Experience with ultrasound use in central venous catheterization (jugular-femoral) in pediatric patients in an intensive care unit

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ABSTRACT

Objectives. Describe ultrasound-guided central venous catheterization use comparing the number of attempts (1 versus 2 or more attempts) in relation to catheters placed in the internal jugular vein (IJV) versus the femoral vein (FV).

Material and methods. Descriptive, prospective study of central venous catheters (CVCs) inserted via ultrasound-guided puncture in patients aged 1 month to 18 years. A multivariate regression model was done considering the primary endpoint, first puncture success in relation to the insertion site (IJV versus FV), and predictors of success.

Results. A total of 257 CVCs were inserted: IJV 118 (45.9%), FV 139 (54.1%); 161 (62.7%) were inserted in the first attempt and 96 (37.3%) required more than 1 attempt. IJV insertions were successful with the first puncture in 86 patients (53.5%) and FV insertions, in 75 (46.5%) (p 0.0018; OR: 0.43 [95% CI: 0.24-0.76]). There were 21 (8.1%) immediate complications: 3 (1.86%) were related to the first puncture, 18 (18.75%), to more than 1 puncture (p 0.0001 [95% CI: 3.36-45.68]). There were 4 cases of severe complications, including pneumothorax.

Conclusions. Ultrasound-guided venous catheterization demonstrated to be significantly successful in the first attempt when using the IJV versus FV, especially in infants younger than 6 months. Immediate complications occurred more frequently in patients requiring more than 1 puncture.

Key words: *ultrasound, vascular access devices, adverse events, pediatric intensive care units, pediatrics.*

http://dx.doi.org/10.5546/aap.2022.eng.167

To cite: Pellegrini S, Rodríguez R, Lenz M, Berros F, et al. Experience with ultrasound use in central venous catheterization (jugular-femoral) in pediatric patients at an intensive care unit. *Arch Argent Pediatr* 2022;120(3):167-173.

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Funding:
None.

Conflict of interest:
None.

Received: 5-10-2021
Accepted: 10-28-2021

INTRODUCTION

Vascular catheterization is an essential technique for critically ill patient care. It is very important to establish a venous access, which may be a technical challenge due to vessel size in pediatric age.

Reports have been made since 1977 about ultrasound-guided vascular access insertion. In the guidelines published by the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists and the NICE guidance, Toianos et al., recommend ultrasound-guided vascular catheterization whenever available, both in children and adults.[1,2]

Ultrasound use reduces the number of attempts and procedure duration, increases the successful insertion rate, and reduces complications compared to the skin surface anatomic landmarks technique. This is feasible because it allows to directly locate the position of anatomic structures in real time, highlighting pathological anomalies (thrombi) or physiological anomalies, such as displacements or abnormal vessels.[1]

De Souza et al.,[3] observed a high first attempt success rate: 95% of ultrasound-guided venous punctures compared to 34% in the control group. Complications were significantly lower in the ultrasound-guided group. Pietroboni[4] and Rivera-Tocancipá[5] published similar results. Currently, the ultrasound is considered the gold standard in clinical practice in adults.[1]

In infants and children, some trials assessed central venous catheterization using the IJV, but the evidence is scarce in younger babies.[1] Timsit et al.,[6] published a guideline based on an expert consensus about children and adults (GRADE approach), which stated that ultrasound-guided should be used to reduce mechanical complications in IJV (grade 1, high level of evidence and strong recommendation). No study comparing 2 anatomic sites, IJV versus FV, has been found.

The objective of this study was to describe our experience using ultrasound-guided central venous catheterization in a pediatric intensive care unit, compare 2 anatomic sites, IJV versus FV, and establish if this technique improves first puncture success.

MATERIAL AND METHODS

This was a descriptive, prospective, and observational study. Its primary endpoint was to compare the use of ultrasound-guided CVC insertion and establish the relationship among the number of attempts (1 versus 2 or more attempts), the puncture site (IJV-FV), patient age and weight.

A secondary endpoint was to assess whether there was a relationship between the site and number of punctures performed in patients with a weight of less than 10 kg and 10 kg or more. Immediate complications associated with the technique were assessed.

The accessible population included patients aged 1 month to 18 years admitted to the pediatric intensive care unit (PICU) between May 2018 and December 2019. Patients who required ultrasound-guided CVC insertions were included. The vessel for CVC insertion had not been catheterized before.

Vascular access insertion was defined as successful if achieved in 1 puncture attempt; failure, as more than 1 attempt. If the operator performed a new puncture, even without completely removing the needle, it was considered a new attempt. Catheterized vessels were selected at the operator's discretion.

Age was grouped into younger than 6 months and 6 months and older, based on distribution. Patients included in the first and second quartiles were assigned to the first group, and those in the third and fourth quartiles, to the second group. In terms of weight, patients were divided into those with a weight of less than 10 kg and 10 kg or more.

Complications were defined as untoward effects directly related to the procedures, arterial puncture, bruising, pneumothorax, thrombosis, and catheter-associated infections. Screening was done based on clinical data, chest X-ray, ultrasound, and microbiological cultures. The insertion method was defined as safe if severe complications did not exceed 5%. Severe complications were those that required a pleural drainage tube or blood product administration, or resulted in death attributable to the procedure.

A written consent, signed by parents or tutors, was obtained upon admission to the ICU to authorize any practice necessary to provide care to their children while in the ICU.

Procedures were performed by 2 operators: 1 was in charge of guiding the procedure and 1, of attempting the puncture.

Peltan et al.,[7] and the Safety Committee of the Japanese Society of Anesthesiologists[8] recommend that central venous catheterization and management education requires standardized structures and simulations. First, second, and third year fellows and staff physicians involved were trained on ultrasound scanner use and technique performance. The training program consisted in a virtual stage, which was theoretical, mandatory, delivered online, and offered activities in the hospital's online campus, and an in-person stage, conducted at the Garrahan Simulation Center, where trainees learned to recognize and locate vascular structures using ultrasound guidance. A silicone phantom specially designed for training was used (*Figure 1*). Training programs on ultrasound-guided vascular cannulation help to acquire basic knowledge and its practical applications, and are usually carried out using simulation models.[9,10]

We used a Sonosite-nerve 180 PLUS® device with a linear matrix transducer L25/10 at 5 MHz (SonoSite, Inc., Bothell, WA). The transducer was covered in a sterile sheath. The patient was positioned using the usual technique to achieve an adequate vessel exposure. Using the B-mode (two-dimensional), the transducer was guided in the short or cross-sectional axis, where the vessel is seen as an anechoic circle on the screen (*Figure 2*) and the needle appears as a hyperechoic point. In the longitudinal axis, the vessel appears parallel to the skin with the needle in the same plane, to localize the vascular bundle.[11]

The vein was centered on the screen and the operator performed the necessary punctures (maximum 3) until obtaining the venous flow

required for catheter insertion. The Seldinger technique was used with a multilumen CVC (4-12 Fr) (Arrow International). Patients were given ketamine 2 mg/kg/dose and midazolam 0.1 mg/kg/dose for analgesia. Patients receiving mechanical ventilation received muscle relaxants.[12]

FIGURE 1. *Simulator for ultrasound-guided central venous catheterization practice (internal jugular vein). The lower image shows a 2D longitudinal section of the vein and the needle inside on the ultrasound scanner screen.*

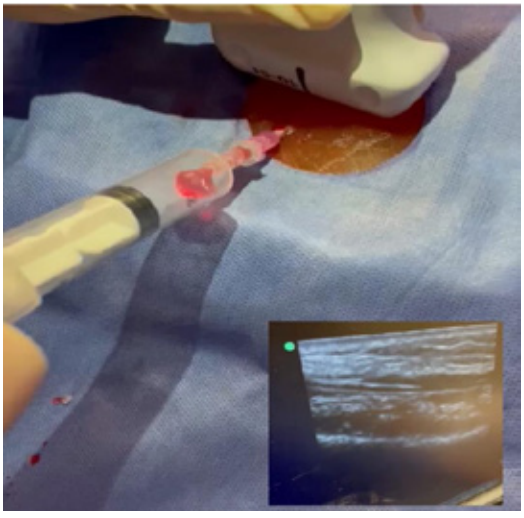
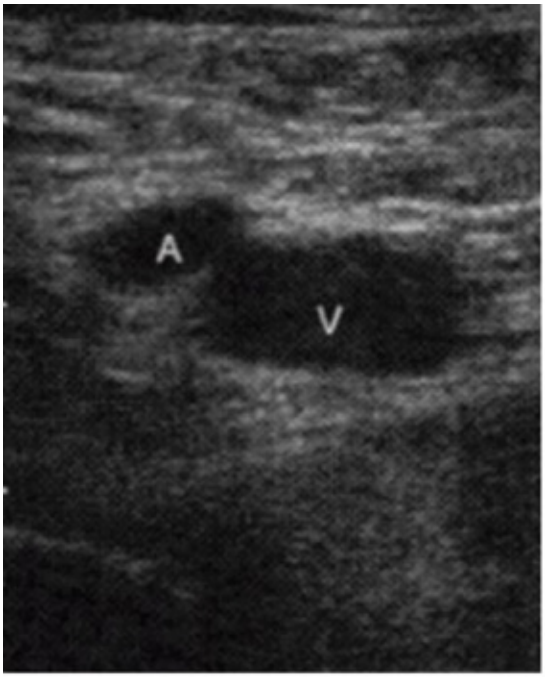


FIGURE 2. *E2D ultrasound to identify the anatomy of the target vein. Image of the short-axis cross-section of the right internal jugular vein (V) and its anatomical relationship to the carotid artery (A)*



Statistical analysis

Continuous variables are summarized as mean and standard deviation (SD) or median and interquartile range (IQR 25-75); categorical variables are expressed as percentage.

The association between potential predictors and the primary endpoint was assessed using a bivariate and multivariate logistic regression analysis. Student's t test or Wilcoxon test were used to compare continuous variables, and the χ^2 test for categorical variables.

A p value < 0.05 was considered as significant, with a 95% confidence interval (CI). The multivariate analysis included the variables that showed a significant p value < 0.25 in the bivariate analysis. The significant variables observed in the multivariate model were included in the final model. The final model was calibrated using the Hosmer-Lemeshow goodness-of-fit test and the ROC curve, accepting a p value > 0.05 as an adequate calibration.[13,14]

The statistical analysis was performed with the software Stata 14 Stata-Corp LLC® package.[15]

RESULTS

A total of 257 CVCs were placed using ultrasound guidance (*Figure 3*). Patients' median age and weight was 8 months (IQR 25-75: 5-24) and 8 kg (IQR 25-75: 5-11), respectively.

There were 93 patients who weighed less than 10 kg in whom only 1 puncture was required (57.8%) versus 68 (42.2%) who required more than 1 attempt (p 0.036; OR: 1.77; 95% CI: 1.00-3.17).

In relation to the number of attempts, 161 CVCs (62.7%) were inserted in the first attempt and 96 (37.3%) required more than 1 attempt.

There were 86 patients (72.9%) who had a successful insertion in the IJV in the first attempt versus 32 (27.1%) who required more than 1 attempt (p 0.0018; OR: 0.43; 95% CI: 0.24-0.76) (*Table 1*).

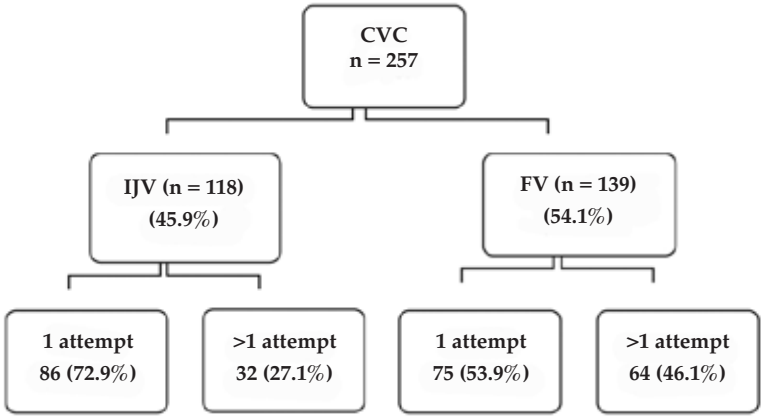
In a secondary analysis to relate the number of punctures, the site (IJV versus FV), and patient weight (< 10 kg and ≥ 10 kg), those with a weight of less than 10 kg had a better outcome when the insertion site corresponded to the IJV because they had a lower risk for more than 1 attempt than those in whom the FV was selected (p 0.0005; OR: 2.5 versus 3.2). The same pattern was observed in patients younger than 6 months (p 0.0005; OR: 2.78 versus 2.59).

Technique-related complications occurred in 8.1% of cases: 4 corresponded to pneumothorax (1.5%) and the rest, to arterial punctures and bruising. It was evidenced that patients who required more than 1 puncture had 12 times more complications than those who achieved a successful insertion in the first attempt.

The multivariate logistic regression model included variables that showed a significant p value < 0.25 in the univariate analysis (*Table 2*). The variables related to the site of insertion (jugular / femoral), the physician guiding the procedure, and complications were significant and, therefore, independent predictors in relation to the primary endpoint (*Table 3*).

The logistic regression model was calibrated using the Hosmer-Lemeshow test; and groups were created based on the risk estimation reported

FIGURE 3. *Flowchart of patients included in the study*



CVC: central venous catheter; IJV: internal jugular vein; FV: femoral vein.

by the model according to the combination of different variables with a *p* value of 0.12.

The model's discrimination was done using an area under the ROC curve, with a value of 0.69.

DISCUSSION

Historically, in our hospital, central venous catheterization in the FV has been selected as a preferential site, probably due to its lower

TABLE 1. *Demographic characteristics of the population and results of univariate analysis*

	Total (n = 257)	**1 puncture attempt (%) (n = 161)**	**> 1 puncture attempt (%) (n = 96)**	***p* value**	**OR (95% CI)**
Age (months old)					
< 6 months	102 (39.6)	60 (37.3)	42 (43.7)	0.30	1.30 (0.75-2.25)
≥ 6 months	155 (60.3)	101 (62.7)	54 (56.3)		
Weight					
< 10 kg	161 (62.7)	93 (57.7)	68 (70.8)	0.036	1.77 (1.00-3.17)
≥ 10 kg	96 (37.3)	68 (42.3)	28 (29.2)		
Sex (female)	131 (50.9)	82 (50.9)	49 (51.04)	0.98	0.99 (0.58-1.70)
Route					
Internal jugular vein	118 (45.9)	86 (53.5)	32 (33.4)	0.0018	0.43 (0.24-0.76)
Femoral vein	139 (54.1)	75 (46.5)	64 (66.6)		
Inserting physician					
F1	133 (51.7)	77 (47.8)	56 (58.4)	0.10	0.65 (0.38-1.12)
F2	124 (48.3)	84 (52.2)	40 (41.6)		
Guiding physician					
Assistant and F3	122 (47.4)	72 (44.7)	50 (52.1)	0.25	0.74 (0.43-1.27)
F1 and F2	135 (52.6)	89 (55.3)	46 (47.9)		
Gauge					
< 5.5 Fr	212 (82.5)	130 (80.7)	82 (85.5)	0.34	0.71 (0.33-1.48)
≥ 5.5 Fr	45 (17.5)	31 (19.3)	14 (14.5)		
Immediate complications	21 (8.1)	3 (1.86)	18 (18.75)	0.0001	12.15 (3.36-45.68)

F1: first year fellow; F2: second year fellow; F3: third year fellow; OR: odds ratio; CI: confidence interval; Fr: French.

TABLE 2. *Complete multivariate model. The table shows the variables included in the model with a p value < 0.25*

Variable	**OR (95% CI)**
Weight (< 10 kg or ≥ 10 kg)	1.77 (1.00-3.17)
Percutaneous jugular/femoral puncture site	0.43 (0.24-0.76)
Physician performing ultrasound guidance (F3 or staff physician)	0.74 (0.43-1.27)
Physician performing percutaneous puncture (fellow)	0.65 (0.38-1.12)
Immediate complications	12.15 (3.36-45.68)

OR: odds ratio; CI: confidence interval; F3: third year fellow.

TABLE 3. *Final multivariate model. The table shows independent predictors compared to the primary endpoint*

Variable	**OR (95% CI)**	***p* value**
Percutaneous (jugular/femoral) puncture site	0.33 (0.18-0.60)	0.0001
Physician performing ultrasound guidance (F3 or staff physician)	0.50 (0.28-0.90)	0.022
Immediate complications	14.31 (3.9-51.9)	0.0001

OR: odds ratio, CI: confidence interval; F3: third year fellow.

risk, away from the chest structures, to prevent potentially vital and trauma injuries in the confluence of the subclavian vein and the internal jugular vein and in its close relation with the internal carotid artery, the lung, and the pleura. In general, these catheters were inserted using the anatomic landmark-guided technique, nowadays replaced by ultrasound guidance, a paradigm shift in relation to a routine procedure performed in the ICU, which offers safety and effectiveness benefits, as demonstrated by various publications. The Point-Of-Care Ultrasound (POCUS) Working Group of the European Society of Paediatric and Neonatal Intensive Care[16] recommends ultrasound-guided percutaneous CVC insertion, both in adults and children, as described by the NICE guidance[2] in 2002.

Our study results showed that a successful ultrasound-guided CVC insertion is related to a lower number of punctures in the IJV versus the FV. IJV insertions showed a 53.5% successful first puncture rate, compared to 46.5% with FV insertions. The same association was observed in infants younger than 6 months and children with a weight of less than 10 kg, who accounted for the most vulnerable population.

Reyes Ríos et al.,[17] analyzed ultrasound-guided central venous catheter insertion in newborns and infants and concluded that using ultrasound guidance increased first attempt success in 75% of infants and in 50% of newborns. López Alvarez et al.,[18] reported a 79% success rate, associated with a larger diameter and a lower vessel depth, and a significant difference between the IJV and the FV; they also reported a lower number of punctures to achieve a successful catheterization in the first attempt. IJV catheterization in newborns and children is a strong recommendation based on level A evidence.[2,3] Multiple studies have demonstrated a lower risk for cannulation failure, artery puncture, and a higher success rate in the first attempt with a lower incidence of complications.[19,20]

In our study, although the procedure duration was not assessed, it was estimated to be probably shorter because, in particular, duration is usually directly related with the number of punctures and successful catheter insertion.

No significant differences were observed between first and second year fellows in terms of number of punctures, so this does not appear to depend on years of experience but on training prior to performing the procedure. Froehlich[21] published that ultrasound-guided CVC insertion in children is associated with a lower number of attempts and a shorter insertion time among residents.

Verghese et al.,[22] compared ultrasound use by inexperienced operators (fellows) for IJV cannulation versus the anatomic landmark-guided technique and found that success, cannulation time, and a lower incidence of carotid puncture improved with ultrasound guidance. The same conclusions were described by Aouad.[23]

The multivariate analysis showed a significant difference in terms of the physician guiding the procedure. This may be related to a greater level of experience and a better structure visualization and positioning technique, which may facilitate the procedure. On their side, Fresado et al.,[24] did not find any difference in the technique with 1 or 2 operators.

Our study found 8% of complications; the most frequent ones were artery punctures and bruising in the puncture site and were directly related to the number of punctures performed. The results of our study reinforce what has been demonstrated in adults: ultrasound guidance increases the success rate and is associated with a lower risk for complications.[25,26] Dambkowski et al.,[27] like Froehlich et al.,[21] described inadvertent vascular, nervous or pleural structures punctures as the most common adverse events and assigned ultrasound guidance a relevant role in complication prevention.

A significant limitation of our study was the lack of follow-up, which did not allow us to screen for potential complications in the long term. Another weakness is the lack of a control group or historical records, which would not allow us to state that this insertion method is superior to the one used previously (anatomic landmarks). However, and in the light of the bibliographic evidence and its generalized use in the ICU, such comparison did not seem ethical. Most articles published about pediatrics mention ultrasound use for central vascular access insertion, with a reduced insertion time and a reduced number of attempts and complications, such as thrombosis and catheter-associated infections.[28-30]

The variables related to the site of catheter insertion (IJV or FV), the physician guiding the procedure, and immediate complications demonstrated to be independent predictors in relation to the number of punctures performed during CVC insertion.

CONCLUSION

2D ultrasound has demonstrated to be very useful and safe for CVC insertion, with a successful first attempt rate, especially into the IJV, in infants younger than 6 months, and children with a weight of less than 10 kg. Immediate complications occurred more frequently in patients requiring more than 1 puncture. ■

Acknowledgments

The authors would like to thank Horacio Questa, M.D. and Head of the Surgery Clinic of Hospital Nacional de Pediatría "Prof. Dr. Juan P. Garrahan," for his valuable help with training in ultrasound-guided vascular access insertion in children.

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