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Ultrasonographic anatomic variations of the major veins in paediatric patients

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Editors' key points

- This study investigated localization of the internal jugular (IJV), subclavian (SCV), and femoral (FV) vein sites.
- The relevant percentages of anatomic variations obtained for all these areas support the future systematic use of ultrasound guidance to facilitate central venous cannulation in paediatric patients.

Background. The aim of our study was to describe the anatomic relationships in internal jugular (IJV), subclavian (SCV), and femoral (FV) vein sites.

Methods. One hundred and forty-two children had a two-dimensional (2D) ultrasound (US) evaluation of IJV, SCV, and FV sites. They were enrolled according to their age: 0–1 month old ($n=9$), 1 month old to 2 yr old ($n=61$), 2–6 yr old ($n=22$), 6–12 yr old ($n=32$), and 12–18 yr old ($n=18$).

Results. We found about 7.7% variation for the IJV. The most common anatomic variations were a lateral (nine children) or anterior (nine children) position of the IJV to the carotid artery. Regardless of the age category, about 9.8% of the anatomic variations were found for the FV. The most common anatomic variation in our study was that the FV ran anteromedially to the femoral artery (17 children). Anatomic variation of the SCV, regardless of age category, was about 7.4%. The most common anatomic variation was the SCV, which ran medially (10 children) to the subclavian artery.

Conclusions. The relevant percentages of anatomic variations obtained for all these areas support at least a systematic US screening before attempting to obtain central venous access, ideally using a US-guided technique.

Keywords: central venous catheters; femoral vein; jugular veins; paediatrics; subclavian vein; ultrasonography

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The main sites for central venous catheter insertions are the internal jugular (IJV), subclavian (SCV), femoral (FV), and arm veins (cephalic and basilic). In most cases, the success rates of catheter insertion are higher when using two-dimensional ultrasound (US) techniques.[1–4] US guidance for central venous access is mandatory, especially when there is a risk of hypovolaemia or anterior cannulation failure, in morbidly obese patients and in young children.[1–4] Anatomic variations, occurring in up to 18% of patients, could explain the occurrence of catheterization failures or complications of this landmark technique.[5 6] US evaluations were able to confirm variations in the position of the IJV and highlight other malpositions of the FV and the SCV in a paediatric population. The aim of our study was to describe the anatomic relationships of the IJV, SCV, and FV sites.

Methods

Patients

This study was approved by the local ethics committee and was in accordance with the Declaration of Helsinki (2000). After explaining the experimental procedure, we obtained parental written informed consent.

We prospectively studied paediatric patients for elective neurosurgery who underwent general anaesthesia with mechanical ventilation in the supine position before fluid expansion.

Patients with previous ventriculoatrial shunt, regional surgery or irradiation, cannulation, or deep venous thrombosis were excluded.

Technique

Structures were analysed with a US device (Acuson X300 Ultrasound System, Siemens Medical Solutions USA, Malvern, PA, USA). The US images were performed by a team practising in the anaesthesiology and intensive care unit of the Hôpital Neurologique Pierre Wertheimer (F.Du., S.G. and E.P.S.N.).

All children fasted for 6 h, but were allowed clear fluids (10 ml kg^{-1}) up to 2 h before surgery. Anaesthesia management of all patients followed standard procedures. After anaesthesia induction, mechanical ventilation was started. No positive end-expiratory pressure (PEEP) was applied during the mechanical ventilation. No neuromuscular blocking agent was administered. Haemodynamic variables, including heart rate and systolic, diastolic, and mean arterial pressures, were continuously monitored and recorded before and after measurements.

After anaesthetic induction and 15 min before US measurements, the patient was placed in a reverse Trendelenburg position of 15°, a suitable posture according to the predefined central venous site: neutral position of the head (IJV); lower limb abduction (FV) and neutral head position with a transverse block placed under the shoulders (SCV). The US used for this study involved the acquisition of real-time two-dimensional (2D) images using a transducer at high frequencies (user selectable multi-hertz imaging with 2D beam steering and trapezoidal imaging capabilities, frequency bandwidth 5–13 MHz and a VF13-5SP transducer if the patient's weight was <10 kg). The vein was identified by its position relative to the artery and its absence of pulsatility and collapsibility were studied by applying gentle pressure. Normal vein locations were defined by their position relative to the satellite artery:[7 8]

- anterolateral for the IJV, the transducer was placed at the level of the cricoid cartilage (Fig. 1A);
- posteromedial or medial for the FV, the transducer was placed below the inguinal ligament over the pulsation of the femoral artery (Fig. 1C); and
- anteromedial for the SCV, the transducer was placed infraclavicularly (Fig. 1F).

The following parameters were measured: vein and artery diameter, the depth and distance between them, and the position of the vein compared with the artery (eight possible quadrants: anterior, posterior, medial, lateral, anteromedial, anterolateral, posteromedial, and posterolateral). To achieve accurate measurements, all images were obtained by the same investigator and were analysed later by two other investigators.

The internal diameters of the blood vessels were measured from the lateral to the medial wall using a calliper. The US device was calibrated so that the image projected was magnified at a 2:1 ratio. Measurement accuracy was on the order of 0.01 cm.

There were five age groups in this study: 0–1 month old (i.e. birth to 30 days old); 1 month old to 2 yr old (i.e. 31 days old to the day before the second birthday); 2–6 yr old (i.e. from the second birthday to the day before the sixth birthday); 6–12 yr old (i.e. from the sixth birthday to the day before the 12th birthday), and 12–18 yr old (i.e. from the 12th birthday to the day before the 19th birthday). The data collected included age, gender, weight, body surface area (BSA), diagnosis according to the neurosurgical procedure, cross-sectional vessel diameter and depth (from the skin surface), and the time required to measure the three bilateral vessels in the central sites using the US procedure. BSA was calculated based on height and weight using the Haycock method.[9]

Statistics

The Fisher exact test was performed to compare anatomic venous location variations between the right and left sides within each age category. All results are expressed as median [median absolute deviation (MAD)], except age, which is expressed as median and range. *P*-values less than the chosen level of 0.05 were regarded as statistically significant. All statistical analyses were performed using StatView for Windows (version 4.57; Abacus Concepts, Berkeley, CA, USA).

Results

A total of 142 children, ASA I or II, were enrolled in this prospective study. None of the patients had a history of previously attempted central venous cannulation. The patient characteristics of the study subjects are summarized in Table 1.

A total of 852 measurements (three central venous sites explored bilaterally in 142 patients) were performed with the US procedure, lasting 13 (4) min for each patient. Anatomic variations are presented in Table 2 and in Figure 1B, D, E, G, and H.

The cross-sectional internal diameters of the blood vessels studied are summarized in Table 3. There were no accidental arterial punctures in the children who underwent central venous cannulation.

Discussion

US is considered the gold standard for vascular access placement. Many authors have stated that direct US visualization of a central vein provides advantages over 'blind' techniques.[3–5 10–18] The main advantage of US-guided interventions lies in the fact that the needle position can be seen in real-time, which increases the number of successful central venous cannulations.[4 17]

Even though both the National Institute for Health and Care Excellence and new evidence-based guidelines recommend the use of US guidance when placing central venous catheters, this has not been universally accepted.[4 13 19–21] Critics have raised concerns about the small evidence base and have questioned the advantages of US for regular practitioners.[19–21] Furthermore, US has its limitations in vascular access: the need for special equipment, the high cost, and the time required to master the technique.[3 4]
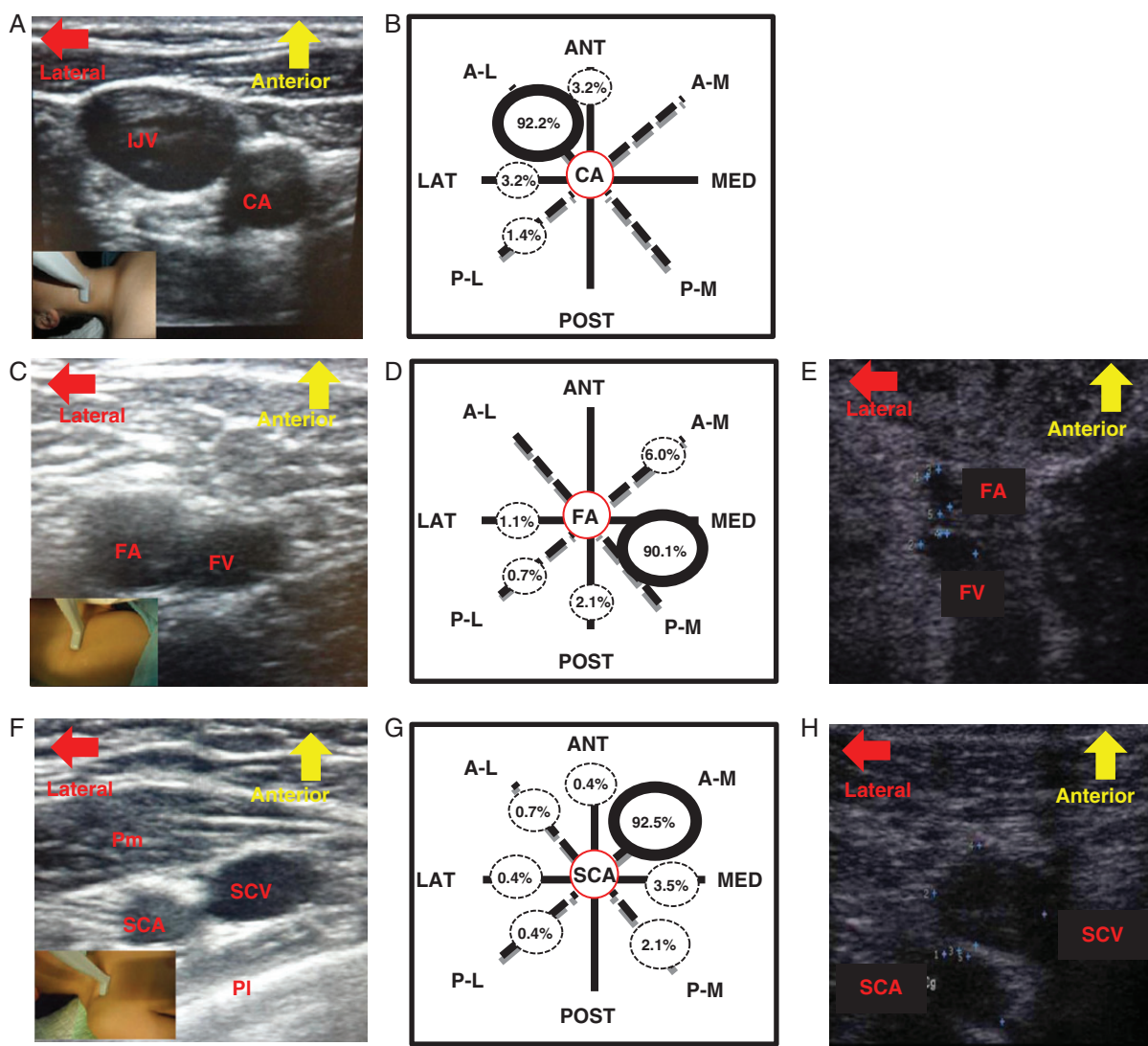
Fig 1 (A)Two-dimensional US probe placed at the level of the cricoid cartilage to obtain the transversal view of the IJV. (B) Normal (solid bold) and variation (dashed) in position of IJV relative to CA. Normal IJV locations were defined as anterolateral. (C) Two-dimensional US images (transversal view) of FV and FA. The transducer was placed below the inguinal ligament, over the pulsation of the FA. (D) Normal (solid bold) and variation (dashed) in position of FV relative to FA. Normal FV locations were defined as posteromedial or medial. (E) Two-dimensional US images (transversal view) with an example of a vessel malposition. The FV is posterior from FA. (F) Two-dimensional US images (transversal view) of SCV and SCA. The transducer was placed in infraclavicular level. (G) Normal (solid bold) and variation (dashed) in position of SCV relative to SCA. Normal SCV locations were defined as anteromedial. (H) Two-dimensional US images (transversal view) with an example of a vessel malposition. The SCV is anterior from SCA. A-L, anterolateral; A-M, anteromedial; ANT, anterior; CA, carotid artery; FA, femoral artery; FV, femoral vein; IJV, internal jugular vein; LAT, lateral; MED, medial; Pl, pleura; Pm, pectoral muscles; P-L, posterolateral; P-M, posteromedial; POST, posterior; SCA, subclavian artery; SCV, subclavian vein.

Despite these disadvantages, US-guided venous access has many clinical advantages and may reduce costs by reducing complications.[22][23] Studies of the quality and performance of US systems have been increasing, and the number and types of imaging procedures.[4][24] Also, operators with little or no US experience can rapidly learn US procedures and improve their speed and accuracy by performing simulated interventional US procedures.[25]

Other studies have measured the lengths and diameters of central veins and arteries in children using autopsy,[26] ultrasonography,[6][26][27] or computerized tomography (CT).[28] Even though these studies were not performed under the same conditions or in the same age group, they found vessel dimensions that were close to our measurements (Table 3).

Internal jugular vein

The position of the head and the landmarks chosen for IJV access have been shown to influence the diameter of the IJV.[29][30] Studies have shown that the Trendelenburg position without a roll under the shoulders is the best position.[29][30]

The Trendelenburg position is used during IJV cannulation to distend the veins by increasing the venous return in the jugular vessels. One possible mechanism is by increasing the height between the right atrium and the right IJV so there is a decrease in the venous return to the heart via the superior vena cava.[29][30] However, in a study by Verghese and colleagues,[29] the Trendelenburg position was found to have less effect on the infants (1 month to <1 yr) than on older children (1–6 yr), probably because the small-sized IJV does not have as much elasticity or compliance. The Trendelenburg position may also minimize the chance of gas embolism.[29][30]

In addition, overlaps between the IJV and the carotid artery (CA) increase as the head is rotated contralaterally.[18] Consequently, IJV–CA overlap increases the likelihood of unintentional CA puncture by a through-and-through puncture of the vein.[4][31] Moreover, the anterior wall of the vein is compressed as the needle approaches the vein, allowing puncture of its anterior and posterior walls without blood aspiration into the syringe.[31]

In our IJV study, we found that about 7.7% of patients had US anatomic variations. Our results were less than in other studies, which found anatomic variations of the IJV in up to 18% of patients.[5][6] However, in our study, the percentages of US anatomic variations were different according to age category. For example, in the 1-month to 2-yr age category, US anatomic variations were about 9% of patients (considering anatomic variations on both sides). In our study, the most common anatomic variations were that the IJV ran lateral (nine children) or anterior (nine children) to the CA (Fig. 1B).

Femoral vein

The FV is typically located medial to the common femoral artery, but significant vessel overlap may occur, particularly in children.[7][32] Some studies have demonstrated that the reverse Trendelenburg position and inguinal compression on the ipsilateral fossa can increase the FV cross-sectional area in paediatric patients.[6][28][33][34]

Just as with the IJV, position is a very important factor in measurements; hip rotation with $60°$ leg abduction decreased femoral artery overlap at the level of the inguinal crease in both infants and children.[34][35] Warkentine and colleagues[7] found that 4% of paediatric patients have an FV that is partially overlapped by the femoral artery and 8% of paediatric patients have an FV that is completely under the femoral artery. In contrast, Suk and colleagues[35] found that the femoral artery partially or completely overlaps the FV in most infants and children, regardless of the level and leg position.

Table 1 Patient characteristics of the 142 subjects included in the study. Data are expressed as median (MAD)

Age category months or years	Number of children	Weight (kg)	Size (cm)	Body surface area (m^2)
0–1 month	9	3 (0.6)	50.7 (0.5)	0.21 (0.02)
1 month–2 yr	61	8 (2.2)	65 (7)	0.39 (0.08)
2–6 yr	22	15 (2)	102 (5.5)	0.64 (0.06)
6–12 yr	32	29 (6.2)	132.5 (10)	1.02 (0.16)
12–18 yr	18	56 (7)	164 (10)	1.72 (0.10)

Table 2 Variations in sonographic according to age category. IJV, FV, SCV, total number of measures=number of patients×2 (bilateral)×3 (number of central venous sites explored)

Age category	Total number of measurements	IJV	FV	SCV	All	%
0–1 month	54	2	3	1	6	11.1
1 month–2 yr	366	11	15	10	36	9.8
2–6 yr	132	7	2	5	14	10.6
6–12 yr	192	0	5	2	7	3.6
12–18 yr	108	2	3	3	8	7.4
All (%)	852	22 (7.7%)	28 (9.9%)	21 (7.4%)	71 (8.3%)	

Table 3 US measures of cross-sectional internal diameters of the deep veins and arteries according to age category. CA, carotid artery; IJV, internal jugular vein; FV, femoral vein; FA, femoral artery; SCV, subclavian vein; SCA, subclavian artery; n, number of patients; mm, mean of bilateral cross-sectional internal diameters of the central vessel expressed in millimetres [(right side+left side)/2]. Data are expressed as median (MAD)

Age category	IJV (mm)	CA (mm)	FV (mm)	FA (mm)	SCV (mm)	SCA (mm)
0–1 month (*n*=9)	5.5 (0.8)	3.0 (0.5)	3.8 (0.6)	2.8 (0.3)	5.6 (0.9)	3.5 (0.3)
1 month–2 yr (*n*=61)	8.9 (1.6)	4.3 (0.5)	4.5 (0.9)	3.1 (0.5)	5.5 (0.9)	4.1 (0.7)
2–6 yr (*n*=22)	10.5 (1.6)	5.3 (0.5)	7.3 (0.8)	5.0 (0.6)	6.9 (1.0)	4.4 (0.5)
6–12 yr (*n*=32)	11.9 (1.8)	6.0 (0.6)	7.7 (1.3)	5.9 (0.8)	8.5 (1.4)	5.6 (1.2)
12–18 yr (*n*=18)	11.3 (1.9)	6.9 (0.7)	8.9 (1.2)	7.4 (0.7)	11 (2.0)	6.6 (0.8)

In our study we found about 9.8% of patients had anatomic variations, regardless of the age category. However, as with the IJV, the percentages of US anatomic variations are different according to age. For example, in the 1-month to 2-yr age category, US anatomic variations occurred in about 24% of patients (considering anatomic variations on both sides). The most common anatomic variation in our study was the FV that ran anteromedially (17 children) to the femoral artery (Fig. 1D).

Subclavian vein

US vascular cannulation of the SCV in children has been less studied than the IJV and FV.[3 4 27] Pirotte and Veyckemans[3] suggest a subclavian approach, which means placing the US probe at the supraclavicular level to obtain a longitudinal view of the SCV and gaining access to the vein via the usual infraclavicular route to cannulate it under ultrasonographic control. Grousson and colleagues[36] suggest a more lateral approach for both infra- and supraclavicular probe positioning to optimize the thoracic apex view. The main advantage of this approach is that it identifies the bone markers, subclavian vessels, and pleural dome on the same screen. With this specific US beam orientation, the different anatomic structures are aligned to better prevent pneumothorax since the pleural dome is protected by the first rib.[36]

Anatomic variations of the SCV in our study, considering all age categories, occurred in about 7.4% of patients. However, as for IJV and FV, US anatomic variation percentages were different according to the age group. In the 1-month to 2-yr age category, US anatomic variations occurred in about 16% of patients (considering anatomic variations on both sides). The most common anatomic variation was the SCV that ran in the medial position (10 children) to the subclavian artery (Fig. 1G).

Limitations of the study

Ultrasonography is an operator-dependent technology. Some variance in measurements may have occurred secondary to calliper placement. We minimized interobserver variability for all measurements by using a single ultrasonographer with previous US training and experience.

We acknowledge that US evaluations for the SCV could be done at the proximal part of the axillary vein just before it becomes the SCV when passing below the clavicle. However, we believe that the anatomic variations between these vessels do not change as they run a few millimetres cephalad.[37 38]

Measurements were performed after anaesthesia induction and the size of the vein may have changed under those conditions. However, this represents the usual situation in performing central venous cannulation.

Conclusion

US localization of the FV, SCV, and IJV in children is particularly easy to perform without extending the surgical procedure. The relevant percentages of anatomic variations obtained for all

these areas support the future systematic use of US guidance to facilitate central venous cannulation in paediatric patients.

Authors' contributions

E.P.S.N.: study design, data collection, data analysis, and writing the paper; S.G.: study design, data collection, and data analysis; F.Du.: study design, data collection, and data analysis; F.T.: study design and data analysis. C.M.: study design, patient recruitment, and data analysis; F.Da.: study design and data analysis.

Declaration of interest

None declared.

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