The Effect of Ultrasound-guided Central Venous Catheterization on Complications and Success Rate in Critically-ill Children: A Multicenter Study

Kritik Hasta Çocuklarda Ultrason Eşliğinde Santral Venöz Kateterizasyonun Komplikasyonlar ve Başarı Oranına Etkisi: Çok Merkezli Çalışma

Serhat EMEKSİZ[1], Tanıl KENDİRLİ[2], Dinçer YILDIZDAŞ[3], Ayhan YAMAN[4], Çağlar ÖDEK[5], Mehmet BOŞNAK[6], Süleyman BAYRAKTAR[7], Hasan AĞIN[8], Ayşe Berna ANIL[9], Nurettin Onur KUTLU[10], Gazi ARSLAN[11], Benan BAYRAKÇI[12], Gökhan KALKAN[13], Oğuz DURSUN[14], Esra ŞEVKETOĞLU[15], Ebru AZAPAĞASI[16], Oktay PERK[17], Hayri Levent YILMAZ[18]

[1]Department of Pediatric Intensive Care, Faculty of Medicine, Ankara Yıldırım Beyazıt University, Ankara, Türkiye
[2]Department of Pediatric Intensive Care, Faculty of Medicine, Ankara University, Ankara, Türkiye
[3]Department of Pediatric Intensive Care, Faculty of Medicine, Çukurova University, Adana, Türkiye
[4]Department of Pediatric Intensive Care, Bahcesehir Liv Hospital, School of Medicine, İstinye University, İstanbul, Türkiye
[5]Department of Pediatric Intensive Care, Faculty of Medicine, Uludağ University, Bursa, Türkiye
[6]Department of Pediatric Intensive Care, Faculty of Medicine, Gaziantep University, Gaziantep, Türkiye
[7]Department of Intensive Critical Care, Haseki Research and Training Hospital, İstanbul, Türkiye
[8]Department of Pediatric Intensive Care, Dr Behçet Uz Children's Hospital, İzmir, Türkiye
[9]Department of Pediatric Intensive Care, İzmir Katip Çelebi University, İzmir, Türkiye
[10]Department of Pediatric Intensive Care, Kanuni Sultan Süleyman Research and Training Hospital, İstanbul, Türkiye
[11]Department of Pediatric Intensive Care, Faculty of Medicine, Dokuz Eylül University, İzmir, Türkiye
[12]Department of Pediatric Intensive Care, Faculty of Medicine, Hacettepe University, Ankara, Türkiye
[13]Department of Pediatric Intensive Care, Faculty of Medicine, Gazi University, Ankara, Türkiye
[14]Department of Pediatric Intensive Care, Faculty of Medicine, Akdeniz University, Antalya, Türkiye
[15]Department of Pediatric Intensive Care, Bakirkoy Dr Sadi Konuk Training and Research Center, University of Health Sciences, İstanbul, Türkiye
[16]Department of Pediatric Intensive Care, School of Medicine, Gazi University, Ankara, Türkiye
[17]Department of Pediatric Intensive Care, Ankara Bilkent City Hospital, Ankara, Türkiye
[18]Department of Pediatric Emergency, Faculty of Medicine, Çukurova University, Adana, Türkiye

0000-0003-1026-0386 : EMEKSİZ S
0000-0001-9458-2803 : KENDİRLİ T
0000-0003-0739-5108 : YILDIZDAŞ D
0000-0002-5651-1286 : YAMAN A
0000-0002-2521-3411 : ÖDEK Ç
0000-0002-8390-5109 : BOŞNAK M
0000-0002-8080-2438 : BAYRAKTAR S
0000-0003-3306-8899 : AĞIN H
0000-0003-3670-3771 : ANIL AB
0000-0002-3306-6570 : KUTLU NO
0000-0002-8616-3761 : ARSLAN G
0000-0003-3307-0948 : BAYRAKÇI B
0000-0003-1878-9866 : KALKAN G
0000-0001-5482-3780 : DURSUN O
0000-0002-8330-2877 : ŞEVKETOĞLU E
0000-0002-0684-8219 : AZAPAĞASI E
0000-0002-2586-5954 : PERK O
0000-0003-0873-9814 : YILMAZ HL

Conflict of Interest / *Çıkar Çatışması*: On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethics Committee Approval / *Etik Kurul Onayı*: This study was conducted in accordance with the Helsinki Declaration Principles. This study was approved by an ethics committee of the University of Health Sciences, Ankara Child Health and Diseases Hematology Oncology Training and Research Hospital (no: 2018:117).

Contribution of the Authors / Yazarların katkısı*: *EMEKSİZ S: Constructing the hypothesis or idea of research and/or article, Planning methodology to reach the conclusions, Organizing, supervising the course of progress and taking the responsibility of the research/study, Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Taking responsibility in logical interpretation and conclusion of the results, Taking responsibility in necessary literature review for the study, Taking responsibility in the writing of the whole or important parts of the study, Reviewing the article before submission scientifically besides spelling and grammar. ***KENDİRLİ T:*** Constructing the hypothesis or idea of research and/or article, Planning methodology to reach the conclusions, Organizing, supervising the course of progress and taking the responsibility of the research/study, Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Taking responsibility in logical interpretation and conclusion of the results, Taking responsibility in necessary literature review for the study, Taking responsibility in the writing of the whole or important parts of the study, Reviewing the article before submission scientifically besides spelling and grammar. ***YILDIZDAŞ D:*** Planning methodology to reach the conclusions, Organizing, supervising the course of progress and taking the responsibility of the research/study, Taking responsibility in logical interpretation and conclusion of the results, Taking responsibility in necessary literature review for the study, Taking responsibility in the writing of the whole or important parts of the study, Reviewing the article before submission scientifically besides spelling and grammar. ***YAMAN A:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***ÖDEK Ç:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***BOŞNAK M:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and gramma.r ***BAYRAKTAR S:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***AĞIN H:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***ANIL AB:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***KUTLU NO:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reportİng, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***ARSLAN G:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***BAYRAKÇI B:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***KALKAN G:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***DURSUN O:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***ŞEVKETOĞLU E:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar. ***AZAPAĞASI E:*** Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar PERK O: Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar YILMAZ HL: Taking responsibility in patient follow-up, collection of relevant biological materials, data management and reporting, execution of the experiments, Reviewing the article before submission scientifically besides spelling and grammar.

How to cite / *Atıf yazım şekli* : Emeksiz S, Kendirli T, Yıldızdaş D, Yaman A, Ödek Ç, Boşnak M, et al. The Effect of Ultrasound-guided Central Venous Catheterization on Complications and Success Rate in Critically Ill Children: A Multicenter Study. Turkish J Pediatr Dis 2024;18:281-288.

Correspondence Address / Yazışma Adresi:
Serhat EMEKSİZ
Department of Pediatric Intensive Care, Faculty of Medicine,
Ankara Yıldırım Beyazıt University, Ankara, Türkiye
E-posta: serhatemeksiz@yahoo.com

Received / Geliş tarihi : 06.03.2024
Accepted / Kabul tarihi : 15.04.2024
Online published : 04.06.2024
Elektronik yayın tarihi
DOI: 10.12956/tchd.1442586

ABSTRACT

Objective: The aims of this study were to compare the results of ultrasound (US) guidance and the landmark (LM) technique for central venous catheter (CVC) placement in pediatric intensive care units (PICUs) as performed by clinicians.

Material and Methods: The patients were divided into two groups according to the technique used: an LM group (459 patients) and a US-guided group (200 patients). We evaluated the success rate, the number of attempts, and the complication rates based on each patient's age and weight.

Results: The time required for the successful placement of the CVC was significantly different between the two groups: 10.9±10.8 min in the LM group and 8.1±7.6 min in the US-guided group (p=0.012). Additionally, the average number of attempts for successful catheterization was 1.8±0.8 in the US-guided group; and 2.5 ± 1.4 in the LM group (p=0.024). A total of 115 (17.3%) complications were noted: 24 (3.6%) in the US-guided group and 91 (13.7%) in the LM group (p=0.014). The frequency of complications decreased as the age and weight of the patients increased. When the inserted catheters used by ultrasound were evaluated, 59.5% of them were placed by clinicians who had ultrasound training while 40.5% were inserted by clinicians who did not have ultrasound training. There was no significant difference in the complication rate, number of punctures, and success rates between the ultrasound-trained and untrained clinicians (p=0.476).

Conclusion: This is the largest multicenter study comparing the US-guided vs. LM technique for CVC placement in children. We believe that the US-guided CVC procedure is more safe and takes less time than the LM technique. Also, point-of-care ultrasound is useful, beneficial, and easily available for pediatric intensivists.

Key Words: Central venous catheter, Ultrasound, Pediatric intensive care units

ÖZ

Amaç: Bu çalışmada çocuk yoğun bakım ünitelerinde ultrasonografi eşliğinde yapılmış olan santral venöz kateter uygulamalarının değerlendirilmesi ve ultrason kullanılmadan takılan kateterizasyonlarla karşılaştırılması amaçlanmıştı.

Gereç ve Yöntemler: Hastalar, kullanılan tekniğe göre iki gruba ayrıldı: Ultrason kullanılmayan hasta grubu (459 hasta) ve US kullanılan hasta grubu (200 hasta). Başarı oranını, girişim sayısını ve komplikasyon oranlarını her hastanın yaşına ve kilosuna göre değerlendirdik.

Bulgular: SVK'nın başarılı bir şekilde yerleştirilmesi için gereken süre iki grup arasında önemli ölçüde farklıydı: Ultrason kullanılmayan grupta 10.9±10.8 dakika ve ultrason kılavuzluğundaki grupta 8.1±7.6 dakika (p=0.012). Ek olarak, başarılı kateterizasyon için ortalama girişim sayısı, ultrason kılavuzluğundaki grupta 1.8±0.8'di; ultrason kullanılmayan grupta 2.5±1.4 (p=0.024). Toplam 115 (%17.3) komplikasyon kaydedildi: Ultrason kullanılan grupta 24 (%3.6) ve ultrason kullanılmayan grupta 91 (%13.7) (p=0.014). Hastaların yaşı ve kilosu arttıkça komplikasyon sıklığı azaldığı saptandı. Ultrason kullanılarak takılan kateterler değerlendirildiğinde %59.5'inin ultrason eğitimi almış klinisyenler tarafından, %40.5'inin ultrason eğitimi almamış klinisyenler tarafından yerleştirildiği görüldü. Ultrason eğitimi almış ve almamış klinisyenler arasında komplikasyon oranı, girişim sayısı ve başarı oranları açısından anlamlı fark yoktu (p=0.476).

Sonuç: Çalışmamız çocuklarda ultrason eşliğinde ve ultrason kullanılmadan SVK yerleştirmesini karşılaştıran en büyük çok merkezli çalışmadır. Ultrason eşliğinde takılan SVK işleminin daha güvenli ve daha az zaman aldığına inanıyoruz. Ayrıca, yatakbaşı ultrason pediatrik yoğun bakım uzmanları için yararlı ve kolayca elde edilebilir bir yöntemdir.

Anahtar Sözcükler: Santral venöz kateter, Ultrason, Çocuk yoğun bakım

INTRODUCTION

In the past ten years, ultrasound (US) use has been increasing with the application point of care ultrasound (POCUS) in emergency care and pediatric intensive care units (PICUs). Nowadays, POCUS is frequently used for central venous catheter (CVC) insertion, cardiac, and abdominal-related focused assessment with sonography in trauma (FAST), thorax, and lung assessment. POCUS is safe, easy to use, and readily available at any time. US-guided CVC insertion has been widely used in recent years in PICUs and pediatric emergency services (1,2).

Central venous catheters (CVCs) are extensively used in Pediatric Intensive Care Units (PICUs) and emergency care units to facilitate hemodynamic monitoring, prolonged and multiple fluid therapy, administration of medications and blood products, total parenteral nutrition, plasma exchange, renal replacement therapy, and vascular access (3). Commonly utilized sites for central venous catheterization in pediatric patients encompass the internal jugular vein (IJV), femoral vein (FV), and subclavian vein (SCV). The placement of a CVC is technically more challenging in pediatric patients than in adults: unsuccessful attempts, arterial puncture, bleeding, and long attempts are seen frequently in infants. The success rate for CVC placement in the pediatric population varies between 81% and 95%, accompanied by reported complication rates ranging from 2.5% to 22% (4). Complications during central venous catheterization, such as arterial puncture, pneumothorax, hemothorax, and hematoma, have the potential to result in fatal outcomes. Many complications are correlated with the iterative

needle cannulation of the central vein (5). Recent studies have indicated that ultrasound-guided central venous catheterization exhibits a heightened success rate and fewer complications when compared to alternative techniques (3-5).

US-guided central venous catheterization has become widespread with technological improvements, allowing for the selection of the most appropriate and safe blood vessel, and the safe puncture of the target vessel. Frequently, IJV is the preferred vein, followed by FV; SCV is rarely used. We aimed to compare the results of US guidance and the landmark (LM) technique for CVC placement in PICUs as performed by clinicians. Furthermore, we aimed to evaluate the success rate, the time required for successful cannulation, the number of attempts, and the complication rates. This is the largest multicenter study comparing the US-guided vs. LM technique for central venous catheterization in children. In addition, we described the current practices for central venous catheterization used in many PICUs in Türkiye.

US-guided central venous catheterization has become widespread with technological improvements, allowing for the selection of the most appropriate and safe blood vessel, and the safe puncture of the target vessel. Our objective was to conduct a comprehensive comparative analysis of outcomes between ultrasound-guided (US) and landmark (LM) techniques for CVC placement in PICUs, performed by skilled clinicians. This study aimed to evaluate and contrast the success rates, time durations for successful cannulation, number of attempts, and complication rates between the US-guided and LM techniques. Notably, this research represents the most extensive multicenter investigation to date, directly comparing the two aforementioned methodologies for central venous catheterization in the pediatric population. Additionally, we described the current practices for central venous catheterization used in many PICUs in Türkiye.

MATERIALS and METHODS

A prospective, multicenter, observational study was undertaken spanning the period from September 1, 2018, to December 31, 2018, involving 14 Pediatric Intensive Care Units (PICUs). The study cohort comprised 659 critically ill children necessitating central venous catheterization (CVC) due to diverse clinical imperatives, such as the administration of multiple fluids and medications, infusion requirements, vasoactive drug administration, prolonged intravenous therapy, hemodialysis, plasma exchange, total parenteral nutrition. It heightened susceptibility to extravasation, among other indications. The patients were divided into two groups according to the technique used: an LM group (459 patients) and a US-guided group (200 patients).

Central venous catheterization was conducted utilizing the internal jugular vein (IJV), subclavian vein (SCV), and femoral vein (FV). The catheterization procedures encompassed the insertion of conventional double-lumen catheters or hemodialysis catheters, with diameters spanning from 4 Fr to 12 Fr, contingent upon the child's weight and vascular dimensions, into either the IJV, SCV, or FV. The selection of the catheterization site was determined by the patient's specific attributes, the rationale for catheterization, and the cumulative experience of the medical facility.

The procedures were performed by pediatric intensivists, fellows, and pediatricians. All the clinicians who participated in the study had at least one year of experience in CVC placement. In addition, some of the clinicians underwent formal US-guided training (hands-on training by radiologists), and their peers trained some of the clinicians. Formal ultrasound training given by qualified radiologists included the use of ultrasound, ultrasound settings, and evaluation of vessels and organs by ultrasound imaging.

Various parameters were recorded during the study, encompassing the patient's demographic information, the chosen access site, the number of attempts made, and the time required for catheter placement. The procedure time, delineated from the initial skin puncture to the successful placement of the guidewire, was recorded. Clinicians assessed and reported insertion-related complications, including pneumothorax, hematoma, and arterial puncture. The procedural timing was conducted by Pediatric Intensive Care Unit (PICU) personnel utilizing a stopwatch, commencing from the instant the needle first penetrated the skin. The number of skin entries and the time of successful guidewire placement were systematically documented. Termination of the procedure was designated as the moment of successful guidewire insertion. A procedure was deemed successful when the catheter was effectively placed into the vein. Instances of procedure failure were defined as either exceeding six attempts, irrespective of arterial puncture occurrence, or surpassing 40 minutes of cannulation time.

The identification of a pulsatile flow characterized by bright red blood emanating from the needle served as an indicative marker for an arterial puncture. Hematoma formation, exceeding a diameter of 1 cm, at the skin access site was documented. In cases where catheters were positioned in the internal jugular vein (IJV) and subclavian vein (SCV), a chest X-ray was performed. Sedation protocols were implemented for patient comfort. The patient cohort was stratified into two distinct groups based on age (i.e., <2 years vs. >2 years old) and weight (<10 kg vs. >10 kg). The success rate, number of attempts, and complication rates were systematically assessed and compared across these delineated age and weight categories.

LM Technique

For internal jugular vein (IJV) catheterization, anatomical landmarks included the medial border of the sternocleidomastoid muscle and the pulsations of the carotid artery. Subclavian vein (SCV) catheterization was executed 1 cm below the junction of the medial one-third and lateral two-thirds of the clavicle.

In the case of femoral vein (FV) catheterization, the superior anterior thigh served as the entry point, situated just below the level of the inguinal ligament and approximately 1 cm medial to the point of maximal pulsation of the femoral artery (6,7). To maintain aseptic conditions, the entry site was disinfected using a 2% chlorhexidine solution and subsequently covered with a sterile drape. The catheterization needle was cautiously advanced towards the anticipated position of the targeted vein, with simultaneous aspiration. Upon observation of venous blood entering the syringe, the needle guide was placed, and the procedure was concluded (6-8).

US-guided Technique

For the IJV catheterization, the US probe was applied to the lateral aspect of the neck. For subclavian vein (SCV) catheterization, the probe was positioned on the anterolateral aspect of the thorax, precisely 1 cm below the clavicle. Regarding femoral vein (FV) catheterization, the probe was situated on the anterolateral aspect of the femoral region, approximately 2 cm below the inguinal ligament (6,7). The US-guided technique employed two primary approaches for vascular access: the long-axis and short-axis techniques, with emphasis given to the latter in this study. In the short-axis technique, the probe orientation was vertical to the vessel, not parallel to the skin. To optimize visibility within the ultrasound beam's area, the needle was inserted as closely as possible to the probe. Following vein selection, the puncture site was shielded, and the US probe (linear transducer: 5 MHz to 10 MHz) was aseptically covered with a sterilized sheath or glove, along with the application of the conductive gel. Subsequently, the clinician or practitioner manually manipulated the probe to delineate the artery and vein on the ultrasound image. Additionally, by aligning a large-bore needle beneath the center of the probe, the clinician or practitioner confirmed the needle trajectory and proceeded with cannulation attempts. Upon encountering a visual indication of blood, the US probe was retracted, and the conventional Seldinger technique was implemented (8,9).

This study was approved by an ethics committee of the University of Health Sciences, Ankara Child Health and Diseases Hematology Oncology Training and Research Hospital (no: 2018:117). Furthermore, written consent was obtained from each patient's family to include them in this study.

Statistical Analyses

Statistical analyses were conducted utilizing the SPSS 22.0 version for Windows (SPSS Inc., Chicago, IL, USA). Demographic data underwent assessment employing both parametric and non-parametric tests. Continuous variables were presented as mean and standard deviation (SD), while categorical variables were represented as frequencies and percentages. The Student's t-test was utilized to assess differences in the time required for catheterization and the number of attempts, both treated as continuous variables. The comparison of success rates and the incidence of complications among patients was executed through Fisher's exact test. A significance level of $p \leq 0.050$ was deemed statistically significant.

RESULTS

The study cohort included 289 males and 370 females, ranging from one month to 232 months (mean: 58.8±63.2 months). Of the 659 critically ill children in this study, mechanical ventilation was performed in 392 patients (59.5%). The body weight of the patients ranged from 2 kg to 94 kg (mean: 17.5±16.5 kg). There was respiratory failure in 324 (49.1%) patients, neurological diseases in 47 (7.2%) patients, metabolic problems in 43 (6.5%) patients, sepsis in 36 (5.4%) patients, heart disease in 33 (5.2%) patients, renal diseases in 29 (4.4%) patients, hematologic diseases in 28 (4.2%) patients, and electrolyte abnormalities in 24 (3.6%) patients (Table I).

Significant disparities were observed in the time required for successful Central Venous Catheter (CVC) placement between the two groups, with durations of 10.9±10.8 minutes for the

Table I: Demographics and baseline characteristics for 659 children in whom central venous catheters (CVC) were placed by landmark or ultrasound-guided approach

Demographics	
Age (month)*	58.8 ± 63.2 (1-232)
Weight (kg)*	17.5 ±16.5 (2-94)
Gender†	
Female	289 (43.9)
Male	370 (56.1)
Intubation†	
Yes	392 (59.5)
No	267 (40.5)
Weight (kg)†	
≤3.5	49 (7.4)
3.51-10 kg	279 (42.3)
10.01-20 kg	151 (23)
> 20 kg	180 (27.3)
Diagnosis†	
Respiratory failure	324 (49.1)
Sepsis	36 (5.4)
Neurologic	47 (7.2)
Cancer	17 (2.5)
Renal	29 (4.4)
Trauma	22 (3.4)
Gastrointestinal diseases	18 (2.7)
Heart diseases	33 (5.2)
Hematologic	28 (4.2)
Electrolyte abnormalities	24 (3.6)
Metabolic diseases	43 (6.5)
Drug intoxication	18 (2.8)
Central nervous system infections	12 (1.8)
Immunodeficiency	8 (1.2)

**: mean ± SD (minimum-maximum), †: n(%)*

Table II: Comparison of outcome measure in the landmark technique and ultrasound technique

Variable	Landmark (n=459)	Ultrasound (n=200)	p
Catheter type*			
Double lumen	364 (79.3)	152 (76)	
Hemodialysis	95 (20.7)	48 (24)	
Insertion site*			
Jugular vein	150 (32.6)	146 (73)	
Subclavian vein	87 (19)	9 (4.5)	
Femoral vein	222 (48.4)	45 (22.5)	
Success rate*			
All	448 (97.6)	197 (98.5)	0.568‡
Jugular vein	147 (98)	144 (98.6)	0.685‡
Subclavian vein	84 (96)	9 (100)	0.354‡
Femoral vein	217 (97)	44 (97)	0.296‡
Success rate*			
First attempt	196 (42.7)	120 (60)	0.015‡
Complication rate*			
All	91 (13.7)	24 (3.6)	0.014‡
Jugular vein	33 (5)	9 (1.3)	0.001‡
Subclavian vein	16 (2.4)	0 (0)	0.001‡
Femoral vein	42 (6.3)	15 (2.2)	0.032‡
Number of attempts†			
All	2.5 ± 1.4	1.8 ± 0.8	0.024§
Jugular vein	2.5 ± 1.6	1.7± 0.7	0.012§
Subclavian vein	2.8 ± 1.8	2.1 ± 1.2	0.068§
Femoral vein	2.6 ± 1.6	2.2 ± 1.4	0.184§
Procedure time, minutes†			
All	10.9 ±10.8	8.1 ± 7.6	0.012§
Jugular vein	9.3 ±9.1	7.3 ± 7.2	0.022§
Subclavian vein	12 ± 11.1	12.1 ± 8.8	0.124§
Femoral vein	11.6 ± 10.6	9.9 ± 7.7	0.325§

***:** *n (%),* **†:** *mean±SD,* **‡:** *Fisher's exact test,* **§:** *Student's t-test*

Landmark (LM) group and 8.1±7.6 minutes for the Ultrasound-guided (US-guided) group (p=0.012). Notably, the time needed for successful Internal Jugular Vein (IJV) catheterization exhibited a statistically significant difference, with 7.3±7.2 minutes for the US-guided group and 9.3±9.1 minutes for the LM group (p = 0.022). The US-guided group demonstrated a superior success rate at the first attempt, with 60% compared to 42.7% in the LM group (p=0.015). The average number of attempts for successful catheterization was 1.8±0.8 in the US-guided group, whereas it was 2.5±1.4 in the LM group (p=0.024). Additionally, the US-guided group necessitated fewer puncture attempts to access the IJV compared to the LM group (1.7±0.7 vs. 2.5±1.6, respectively; p=0.012). Regarding complications, the incidence of arterial puncture was 8% for the LM group and 2.4% for the US-guided group. In comparison, hematoma formation was 4.7% for the LM group and 1% for the US-guided group. Pneumothorax occurred in 1% of the LM group and 0% in the US-guided group. A total of 115 complications were noted in the study, accounting for 17.3% of cases, with 24 complications (3.6%) in the US-guided group (nine for IJV, 15 for FV) and 91 complications (13.7%) in the LM group (33 for IJV, 42 for FV, 16 for SCV) (p=0.014) (Table II).

We evaluated the success rate, the number of attempts, and the complication rates based on the age and weight of the patients. The success rate was 96.7% for children < 2 years old and 99.1% for children > 2 years old (p=0.038). When the number of attempts was evaluated in the age groups, the percentage for two or more attempts was 38.3% for children < 2 years old and 26% for children > 2 years old (p=0.026) (Figure 1). When the number of attempts was evaluated based on the weight groups, the percentage for two or more attempts was 38.5% for the low-weight group (<10 kg) and 25.9% for the high-weight group (>10 kg) (p=0.014) (Figure 2). Technique, complication rates, catheter type, insertion site according to patient's weight, and type of catheter are shown in Table III.

In addition, 59% of the CVC insertions were performed by fellows, 32% were performed by pediatric intensivists, and 9% were performed by pediatricians. When the catheters inserted using the US-guided technique were evaluated, 59.5% were inserted by clinicians with formal US-guided training and 40.5% were inserted by clinicians who had been trained by their peers. There was no significant difference in the complication rate, the number of punctures, and the success rates between the formally trained and the peer-trained clinicians (p=0.476).

Table III: Technique, catheter type, insertion site, complication rate compared with weight

Variable	Total*	≤3.5 kg*	3.51-10 kg*	10.01-20 kg*	>20 kg*
Technique					
Landmark technique	459 (69.7)	34 (7.5)	192 (41.8)	107 (23.3)	126 (27.4)
US-guided	200 (30.3)	15 (7.5)	87 (43.5)	44 (22)	54 (27)
Catheter type†					
Single-double lumen	516 (78.3)	43 (8.4)	253 (49)	114 (22)	106 (20.6)
Hemodialysis	143 (21.7)	6 (4.2)	26 (18.2)	37 (25.8)	74 (51.8)
Insertion site†					
Internal jugular vein					
Right	195 (29.6)	18 (9.2)	88 (45.2)	44 (22.6)	45 (23)
Left	101 (15.3)	7 (7)	51 (50.4)	27 (26.8)	16 (15.8)
Subclavian vein					
Right	63 (9.6)	11 (17.5)	23 (36.5)	13 (20.6)	16 (25.4)
Left	33 (5)	6 (18.2)	13 (39.4)	7 (21.2)	7 (21.2)
Femoral vein					
Right	197 (29.9)	4 (2)	78 (39.5)	42 (21.4)	73 (37.1)
Left	70 (10.6)	3 (4.2)	26 (37.2)	18 (25.8)	23 (32.8)
Complication rate†					
Artery puncture	59 (9)	4 (6.8)	27 (45.8)	14 (23.7)	14 (23.7)
Hematoma	29 (4.4)	0(0)	18 (62)	6 (20.6)	5 (17.4)
Pneumothorax	5 (0.8)	0(0)	2 (40)	2 (40)	1 (20)
Artery puncture and hematoma	19 (2.9)		12 (63.2)	4 (21)	3 (15.8)
Artery puncture and pneumothorax	2 (0.3)	1 (50)	1 (50)		
No complication	545 (82.6)	44 (8)	219 (40)	125 (23)	157 (29)

**n (%)*

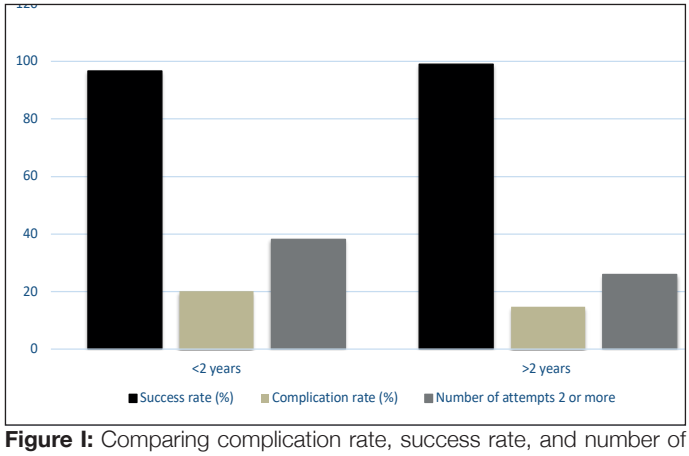

Figure I: Comparing complication rate, success rate, and number of attempts between <2 versus >2 years old in all patients.

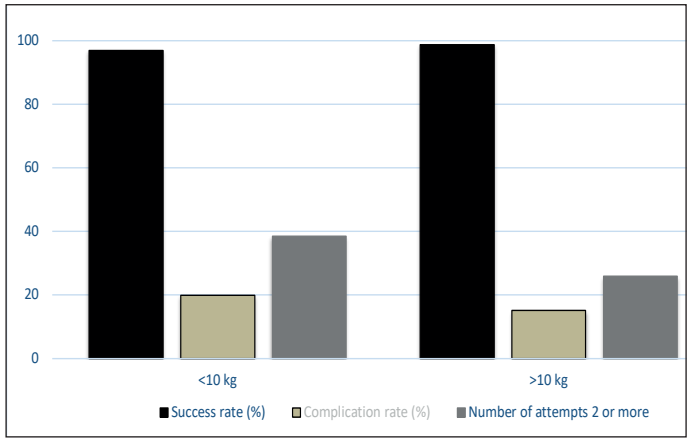

Figure 2: Comparing complication rate, success rate, and number of attempts between <10 kg versus >10 kg in all patients.

DISCUSSION

This study is the largest multicenter comparison of US-guided and LM techniques for central venous catheterization in critically ill children. We found that the US-guided technique reduces the complication rate and increases the first attempt success rate.

Anomalies in anatomy, prior Central Venous Catheter (CVC) placement, and conditions such as venous thrombosis or a small vessel diameter may detrimentally impact the success rate and augment the risk of complications during catheterization (10). Consistent with numerous prior investigations, the Ultrasound-guided (US-guided) technique has demonstrated superiority over the Landmark (LM) technique, manifesting in decreased complication rates and increased success rates. Several studies employing both techniques support this assertion (5,10,11). For instance, Kayir et al. (12) reported a complication rate of 24% for the LM group as opposed to 6% for the US-guided group, while Sazdov et al. (13) found a complication rate of 14.5% for the LM group and 4% for the US-guided group. The findings of the present study align with the existing literature, substantiating that the US-guided technique mitigates complications associated with central venous catheterization in Pediatric Intensive Care Unit (PICU) patients compared to the LM technique. Specifically, complications such as arterial puncture, pneumothorax, hemothorax, and hematoma were notably lower in the US-guided group than in the LM group. Arterial puncture emerged as the most prevalent complication for Internal Jugular Vein (IJV) and Femoral Vein (FV) catheterizations, while pneumothorax was most commonly

associated with Subclavian Vein (SCV) catheterization (10,14). In the literature, the reported incidences of these complications range between 10% and 14% for arterial puncture, 4% and 9% for hematoma formation, and 1% and 8% for pneumothorax (4,5,10,13,15). Importantly, the complication rates observed in our study closely resemble those reported in prior investigations.

Oulego-Erroz et al. (16) conducted a multicenter study demonstrating that the Ultrasound-guided (US-guided) technique significantly reduced the number of punctures and complication rates, while concurrently increasing the success rate when compared to the Landmark (LM) technique. In a study by Froehlich et al. (4), the cannulation success rate was reported as 88.2% in the LM group and 90.8% in the US-guided group, with no significant difference noted (p=0.540). In our cohort, the success rates for US-guided cannulation and anatomically LM-guided cannulation were 97.6% and 98.5%, respectively, and these rates were not found to be significantly different (p= 0.568). Several studies have reported a shorter duration for central vein cannulation using the US-guided technique compared to the LM technique, ranging from 4.2 minutes to 14.3 minutes (10,13,17). In alignment with these findings in the literature, our study indicates that the US-guided technique contributed to a reduction in the number of attempts and the duration of successful placement. The real-time nature of ultrasound application is notably advantageous for clinicians in localizing the vein during the procedure, leading to a more efficient process with reduced attempts and duration for successful catheter placement.

The impact of patient weight and age on cannulation success is well-documented in the literature. Leyvi et al. (17) reported varying success rates in their study group, with an overall success rate of 91%, 94.7% for children older than 1 year, and 77.8% for children younger than 1 year. Similarly, Froehlich et al. (4) observed that children in the low-weight group (median weight < 16.25 kg) exhibited lower success rates and required more placement attempts for both techniques compared to children in the high-weight group (median weight >16.25 kg). In this study, we analyzed success rates, the number of attempts, and complication rates with consideration of the age and weight of the patients. Our study findings align with existing literature, providing support for the notion that as patients age and weight increase, the number of attempts decreases, and the success rate increases. This aligns with the common understanding that placing a central catheter in infants is often more challenging than in older children due to factors such as a lack of patient cooperation and smaller vein size.

The literature consistently highlights that fellows and residents utilizing ultrasound (US) for cannulation experience a significant reduction in the number of attempts. Froehlich et al. (4) reported a noteworthy decrease in the required time for successful Central Venous Catheter (CVC) placement among resident physicians (405 vs. 919 seconds, p=0.020) when employing the US-guided technique, as opposed to the fellows or attending physicians, in comparison to the Landmark (LM)-guided technique. Sigaut et al.(18) demonstrated that the US-guided technique effectively reduced complication rates and failures in Internal Jugular Vein (IJV) catheterization in children, even when performed by physicians with limited experience in venous catheterization. Additionally, Zanolla et al. (19) indicated that specialists trained in ultrasound techniques exhibited reduced time requirements for successful placement, fewer attempts, and lower complication rates. In contrast, our study did not identify a significant difference in access time, success rate, or the incidence of complications for US-guided CVC placement between formally-trained and peer-trained clinicians (p=0.568). However, these findings are not surprising given that many clinicians acquire catheterization skills through peer training. Therefore, peer training can be equally effective as formal training in the context of US-guided CVC placement.

CONCLUSSION

In PICUs and emergency care units, POCUS is used for many invasive procedures in critically ill children. US-guided CVC placement is the technique that is most frequently used and it is beneficial for POCUS. Our large multicenter study confirms that, as evidenced by some studies, the use of US results in a higher rate of first-attempt success, a lower average number of attempts, a shorter access time, and lower complications (such as arterial puncture, hematoma, and pneumothorax) in the children. Hence, a US-guided central venous catheterization is safer and takes less time than the LM technique. Therefore, this technique should be preferred during CVC placement in critically ill children in PICUs.

Limitations

The limitations of this study are as follows. First, patient groups were not standardized. Second, patients and techniques were selected according to the center's experience.

REFERENCES

1. Burton L, Bhargava V, Kong M.Point-of-Care Ultrasound in the Pediatric Intensive Care Unit. Front Pediatr 2022;9:830160.
2. Watkins LA, Dial SP, Koenig SJ, Kurepa DN, Mayo PH. The Utility of Point-of-Care Ultrasound in the Pediatric Intensive Care Unit. J Intensive Care Med 2022;37:1029-36.
3. Rando K, Castelli J, Pratt JP, G Rey, M E Rocca, G Zunini. Ultrasound-guided internal jugular vein catheterization: A randomized controlled trial. Heart Lung Vessel 2014;6:13-23.
4. Froehlich CD, Rigby MR, Rosenberg ES, Li R, Roerig PJ, Easley KA, et al. Ultrasound-guided central venous catheter placement decreases complications and decreases placement attempts compared with the landmark technique in patients in a pediatric intensive care unit. Crit Care Med 2009;37:1090-96.

5. Hoffman T, Du Plessis M, Prekupec MP, Gielecki J, Zurada A, Tubbs RS, et al. Ultrasound-guided central venous catheterization: A review of the relevant anatomy, technique, complications, and anatomical variations. Clin Anat 2017;30: 237-50.
6. Sadzov D, Srceva MJ, Todorova ZN. Comparative Analysis of Ultrasound Guided Central Venous Catheterization Compared to Blind Catheterization. Pril (Makedon Akad Nauk Umet Odd Med Nauki) 2017; 38: 107-14.
7. Gu Y, Min K, Zhang Q, Chen Z, Feng D, Wei J, et al. Central venous catheterization site choice based on anatomical landmark technique: a systematic review and meta-analysis. J Anesth 2021;35:801-10.
8. Saugel B, Scheeren TWL, Teboul JL. Ultrasound-guided central venous catheter placement: a structured review and recommendations for clinical practice. Crit Care 2017;21:225.
9. Garcia-Leal M, Guzman-Lopez S, Verdines-Perez AM, Leon-Gutierrez H, Fernandez-Rodarte BA, Alvarez-Villalobos NA, et al. Trendelenburg position for internal jugular vein catheterization: A systematic review and meta-analysis. J Vasc Access 2023;24:338-47.
10. Yang EJ, Ha HS, Kong YH, Sun Kim J. Ultrasound-guided internal jugular vein catheterization in critically ill pediatric patients. Korean J Pediatr 2015;58:136-41.
11. Brass P, Hellmich M, Kolodziej L, Schick, Smith GAF. Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. Cochrane Database Syst Rev 2015;1:CD006962.
12. Kayir S, Ozyalcin S, Dogan G, Diken AI, Turkmen U. Internal Jugular Vein Catheterization: The Landmark Technique versus Ultrasonography Guidance in Cardiac Surgery. Cureus 2019;11:e4026.
13. Sazdov D, Srceva MJ, Todorova ZN. Comparative Analysis of Ultrasound Guided Central Venous Catheterization Compared to Blind Catheterization. Pril (Makedon Akad Nauk Umet Odd Med Nauki) 2017;38:107-14.
14. Srisan P, Juhomg S, Kanjanapatanakul W. Central venous catheterization related complications in Pediatric Intensive Care Unit at Queen Sirikit National Institute of Child Health. J Med Assoc Thai 2014; 97 Suppl 6: S83-8.
15. C Rehn, J Balicchi, N Marchiset-Eymard, J Salles. Complication risk factors related to central venous catheter in pediatric. Ann Pharm Fr 2020;78:310-8.
16. Oulego-Erroz I, González-Cortes R, García-Soler P, Balaguer-Gargallo M, Frías-Pérez M, Mayordomo-Colunga J, et al. Ultrasound-guided or landmark techniques for central venous catheter placement in critically ill children. Intensive Care Med 2018;44: 61-72.
17. Leyvi G, Taylor DG, Reith E, Wasnick JD. Utility of ultrasound-guided central venous cannulation in pediatric surgical patients: a clinical series. Paediatr Anaesth 2005; 15: 953-8.
18. Sigaut S, Skhiri A, Stany I, Golmar J, Nivoche Y, Constant I, et al. Ultrasound guided internal jugular vein access in children and infant: a meta-analysis of published studies. Paediatr Anaesth 2009; 19812: 1199-206.
19. Zanolla GR, Baldisserotto M, Piva J. How useful is ultrasound guidance for internal jugular venous access in children? J Pediatr Surg 2018; 54: 789-93.