Vascular ultrasound in pediatrics: estimation of depth and diameter of jugular and femoral vessels

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Abstract

Objectives To estimate, on the basis of anthropometric and demographic variables, the depth (Dp) and diameter (Dm) of femoral and jugular vessels, which have been located and measured by ultrasound, in pediatric patients.

Method 750 measurements of Dp and Dm of the femoral vein (FV), femoral artery (FA) and internal jugular vein (IJV) were made in 125 pediatric patients. The values were correlated with patients' sex, weight, age, size and body surface area (BSA).

Results Mean Dp values were 0.72 (0.34) cm for FA, 0.79 (0.35) cm for FV and 0.77 (0.24) cm for IJV. Mean antero-posterior Dm values were 0.37 (0.17) cm for FA, 0.42 (0.22) cm for FV and 0.59 (0.23) cm for IJV. In the studied pediatric patients, femoral and jugular vessels depth correlated with age, size, weight and BSA ($R = 0.46\text{--}0.60$); vascular depth could be estimated from patients' weight and size (FA-Dp: $R = 0.71$; FV-Dp: $R = 0.72$; IJV-Dp: $R = 0.53$). Correlation with diameter was better for FA and FV ($R = 0.81\text{--}0.89$) than for IJV ($R = 0.42\text{--}0.51$); vascular diameter could be estimated from patient's size (FA-Dm: $R = 0.89$; FV-Dm: $R = 0.86$; IJV-Dm: $R = 0.52$).

Conclusions FV, FA and IJV depth and diameter correlated with weight, size, age and body surface area in the studied pediatric patients. Correlation was better for femoral than for jugular vessels. Depth could be estimated from patients' weight and size, while diameter could be estimated from the size. Such estimations may facilitate the choice of vessels to be cannulated, length and diameter of cannulation needles and the diameter of catheters to be used in pediatric patients.

Sommario

Obiettivi Calcolare in base a variabili antropometriche e demografiche, la profondità (P) e il diametro (D) dei vasi femorali e giugulari dei pazienti pediatrici in seguito alla loro localizzazione e misurazione ecografica.

Metodi Sono state effettuate 750 misurazioni della P e del D della vena femorale (VF), arteria femorale (AF) e della vena giugulare interna (VGI) in 125 pazienti pediatrici. I valori ottenuti sono stati relazionati con il sesso, il peso, l'età, l'altezza e la superficie corporea.

Risultati La P media dell' AF (PAF) è risultata di 0.72 (0.34) cm, quella della VF (PVF) di 0.79 (0.35) cm e quella della VGI (PVGI) di 0.77 (0.24) cm. Il D anteroposteriore medio dell' AF (DAF) fu di 0.37 (0.17) cm, quello della VF (DVF) è risultato di 0.42 (0.22) cm e quello della VGI (DVGI) di 0.59 (0.23) cm. Nei pazienti pediatrici analizzati, è stata riscontrata una relazione tra i parametri di età, peso, altezza e superficie corporea e quelli della profondità dei vasi femorali e giugulari ($R = 0.46\text{--}0.60$), che può essere stimata secondo peso e altezza (PAF: $R = 0.71$; PVF: $R = 0.72$; PVGI: $R = 0.53$). La relazione con il diametro vascolare è risultata maggiore per l' AF e la VF ($R = 0.81\text{--}0.89$) e più bassa per la VGI ($R = 0.42\text{--}0.51$), che può essere stimata in base all'altezza del paziente (DAF: $R = 0.89$; DVF: $R = 0.86$; DVGI: $R = 0.52$).

Conclusioni La profondità e il diametro della VF, dell'AF e della VGI si possono relazionare al peso, altezza, età e superficie corporea nei pazienti pediatrici del nostro studio. Questa relazione è maggiore per i vasi femorali rispetto ai vasi giugulari, rendendo possibile il calcolo della loro profondità in base al peso e all'altezza e il calcolo del loro diametro vascolare in base all'altezza. Questi calcoli possono essere utili per la scelta adeguata del vaso da canalizzare, per la scelta del tipo e del calibro dell'ago e del catetere da usare nei pazienti pediatrici.

Keywords Internal jugular vein · Femoral vein · Femoral artery · Ultrasound measurement, pediatric patients · Estimation vascular diameter and depth

Introduction

The cannulation of central veins in pediatric patients is more complex than in adults and is not devoid of risks and complications, mainly due to the size of children's vessels. Achieving vascular access in Pediatrics may be a challenge both for medical and nursery staff [1–6]. In the last few years, ultrasound imaging has been incorporated to facilitate vascular cannulation [7–10].

Ultrasound examination of the vascular tree in pediatric patients allows for evaluation of vascular depth (Dp), internal diameter (Dm), trajectory and regularity of vessels, proximity to other anatomical structures such as arteries or nerves, and possible anomalies such as hematomas, thrombosis or anatomical variants.

Ultrasound determination of the location, depth and diameter of these vessels may facilitate cannulation [7–9]. The published studies on pediatric vessels are scarce and often focused on certain groups of pediatric population [11–14].

Thus, vascular ultrasound provides easily accessible data. It is free of risks and produces quick results, which can be used in ultrasound-guided cannulation or—if this technique is not available—in estimations, mainly of vascular Dp and Dm, to facilitate the choice of vessels to be cannulated, length and diameter of cannulation needles and diameter of catheters to be used in pediatric patients.

This study, based on vascular ultrasound measurements, is aimed at correlating vascular depth and diameter with anthropometric and demographic variables in pediatric patients.

Patients and methods

This prospective study included 125 pediatric patients (56.2% boys and 43.8% girls) between 2 days and 16 years of age, admitted to the Unit of Intensive Pediatric Medicine between January 2012 and January 2015.

Weight expressed in kilograms (Kg) and size expressed in centimeters were measured by the same healthcare team. Weight was measured with a digital scale and size was measured with a conventional measuring tape from the highest point of head to the Tarsus. Age was expressed in years (y) and/or months (m). Body surface area (BSA) was calculated in square meters (m²) with the Mosteller formula [15]: $BSA: [size (cm) \times weight (kg)/3600]^{1/2}$.

A Philips HD 7[®] ultrasound equipment with multi-frequency linear probe (L12-5) was used, with “vascular” configuration and maximum 3 cm depth.

Table 1 Depth (Dp) measurements of pediatric central vessels (expressed in centimeters)

	<i>N</i>	Mean	SD	Range	
FA-Dp	250	0.72	0.34	0.19	2.00
FV-Dp	250	0.79	0.35	0.30	2.26
IJV-Dp	250	0.77	0.24	0.30	1.80

Vascular ultrasound measurements were taken on the transverse axis, measuring the vessels' antero-posterior diameters. IJV was measured with the patient in the supine position, head rotated 10°–15° contralateral to the examined cervical region, placing the ultrasound transducer at the cricoid cartilage level. Femoral vessels were measured with 30°–45° thigh abduction, placing the ultrasound transducer 0.5–1 cm below the inguinal ligament.

The echographic measurements were performed in patients with clinical stability.

Statistic analysis was carried out with the statistical package for the social sciences version 19 for Windows (SPSS Inc., Chicago, IL, USA).

Qualitative variables were expressed as frequencies and percentages; numerical variables as mean, standard deviation and median.

Continuous numerical variables were assessed for normality with the Kolmogorov–Smirnov test. Possible associations between categorical variables were evaluated with the Chi-square independence test. The means of continuous variables were compared with the Student's *t* test.

To estimate vascular diameter and depth on the basis of age, weight, size and body surface, covariance analysis techniques and multiple regression models were used.

The significance level was 5%.

Informed consent was requested from patients' parents or legal representatives. The study protocol followed the basic principles of the World Medical Association Declaration of Helsinki [16] and was approved by the Ethical Committee of Clinical Trials of our Hospital.

The authors declare that they have no conflict of interest in relation with this study.

Results

The study included 125 pediatric patients with mean age of 65.7 (61.9) months and sex distribution: 56.2% boys and 43.8% girls. Their mean weight and size were 20.6 (17.6) kg and 96.9 (39.6) cm, respectively. The mean BSA was 0.72 (0.45) m² (Table 1).

We made the following Dp and Dm measurements of main central vessels in our pediatric patients (Tables 1, 2

Table 2 Diameter (Dm) measurements of pediatric central vessels (expressed in centimeters)

	N	Mean	SD	Range	
FA-Dm	250	0.37	0.17	0.15	0.78
FV-Dm	250	0.42	0.22	0.13	1.05
IJV-Dm	250	0.59	0.23	0.16	1.14

Fig. 1 Vascular depth (Dp) and diameter (Dm) measurements of the right FA and FV (RFA and RFV) in a 12-year-old girl **Fig. 2** Vascular depth (Dp) and diameter (Dm) measurements of the right IJV (RIJV) in a 23-month-old boy

and Figs. 1, 2): 250 at the femoral artery level (FA), 250 at the femoral vein level (FV) and 250 of internal jugular veins (IJV).

After analyzing the demographic and anthropometric values, the correlation was established with the aim of estimating the Dp and Dm of the measured vessels. Significant

association was found between the Dp of the main studied vessels, and age, size, weight and BSA of the studied pediatric patients. No correlation was found between vascular Dp and patients' sex. Table 3 shows the level of significance and the Pearson's R correlation coefficient.

The highest correlation coefficient values corresponded to vascular Dp and patients' weight, as shown in Figs. 3, 4, 5. Such correlation was higher for femoral veins, while IJV presented globally lower correlation coefficient values, in pediatric patients.

After a multiple linear regression analysis to find variables that could be used to estimate the Dp of the studied central vessels, the following variables were included in the prediction model: size and weight for femoral vessels (FA-Dp $R = 0.71$; $R^2 = 0.50$ and FV-Dp $R = 0.72$; $R^2 = 0.52$) and weight for IJV-Dp ($R = 0.53$; $R^2 = 0.28$). Table 4 shows the corresponding coefficients, significance and 95% confidence intervals (CI).

The resulting equations for prediction of FA-Dp, FV-Dp and IJV-Dp in the studied pediatric patients were: (a) **FA-Dp** = $0.804 + 0.027$ (weight in Kg) – 0.006 (size in cm); (b) **FV-Dp** = $0.797 + 0.026$ (weight in Kg) – 0.005 (size in cm); and (c) **IJV-Dp** = $0.594 + 0.007$ (weight in Kg).

The diameter of major central vessels was significantly associated with patients' age, size, weight and BSA. No correlation was found between Dm and patients' sex. Table 5 shows the significance level and the Pearson's R correlation coefficient. The highest correlation coefficient values corresponded to vascular Dm and patients' size, as shown in Figs. 6, 7, 8.

After a multiple linear regression analysis, size was the variable included in the model, which most accurately predicted mean FA-Dm ($R = 0.89$; $R^2 = 0.79$), FV-Dm ($R = 0.86$; $R^2 = 0.74$) and IJV-Dm ($R = 0.52$; $R^2 = 0.27$) in the studied pediatric patients. Table 6 shows the corresponding coefficients, significance and 95% CI.

The resulting equations to predict FA-Dm, FV-Dm and IJV-Dm in the studied pediatric patients were: (a) **FA-Dm** = 0.004 (size in cm); (b) **FV-Dm** = 0.005 (size in cm) and (c) **IJV-Dm** = $0.177 + 0.005$ (size in cm).

Our results lead to the conclusion that, in the studied pediatric patients, estimations of vascular depth and diameter at the femoral vessels level ($R = 0.72$ and $R = 0.89$ respectively) were better than estimations at the internal jugular vessels level ($R = 0.53$ and $R = 0.52$, respectively).

Discussion

Estimations of vascular Dp and Dm in pediatric patients may be useful to make decisions at the moment of performing vascular cannulation. Opposite to adult patients, where such variables take values within a rather stable

Table 3 Correlation of demographic and anthropometric variables with vascular depth in the studied pediatric population

	FA		FV		IJV	
	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>
Age	0.54	< 0.001	0.57	< 0.001	0.46	< 0.001
Size	0.49	< 0.001	0.55	< 0.001	0.51	< 0.001
Weight	0.65	< 0.001	0.68	< 0.001	0.53	< 0.001
BS	0.60	< 0.001	0.64	< 0.001	0.53	< 0.001

Fig. 3 Correlation of femoral artery depth (FA-Dp) with the studied pediatric patients' weight **Fig. 5** Correlation of internal jugular vein depth (IJV-Dp) with the studied pediatric patients' weight **Fig. 4** Correlation of femoral vein depth (FV-Dp) with the studied pediatric patients' weight**Table 4** Predictive model of the depth of femoral artery (FA-Dp), femoral vein (FV-Dp) and internal jugular vein (IJV-Dp) in the studied pediatric population

	β	P	95% CI	
FA-Dp				
Coefficient	0.804	< 0.001	0.656	0.953
Weight (kg)	0.027	< 0.001	0.021	0.034
Size (cm)	− 0.006	< 0.001	− 0.009	− 0.004
FV-Dp				
Coefficient	0.797	< 0.001	0.642	0.952
Weight (kg)	0.026	< 0.001	0.019	0.032
Size (cm)	− 0.005	< 0.01	− 0.008	− 0.002
IJV-Dp				
Coefficient	0.594	< 0.001	0.542	0.656
Weight (kg)	0.007	< 0.001	0.005	0.009

range, pediatric patients show highly variable values depending on their growth and development. The pediatric population ranges from newborn to 14–16-year-old children, with sizes from 50 to 160–170 cm.

Having an approximate reference of vascular Dp and Dm helps choosing the adequate size and diameter of cannulation needles, as well as the length and diameter of catheters to be used, to prevent early thrombosis or problems related with distal hypoperfusion and venous return difficulties. With the development of vascular ultrasound, the

Table 5 Correlation of demographic and anthropometric variables with vascular diameter in the studied pediatric population

	FA		FV		IJV	
	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>	<i>R</i>	<i>P</i>
Age (m)	0.84	< 0.001	0.81	< 0.001	0.42	< 0.001
Size (cm)	0.89	< 0.001	0.86	< 0.001	0.51	< 0.001
Weight (Kg)	0.83	< 0.001	0.81	< 0.001	0.44	< 0.001
BS (m ²)	0.88	< 0.001	0.85	< 0.001	0.48	< 0.001

Fig. 6 Correlation of femoral artery diameter (FA-Dm) with the studied pediatric patients' size **Fig. 8** Correlation of internal jugular vein diameter (IJV-Dm) with the studied pediatric patients' size **Fig. 7** Correlation of femoral vein diameter (FV-Dm) with the studied pediatric patients' size**Table 6** Predictive model of the diameter of femoral artery (FA-Dm), femoral vein (FV-Dm) and internal jugular vein (IJV-Dm) in the studied pediatric population

	β	P	95% CI	
FA-Dm				
Coefficient	− 0.002	0.954	− 0.073	0.069
Size (cm)	0.004	< 0.001	0.003	0.006
FV-Dm				
Coefficient	− 0.026	0.296	− 0.074	0.023
Size (cm)	0.005	< 0.001	0.005	0.006
IJV-Dm				
Coefficient	0.177	< 0.05	0.031	0.323
Size (cm)	0.005	< 0.001	0.003	0.007

measurement of vascular Dp and Dm became a side-of-the-bed harmless procedure, which can be easily and quickly performed [7–10].

In our study, the depth of femoral vessels showed a strong correlation with anthropometric variables weight and size

(correlation coefficient $R = 0.72$ for FV and $R = 0.71$ for FA).

Warkentine et al. [11] measured the femoral veins of 84 children younger than 9 years and found correlations between FV-Dm and age, weight, size and body surface. They also established FV-Dm estimations based on those variables; thus, one-year age increase corresponded to 0.065 cm FV-Dm increase; 1 kg weight increase

corresponded to 0.018 cm FV-Dm increase; and one-centimeter size increase corresponded to 0.007 cm FV-Dm increase. Akingbola et al. [14], in a series including 24 children, where they compared two age groups (newborns of 1–3 days mean age versus babies of 3–16 months mean age) found that FV-Dm was highly correlated with weight ($R = 0.80$) in babies (a correlation that decreased with age; $R = 0.56$), but failed to find significant correlation between FV-Dm and weight in newborns. They concluded that patient's weight was a predictor of FV-Dm in babies but not in newborns, a finding that could be accounted for by large weight variability during the first days of life, which might impair vessel size predictions based on this variable. They suggested that BSA was a better parameter to estimate FV-Dm in newborns, although they did not analyze such a correlation in their study.

In our pediatric patient series, mean femoral vessel Dm was strongly and significantly associated (correlation coefficient (R) between 0.83 and 0.89) with size, weight and age. Size was the best predictor in a multiple linear regression analysis ($R = 0.89$ for FA and $R = 0.86$ for FV), where 1 cm increase in a patient's size corresponded to 0.004–0.005 cm increase in femoral vessels Dm. Our results of the estimations of vascular diameter at the femoral level on the basis of patients' size were similar to those reported by Warkentine et al. in their study [11].

In our series, jugular vessels were located at 0.3–1.8 cm Dp and had a Dm within 0.16–0.99 cm. These values increased with age, weight, size and body surface. Both Dp and Dm ($R = 0.50$) showed lower correlation than femoral vessels, which could be accounted for by the fact that the IJV is easily collapsible and its diameter varies with the patient's position (larger in Trendelenburg), venous return difficulties and increased intrathoracic pressure, e.g., in patients with mechanical ventilation, lung hyperinflation or Valsalva maneuver. Thus, opposite to femoral vessels, which usually present a circular image on the transverse axis and similar antero-posterior and transverse diameters, jugular vessels present a rhomboidal image and different antero-posterior and transverse diameters.

Steinberg et al. [17] reported correlation between IJV-Dm and weight, size, age and BSA in pediatric patients by analyzing tomographic and angiographic vascular measurements. In a series reported by Alderson et al. [18], IJV-Dp and IJV-Dm were measured with vascular ultrasound in 50 children from 3 days to 5.5 years of age and 2.7–22 kg body weight. Jugular vessel depth was around 0.4–1 cm and tended to grow with age and weight; the best correlation was found for weight. Jugular vessel diameter ranged between 0.25 and 1.2 cm. Like in our study, these authors found lower correlation between IJV-Dm and age ($R = 0.50$) or weight ($R = 0.39$). Our results with these variables were: age ($R = 0.42$) and weight ($R = 0.44$), where the pediatric

patient's size was the best predictor of IJV-Dm ($R = 0.50$). Although these two series cannot be compared—because our study included patients in wider age and weight ranges (2 days–16 years; 2.4–73 kg)—the results presented by Alderson et al. [18] were globally similar to ours. The measurements reported by Sayin et al. [19] evidenced that patients younger than 1 year had IJV-Dm of 0.5 cm or smaller and that 79.8% of patients with IJV-Dm 0.5 cm or smaller weighted less than 12 kg and were shorter than 80 cm. They found weak correlations of IJV-Dp and IJV-Dm with age, size and weight, although correlations increased with age, weight and size. Eksioglu et al. [12] studied the IJV-Dm and correlation between ultrasound measurements and age, weight, size and BSA in a series of children from birth to 18 years of age, classified into four age groups: 0–2, 3–6, 7–12, and 13–18 years. The authors found clinically significant correlation between IJV-Dm and age, weight and size, only in the 0–2-year group, which corresponded to the fastest growth period in pediatric patients. The correlation decreased with increasing age. However, in our study, we cannot report if the correlation between IJV-Dm and age decreased with age; since it was not an objective, only the global positive correlation between IJV-Dm and patient's age was recorded.

Mortensen et al. [20] measured the jugular vessels of children between 13 months and 16 years of age and found poor correlation between vascular diameter and age, weight, size and BSA. Conversely, other authors, e.g., Karazincir et al. [21], made ultrasound measurements of the jugular vein in 95 children between 0 and 6 years of age at rest and after the Valsalva maneuver. Their measurements at rest were similar to our measurements and estimations based on patients' size.

In our opinion, the observed variability in jugular vessel measurements, as well as their poor correlation as compared to other central vessels, such as femoral vessels, could be due to technical difficulties associated with IJV measurement in children, i.e., such vessels are easily collapsible, even with the pressure of the ultrasound probe; difficulties to place the probe at the cervical level, especially in patients younger than 1 year, because of the reduced space available; variability of vessel diameter depending on the position of the patient; and difficulties in venous return and/or vascular filling.

Conclusion

This study had certain limitations: (a) only one vascular measurement was made; (b) diameter measurements were made on the antero-posterior axis; (c) measurements were not correlated with the clinical situation of the pediatric patient (although were performed in patients with clinical stability); and (d) not specified major or minor congenital

vascular malformation and if so with which instrumental investigation was discovered. However, despite these limitations, we consider that depth and diameter measures of the main vessels to be cannulated in pediatric patients and estimations based on demographic and anthropometric variables are useful to be applied at the moment of choosing a vessel to be cannulated, the needle to be used and the catheter to be implanted.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest in relation with this study.

Ethical approval The study protocol followed the basic principles of the World Medical Association Declaration of Helsinki and was approved by the Ethical Committee of Clinical Trials of our Hospital.

Informed consent Informed consent was requested from patients' parents or legal representatives.

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