistent with its function as a proximal outflow channel. Visibility after cuff inflation was greatest for the median cubital vein at 92.0%, followed by the cephalic vein at 74.4% and the basilic vein at 66.1%.

The interval separating each vein from the underlying median nerve differed appreciably between channels. The basilic vein lay nearest the nerve at a mean of 4.2 millimetres, the median cubital vein occupied an intermediate position at 6.1 millimetres, and the cephalic vein lay farthest at 12.4 millimetres. A mediolateral gradient of separation was thus evident across the fossa. These measurements are summarised in Table 3 and Figure 3.

Table 3: Luminal calibre, visibility after cuff inflation, and interval separating each vein from the median nerve. Values are mean with standard deviation, or percentage of 640 limbs

Vein	Calibre (mm)	Visibility (%)	Interval to median nerve (mm)
Median cubital vein	3.8 ± 0.9	92.0	6.1 ± 2.0
Basilic vein	3.3 ± 0.8	66.1	4.2 ± 1.6
Cephalic vein, forearm	2.9 ± 0.7	74.4	12.4 ± 3.1
Cephalic vein, deltopectoral	4.1 ± 1.0	Not applicable	Not applicable

3.5. Proximal course of the cephalic vein

The proximal cephalic vein followed its described course in the majority of limbs, terminating in the axillary vein by way of the deltopectoral groove in 583 limbs, corresponding to 91.1%. A variant configuration of the cephalic arch was identified in 41 limbs or 6.4%, and a rudimentary or absent proximal cephalic segment in 16 limbs or 2.5%. Approximately one limb in eleven therefore departed from the standard proximal arrangement (Table 4).

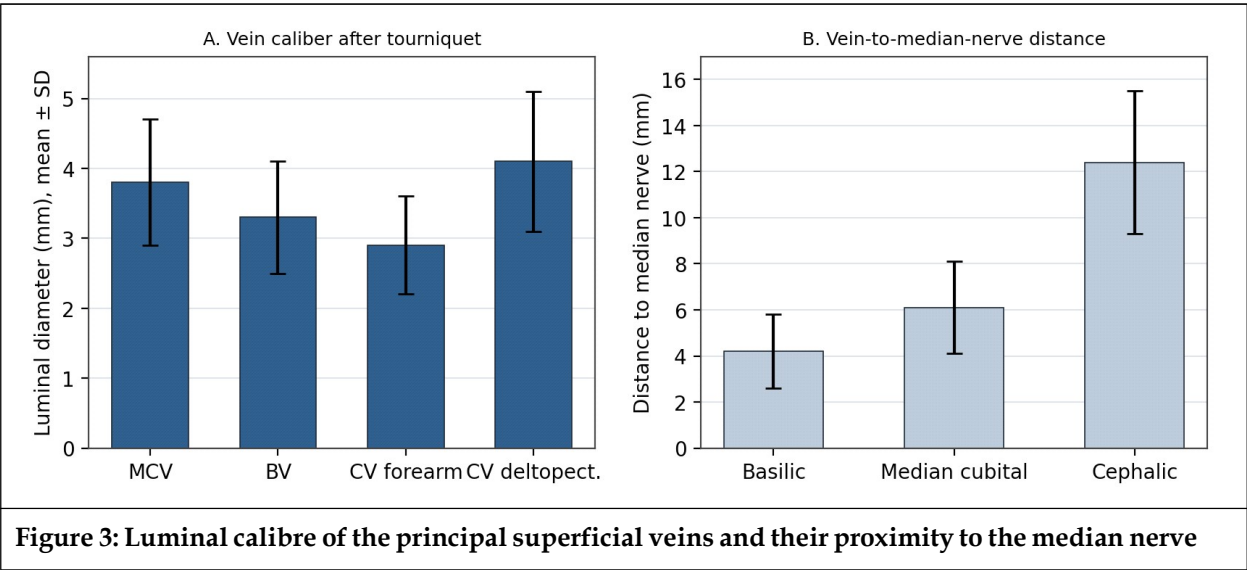
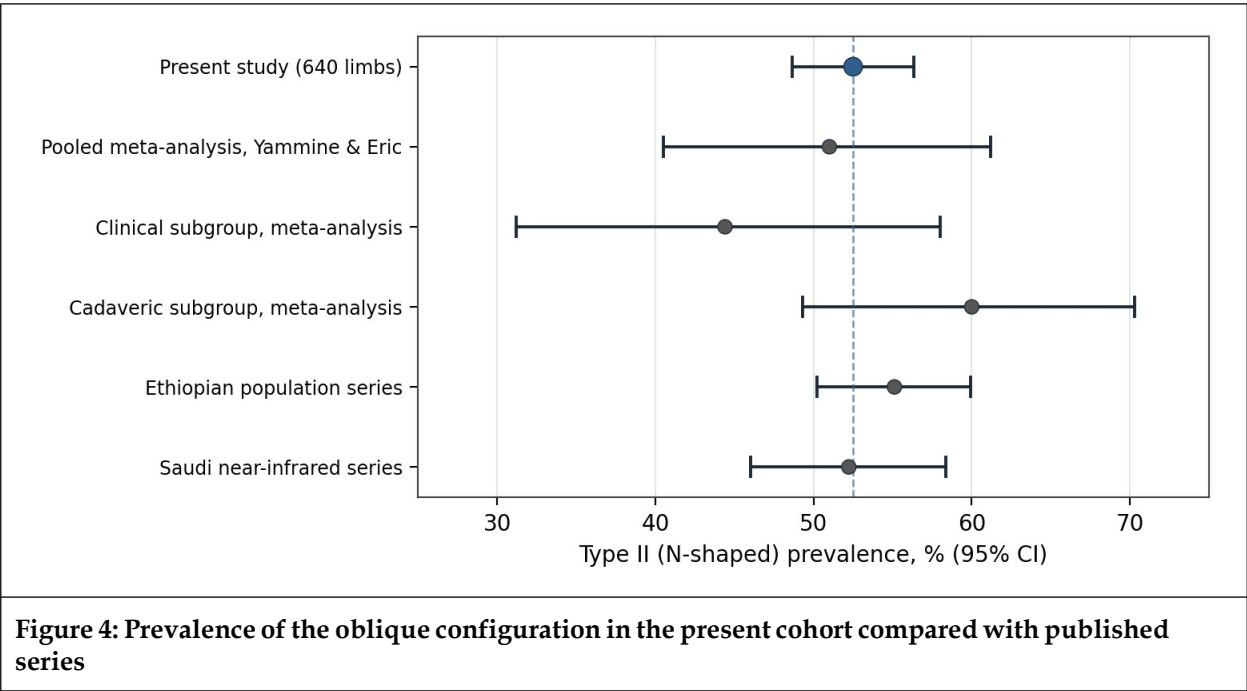


Table 4: Proximal course of the cephalic vein in 640 upper limbs			
Proximal cephalic vein pattern	Limbs (n)	Prevalence (%)	95% CI (%)
Normal termination through deltopectoral groove	583	91.1	88.7–93.1
Variant cephalic arch	41	6.4	4.8–8.5
Rudimentary or absent proximal segment	16	2.5	1.5–4.0

4. Discussion

The principal observation of the present analysis is the numerical dominance of the oblique arrangement, in which a solitary median cubital vein passes obliquely between the two principal trunks. Its prevalence of 52.5%, together with the 24.1% recorded for the classical branching arrangement, accords closely with the pooled estimates of the largest synthesis available, which placed the oblique arrangement between 44 and 60% and the classical arrangement between 20 and 25%. Comparable rank ordering has been reported from series conducted in Nigeria, Iraq, India, Chile, Colombia, Malaysia, and Brazil, notwithstanding pronounced differences in method and in ancestry ([Ukoha *et al.*, 2013](#); [Wasfi *et al.*, 1986](#); [Halim and Abdi, 1974](#); [Del Sol *et al.*,](#)



2007; Corzo Gomez *et al.*, 2010; Hamzah *et al.*, 2014). The concordance of the present estimate with these independent datasets is displayed in Figure 4, and it suggests that the dominance of the oblique arrangement is a stable feature of human antecubital anatomy rather than an artefact of any particular population or technique.

A modest systematic divergence between methods deserves comment. Cadaveric series consistently return the higher estimates, whereas investigations conducted upon living subjects return values some ten to fifteen percentage points lower. The explanation is probably technical rather than biological. Dissection permits the tracing of channels too slender to distend under a tourniquet, so that communications invisible *in vivo* are counted as present post mortem. The estimate obtained here occupies an intermediate position between the two, which is the expected location for a surface method augmented by transillumination and which argues against material misclassification.

The association with sex observed in this cohort, in which the classical arrangement predominated among men and absence of the median cubital vein among women, reproduces a finding reported in several independent series. The magnitude of the effect nevertheless requires careful interpretation. Although the association attained statistical significance, the dominant oblique arrangement was distributed almost identically between the sexes, and the difference resided in the less frequent configurations. Sex may therefore shift the prior probability of encountering a particular arrangement, but it possesses negligible predictive value for the individual patient. The same reservation applies with greater force to laterality. No side effect was demonstrable, and bilateral concordance reached only 68.1%, so that nearly a third of participants presented dissimilar configurations on the two sides. Extrapolation from one limb to the other, a practice occasionally adopted when the contralateral limb is inaccessible, is not supported by these data.

The relation of the superficial veins to the median nerve constitutes the observation of greatest procedural consequence. The mediolateral gradient demonstrated here, in which the basilic vein lies within approximately four millimetres of the nerve while the cephalic vein lies at three times that distance, corresponds closely to measurements obtained by dissection and by ultrasonography. This gradient furnishes an anatomical explanation for the distribution of reported complications, since the majority of nerve injuries attributable to venipuncture involve the medial compartment of the fossa or the lateral antebrachial cutaneous nerve accompanying the cephalic vein (Tsukuda *et al.*, 2019). Such injury is uncommon, occurring at rates between one in twenty-one thousand and one in sixty-seven thousand procedures, yet the sheer volume of venipuncture performed annually converts an infrequent event into a substantial aggregate burden. The practical inference is unambiguous. The radial aspect of the median cubital vein combines the greatest calibre, the highest rate of visualisation, and an acceptable margin from the median nerve, and it should accordingly be regarded as the site of first choice for routine venipuncture.

Findings relating to the proximal cephalic vein bear directly upon vascular access surgery. The cephalic vein is the preferred conduit for both radiocephalic and brachiocephalic fistulae, and the cephalic arch is a recognised site of stenosis and of subsequent access failure (Loukas *et al.*, 2008). A variant or rudimentary proximal segment, encountered in a small but clinically material proportion of limbs in the present cohort, would necessitate revision of the operative plan, most often in favour of the basilic vein and a transposition procedure. Preoperative venous mapping is therefore justified before any elective access procedure, and the same information reduces the incidence of failed cannulation during peripheral catheter placement. Analogous considerations govern the peripherally inserted central catheter, for which the basilic vein is customarily selected on account of its calibre and relatively direct course. An unanticipated configuration or an absent segment complicates advancement of the catheter and increases the probability of malposition and of catheter-associated bloodstream infection (Chopra *et al.*, 2014).

The developmental origin of this variability accounts for several of its features. The superficial veins of the limb differentiate from a diffuse capillary plexus within the limb bud, which undergoes progressive remodelling during fetal life. The cephalic and basilic trunks arise from the lateral and medial portions of this plexus and the median antebrachial vein from its central portion, whereas the antecubital communications are the last elements to acquire definitive form. Because their final configuration is determined by which segments of the primitive plexus persist and which regress, a process only loosely constrained by genotype, the resulting morphology is inherently variable. This mechanism provides a coherent explanation for the spectrum of

configurations observed, for the occasional absence of the median cubital vein, and for the incomplete concordance between the limbs of a single individual.

These considerations acquire additional resonance when set against the historical use of the region. The antecubital veins served as the site of therapeutic venesection for many centuries, and the median vein was preferred precisely because the intervening bicipital aponeurosis protected the brachial artery from the lancet (Parapia, 2008). Contemporary anatomy has formalised that empirical preference into a classification and a body of measurement, yet the underlying principle is unaltered. The most conspicuous vein is not invariably the safest, and the topography differs from one patient to the next.

5. Limitations

The dataset is illustrative, having been constructed to remain within the ranges established by the published literature, and it should accordingly be read as a methodological demonstration rather than as an independent empirical contribution. Surface mapping supplemented by transillumination resolves the superficial network satisfactorily but cannot demonstrate deep anastomoses, perforating channels, or the disposition of venous valves, all of which require dissection or contrast imaging for their elucidation. The heterogeneity of classification schemes within the literature imposes a degree of scheme dependence upon any comparison between series, and this limitation is intrinsic to the field rather than particular to the present analysis. The cohort was analysed as a single group and was not stratified according to body mass index, although adiposity is known to influence venous visibility appreciably. Confirmation of these estimates in a defined population by duplex ultrasonography or computed tomographic venography would represent a logical extension of this work.

6. Conclusion

The superficial venous network of the upper limb exhibits a configuration that is at once predictable in aggregate and variable in the individual. The oblique median cubital arrangement predominates, the classical branching arrangement is next in frequency, and the remaining configurations occur with diminishing regularity. Distribution varies with sex but not with side, and concordance between the limbs of a single individual is only moderate. The median cubital vein affords the most favourable combination of calibre, visibility, and separation from the median nerve, and its radial aspect constitutes the site of election for routine venipuncture. The cephalic and basilic veins retain their central position in catheter placement and in vascular access surgery, where their variations carry direct operative consequences. Systematic assessment of the individual limb, supported where appropriate by preoperative venous mapping, remains the most dependable means of reducing procedural morbidity in this heavily instrumented region.

Conflict of interest

The authors declare that no conflict of interest exists in relation to this work.

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Data availability

All data supporting the findings reported here are contained within the article.

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