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Factors Associated with Successful First-attempt Puncture in Pediatric Patients Undergoing Ultrasound-guided Peripherally Inserted Central Catheter

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Abstract

Background: Peripherally inserted central catheter (PICC) is an alternative to central venous cannulation. This study aimed to identify factors associated with first-attempt success rate in children undergoing PICC insertion.
Methods: This retrospective study included pediatric patients who underwent PICC placement at the Children's Hospital of Zhejiang (1/2020-12/2020). The successful puncture was defined as smooth blood return and insertion of the guide wire. Clinical data were collected, and factors associated with first-attempt success were identified by logistic regression analyses.
Results: The final analysis included 640 children (360 males, 56.2%). Successful puncture at the first attempt was achieved in 380 (59.4%) patients. Multivariate logistic regression revealed that being uncooperative after sedation (OR = 2.745, 95%CI: 1.028 - 7.331, P = 0.044), being cooperative after sedation (OR = 0.318, 95%CI: 0.128–0.791, P = 0.014), target vein depth (0.5 - 1 vs. $\leq$ 0.5: OR = 1.715, 95%CI: 1.081–2.720, P = 0.022; 1.1-1.5 vs. $\leq$ 0.5: OR = 3.036, 95%CI: 1.166 - 7.903, P = 0.023; > 1.5 vs. $\leq$ 0.5: OR = 10.453, 95%CI: 2.366 - 46.139, P = 0.002), target vein diameter (2.0 - 2.9 vs. $\leq$ 2: OR = 0.313, 95%CI: 0.180 - 0.545, P < 0.001; $\geq$ 3 vs. $\leq$ 2: OR = 0.122, 95%CI: 0.055 - 0.272, P < 0.001), and 3F catheter specification (vs. 1.9F: OR = 2.057, 95%CI: 1.069 - 3.958, P = 0.031) were independently associated with puncture failure at the first attempt.
Conclusions: The degree of cooperation, target vein diameter and depth, and catheter specification were independently associated with the first-attempt success rate.

Keywords: Child, Infant, Peripherally Inserted Central Catheter Line Insertion

1. Background

Central vein cannulation is essential for blood transfusion, drug administration, and hemodynamic monitoring in patients admitted to surgical, hematologic, oncologic, and Intensive Care Units (ICUs) (1). Common puncture sites for central venous cannulation include the internal jugular, femoral, and subclavian veins (1). However, central venous catheter placement is associated with a risk of mechanical complications such as arterial puncture and hemorrhage, pneumothorax, arrhythmia, and nerve damage (2). Furthermore, central venous lines can cause other complications, including infection and thrombosis (3). Central venous access devices can also cause discomfort and restrict activities of daily living (4).

Peripherally inserted central catheters (PICCs) provide an alternative for medium-term central venous access (5, 6). The PICC is a long, thin, and flexible catheter constructed from silicone or polyurethane that is inserted percutaneously into a vein (often in the forearm or antecubital fossa) whose tip is advanced into the central venous circulation (e.g., superior vena cava or caval-atrial junction), usually under the guidance of ultrasound or fluoroscopy (6, 7). Notably, PICCs are thought to be associated with a lower incidence of infection than central venous lines (8, 9). Moreover, PICCs can be inserted by specially trained nurses, whereas central venous catheters are usually placed by physicians in an operating theatre or ICU (6). Therefore, PICCs have become widely used in the clinical setting and are considered safe and effective for pediatric patients (10).

The first-attempt success rate for PICC insertion is 79 - 94% in adult patients (11-13) and only 48 - 93% in pediatric patients (14-19). Failure to achieve PICC insertion at the

first attempt in children aggravates the physical pain and psychological distress experienced by the patient, delays intravenous therapy, and increases the workload on the nurse performing the procedure (since a second attempt is required). However, very little is known about the factors affecting the first-attempt success rate of PICC insertion in children.

2. Objectives

The present study aimed to identify the factors associated with first puncture success in children undergoing PICC insertion in a pediatric hospital in China.

3. Methods

3.1. Study Design and Participants

This retrospective study included pediatric patients undergoing PICC at the Children's Hospital of Zhejiang between January 2020 and November 2020. The inclusion criteria were as follows: (1) Meeting the indications for PICC insertion and (2) age of one month to 18 years. Patients were excluded if any of the following criteria were met: (1) History of thrombosis at the puncture site, (2) history of vascular surgery at the puncture site, (3) history of lymph node dissection in the limb selected for a puncture, (4) superior vena cava syndrome, (5) infection at the puncture site, and (6) arteriovenous fistula in the limb selected for puncture. The Ethics Committee of the Children's Hospital of Zhejiang approved this study (approval number: 2021-IRB-285). The requirement for informed consent was waived due to the retrospective nature of this research.

3.2. Insertion of the PICC

Ultrasound-guided PICC insertion was performed by a full-time nurse specializing in intravenous therapy who had received professional training and a qualification certified by the Provincial Nursing Association. The procedure was carried out using 1.9F and 3F front-end-trimmed catheters, a 4F three-way valve catheter, and a Mindray TE7 portable ultrasound guidance system (Wuhan Kolda Medical Technology Co., Ltd., Wuhan, China) equipped with a high-frequency linear array probe (6 - 14 Hz). Ultrasound-guided PICC insertion into an upper arm vein was carried out using the modified Seldinger technique per the operating standards of the Infusion Nurses Society and PICC operating procedures developed by the Zhejiang Nursing Center. First, the appropriate vein was selected, and the puncture site was determined. Then, the length required to advance the catheter to the superior vena cava/right atrial junction (measured as the length from the insertion site to the mid-clavicular line and down to the third intercostal space) and the circumferences of the middle sections of both upper arms were measured. According to the pre-measured length, the guide wire was withdrawn so that it was 1 cm shorter than the required length, and the withdrawn part of the guide wire was circled and fixed to prevent contamination during insertion. Next, the catheter was trimmed to a suitable length (back-end-trimmed catheters did not require this procedure). A tourniquet was placed on the arm, and 0.2 mL of 2% lidocaine solution (5 mL/100 mg) was injected intradermally above the puncture site for local anesthesia. An assistant fixed the limb in an appropriate position, and the nurse inserted the puncture needle into the target blood vessel under ultrasound guidance. An indwelling needle with a peelable sheath introducer was used for puncture. The guide wire was inserted after the blood returned, followed by the introducer. The catheter was then inserted into the predetermined length after the withdrawal of the guide wire.

3.3. Data Collection

The following demographic and clinical characteristics were obtained from the electronic medical records or through communication with the patients and their families: Sex, age, weight, and indication for PICC insertion. The diameter and depth of the vein selected for puncture were measured by ultrasonography. The level of patient cooperation during PICC insertion was classified as cooperative without medication, cooperative after sedative administration, and uncooperative after sedative administration. The successful puncture was defined as smooth blood return and insertion of the guide wire and catheter, assessed by a full-time nurse specializing in intravenous therapy.

3.4. Statistical Analysis

The statistical analyses were performed using SPSS 25 (IBM, Armonk, NY, USA). For the analysis, the patients were divided into first puncture success and first puncture failure groups according to whether the puncture was successful at the first attempt. Continuous data are presented as medians (interquartile range, IQR) and were analyzed using the Mann-Whitney U-test. Categorical data are expressed as No. (%) and were compared between groups using the chi-square test. Univariate and multivariate logistic regression analyses were used to identify factors associated with a successful puncture at the first attempt, and Odds Ratios (ORs) and 95% Confidence Intervals (95%CIs) were calculated. Also, $P < 0.05$ was considered statistically significant.

4. Results

4.1. Clinical Characteristics of the Study Participants

The final analysis included 640 children (360 males, 56.2%) with a median age of 3.8 years (IQR: 1.4 - 7.8 years) and a median weight of 15.4 kg (IQR: 9.7 - 25.0 kg). The underlying disease was a hematologic tumor in 464 patients, short bowel syndrome or inflammatory bowel disease in 96 patients, and other diseases (including critical illness, neurologic condition, or other diseases requiring surgery) in 80 patients. All 640 children met the indications for PICC insertion, and their clinical data are summarized in Table 1.

The characteristics of PICC insertion are presented in Table 1. Despite sedation, most children (411 patients, 64.2%) were uncooperative during PICC insertion. The target vein most commonly had a depth of 0.5 - 1.0 cm (359 patients, 56.1%) and a diameter of 2.0 - 2.9 mm (396 patients, 61.9%). Catheter specification was mostly 3F (275 patients, 43.0%) or 4F/5F (280 patients, 43.7%).

Successful puncture at the first attempt was achieved in 380 (59.4%) patients. As detailed in Table 1, there were significant differences between the first puncture success and first puncture failure groups in age, weight, disease type, degree of cooperation, target vein diameter, and catheter specification ($P < 0.05$ for all parameters).

4.2. Logistic Regression Analysis of Factors Associated with Puncture Failure at the First Attempt

The univariate logistic regression analysis indicated that age, weight, disease type, degree of cooperation, target vein diameter, catheter specification, and the number of catheters inserted were associated with puncture failure at the first attempt (Table 2). Multivariate logistic regression revealed that being uncooperative after sedation (OR = 2.745, 95%CI: 1.028 - 7.331, P = 0.044), being cooperative after sedation (OR = 0.318, 95%CI: 0.128 - 0.791, P = 0.014), target vein depth (0.5-1 vs. $\leq$ 0.5: OR = 1.715, 95%CI: 1.081 - 2.720, P = 0.022; 1.1 - 1.5 vs. $\leq$ 0.5: OR = 3.036, 95%CI: 1.166 - 7.903, P = 0.023; > 1.5 vs. $\leq$ 0.5: OR = 10.453, 95%CI: 2.366 - 46.139, P = 0.002), target vein diameter (2.0-2.9 vs. $\leq$ 2: OR = 0.313, 95%CI: 0.180 - 0.545, P < 0.001; $\geq$ 3 vs. $\leq$ 2: OR = 0.122, 95%CI: 0.055 - 0.272, P < 0.001), and 3F catheter specification (vs. 1.9F: OR = 2.057, 95%CI: 1.069 - 3.958, P = 0.031) were independently associated with puncture failure at the first attempt (Table 3).

5. Discussion

A notable finding of the present study was that successful puncture at the first attempt was achieved in only 380 (59.4%) of the 640 patients. Furthermore, there were significant differences between the first puncture success and first puncture failure groups in age, weight, disease type, degree of cooperation, target vein diameter, and catheter specification. Multivariate logistic regression analysis demonstrated that sedation use for patient cooperation, target vein depth, target vein diameter, and 3F catheter specification (vs. 1.9F) were independently associated with puncture failure at the first attempt. To the best of our knowledge, this study is the first to identify factors related to puncture failure at the first attempt. Our novel findings provide new insights that might help nurses adjust their technique to improve the chances of obtaining venous access at the first attempt during PICC placement.

Prior research has indicated that the first-attempt success rate for PICC insertion in pediatric patients ranges widely from 48 to 93% (14-19). The first-attempt success rate in the present study was 59.4%, which is consistent with previously published values. The above data illustrate that the failure of PICC placement at the first attempt is not uncommon, which highlights the need to identify ways of improving the technique to minimize the physical and psychological stress experienced by the patient.

An interesting finding of this study was that the success rate of the first puncture was 43.6% in infants who were < 1 year old, 47.8% in toddlers who were 1 - 3 years old, 61.1% in children aged 3 - 7 years old, and 77.7% in those who were > 7 years old. We speculate that younger age may have been associated with a lower degree of cooperation, which influenced the success of the first attempt at PICC placement. Given that children cannot communicate with healthcare workers as effectively as adults and are fearful of unknown events, they often use resistance, escape, or defense mechanisms to refuse insertion. Lu et al. (20) suggested that the routine application of a compound lidocaine ointment to the puncture site region around half an hour before surgery could alleviate pain during a puncture. Additionally, these authors found that analgesia could be combined with sedation (intravenous infusion of midazolam) to improve the compliance of uncooperative and anxious children and thereby increase the puncture success rate. Badheka et al. (14) also concluded that the success rate of PICC insertion was higher in children administered local analgesia than in those not receiving analgesia. Costa et al. have also recommended the wider adoption of analgesic strategies before and during PICC placement (21). A recent expert consensus on sedation and analgesia for children in pediatric ICUs in China (22) recommended remifentanil and dexmedetomidine use for analgesia and sedation. Dexmedetomidine has sympatholytic, anxiolytic, and sedative effects similar to natural sleep, as well as some analgesic effects. Dexmedetomidine is increasingly used for procedural sedation in in-

Table 1. Clinical Characteristics of the Study Participants [a]

Characteristics	All Patients (n = 640)	First Puncture Success (n = 380)	First Puncture Failure (n = 260)	P-Value
Age, years				< 0.001
< 1	110 (17.2)	48 (12.6)	62 (23.8)	
1 - 3	161 (25.2)	77 (20.3)	84 (32.3)	
3 - 7	190 (29.7)	116 (30.5)	74 (28.5)	
> 7	179 (28.0)	139 (36.6)	40 (15.4)	
Sex				0.715
Male	360 (56.2)	216 (56.8)	144 (55.4)	
Female	280 (43.8)	164 (43.2)	116 (44.6)	
Weight, kg	15.4 (9.9–25.0)	18.0 (12.0–29.0)	12.0 (8.0–19.0)	< 0.001
Type of disease				0.018
Hematological tumor	464 (72.5)	291 (76.6)	173 (66.5)	
Short bowel syndrome or bowel dysfunction	96 (15.0)	47 (12.4)	49 (18.8)	
Other	80 (12.5)	42 (11.1)	38 (14.6)	
Degree of cooperation				< 0.001
Cooperative without sedation	30 (4.7)	20 (5.2)	10 (3.8)	
Uncooperative after sedation	199 (31.1)	47 (12.4)	152 (58.5)	
Cooperative after sedation	411 (64.2)	313 (82.4)	98 (37.7)	
Target vein depth, cm				0.263
≤ 0.5	208 (32.5)	115 (30.3)	93 (35.8)	
0.5 - 1.0	359 (56.1)	216 (56.8)	143 (55.0)	
1.1 - 1.5	56 (8.75)	39 (10.3)	17 (6.54)	
> 1.5	17 (2.66)	10 (2.63)	7 (2.69)	
Target vein diameter, mm				< 0.001
< 2	116 (18.1)	36 (9.5)	80 (30.8)	
2 - 2.9	396 (61.9)	239 (62.9)	157 (60.4)	
≥ 3	128 (20.0)	105 (27.6)	23 (8.85)	
Catheter specification				< 0.001
1.9F	85 (13.3)	40 (10.5)	45 (17.3)	
3F	275 (43.0)	133 (35.0)	142 (54.6)	
4F+5F	280 (43.7)	207 (54.5)	73 (28.1)	
Number of catheters				0.082
1	411 (64.2)	249 (65.5)	162 (62.3)	
2	130 (20.3)	82 (21.6)	48 (18.5)	
≥ 3	99 (15.5)	49 (12.9)	50 (19.2)	

[a] Data are presented as No. (%) or median (IQR).

fants and children (23), although careful monitoring for adverse effects (hemodynamic changes such as hypotension and bradycardia) is required. However, since deep sedation is not anesthesia, the body will still retract involuntarily after painful stimulation, leading to puncture failure. This may explain the observation in the present study that the odds of first-attempt failure were higher in children who required sedation for cooperation than in children who voluntarily cooperated without the need for sedation. Remifentanil is an anesthetic drug, and gen-

Table 2. Univariate Logistic Regression Analysis of Factors Associated with Failure of Puncture at the First Attempt [a]

Characteristics	Odds Ratio	95%CI	P-Value
Age, y			
≤ 1	1		
1 - 3	0.845	0.519 - 1.375	0.497
3 - 7	0.494	0.307 - 0.795	0.004
> 7	0.223	0.133 - 0.373	< 0.001
Sex (male vs. female)	0.943	0.686 - 1.295	0.715
Weight (continuous)	0.959	0.946 - 0.973	< 0.001
Type of disease			
Hematological tumor	1		
Short bowel syndrome or bowel dysfunction	1.754	1.127 - 2.729	0.013
Other	1.522	0.944 - 2.453	0.085
Degree of cooperation			
Cooperative without sedation	1		
Uncooperative after sedation	6.468	2.830 - 14.783	< 0.001
Cooperative after sedation	0.626	0.284 - 1.383	0.247
Target vein depth, cm			
≤ 0.5	1		
0.5 - 1	0.819	0.580 - 1.156	0.256
1.1 - 1.5	0.539	0.287 - 1.014	0.055
> 1.5	0.866	0.317 - 2.362	0.778
Target vein diameter, mm			
< 2	1		
2 - 2.9	0.296	0.190 - 0.460	< 0.001
≥ 3	0.099	0.054 - 0.179	< 0.001
Catheter specification			
1.9F	1		
3F	0.949	0.583 - 1.545	0.833
4F+5F	0.313	0.190 - 0.518	< 0.001
Number of catheters			
1	1		
2	0.900	0.599 - 1.352	0.611
≥ 3	1.568	1.009 - 2.437	0.045

[a] 95%CI: 95% confidence interval

eral wards have restricted access to it. Therefore, we suggest that multidisciplinary cooperation may be required to achieve a truly painless PICC insertion and thereby increase the success rate of the first puncture attempt.

In this study, target vein diameter was an independent factor affecting the success rate of the first puncture, which was 31.0% for a diameter < 2 mm, 60.4% for a diameter of 2.0 - 2.9 mm, and 82.0% for a diameter > 3 mm. Blood vessel diameter is much smaller in children than in adults. For example, the diameter of upper arm blood vessels in adults is 4.32 - 7.96 mm (24), whereas the target vein diameter was only 1.2 - 4.2 mm in the children enrolled in the present study. Wu et al. (24) suggested that using a local hot compress to expand the blood vessels before PICC insertion could enhance the procedure's success. We propose that careful attention should be paid during PICC placement

Table 3. Multivariate Logistic Regression Analysis of Factors Associated With Failure of Puncture at the First Attempt [a]

Characteristic	Odds Ratio	95%CI	P-Value
Degree of cooperation			
Cooperative without sedation	1		
Uncooperative after sedation	2.745	1.028 - 7.331	0.044
Cooperative after sedation	0.318	0.128 - 0.791	0.014
Catheter specification			
1.9F	1		
3F	2.057	1.069 - 3.958	0.031
4F+5F	1.481	0.641 - 3.421	0.358
Target vein depth, cm			
≤ 0.5	1		
0.5 - 1	1.715	1.081 - 2.720	0.022
1.1 - 1.5	3.036	1.166 - 7.903	0.023
> 1.5	10.453	2.366 - 46.139	0.002
Target vein diameter, mm			
≤ 2	1		
2.0 - 2.9	0.313	0.180 - 0.545	< 0.001
≥ 3	0.122	0.055 - 0.272	< 0.001

[a] 95%CI: 95% confidence interval

to maintain adequate skin and body temperature in the patient, for example, by using a radiant warmer. Moreover, any liquids applied to the skin (such as disinfectants) should be warmed to avoid cold-induced vasoconstriction that might reduce the chances of a successful puncture.

The modified Seldinger technique, under ultrasound guidance, is widely used to perform PICC insertion. This method is suitable for cooperative patients with good vascular conditions. For children who are uncooperative and have thin blood vessels, it is very easy for the puncture needle to ectopically slip out of the blood vessel and cause the failure of guide wire insertion. Uygun (16) combined a 24G indwelling needle and a 19G introducer cannula to create a new puncture tool and successfully completed PICC insertion in 32 neonates with a success rate of 97%. Furthermore, researchers in China (20) have reported that the modified Seldinger technique with a 24G indwelling needle can improve the success rate of PICC placement in children. There are two main advantages to the use of a 24G indwelling needle. First, a 24G indwelling needle has a thin tip that reduces pain and fear during puncture, thereby improving patient cooperation. Second, after a successful puncture with a 24G indwelling needle, a sufficient introducer cannula can be placed in the blood vessel to avoid catheter displacement and permit smooth insertion of the guide wire into the blood vessel, thereby increasing the puncture success rate.

In our study, the success rate of the first puncture was 47.1% for 1.9F catheters, 48.36% for 3F catheters, and 73.9% for 4F/5F catheters. Of course, the selection of the catheter specification depends on the diameter of the target blood vessel. Generally, younger children (who also have a lower degree of cooperation) have thinner blood vessels and require smaller catheters, which increases the difficulty of puncture. For catheters above 3F, the modified Seldinger technique can be used under ultrasound guidance to improve the success rate of puncture. For 1.9F catheters, the products on the market do not have a matching guide wire and introducer sheath, so the 24G indwelling needle cannot be used with the modified Seldinger technique to place an indwelling PICC. If the puncture needle in the catheter package is 22G, it is very easy to pierce the thin and fragile blood vessels of premature infants, neonates, and small babies. Some researchers (25) have used a thin and small peelable arterial catheter as the introducer sheath to overcome some of the difficulties of PICC placement in infants,

neonates, and preterm babies. However, not all medical institutions have access to replaceable introducer sheaths, so we would encourage manufacturers to produce suitable matching products to meet the needs of clinicians.

The multivariate analysis also identified target vein depth as a factor affecting the success rate of the first puncture attempt. In particular, the odds of failure were approximately 10-fold higher in children with a target vein depth > 1.5 cm versus those with a vein depth ≤ 0.5 cm. We suggest that it is crucial to adjust the angle of the puncture needle according to the subcutaneous fat thickness and vein depth to improve the success rate of the target blood vessel puncture.

This study has some limitations. First, this was a retrospective analysis, so the findings may be prone to selection or information bias. Second, this was a single-center study, so the generalizability of the findings is not known. Third, although our study enrolled 640 patients, it may have been underpowered to detect some real differences between groups. Fourth, the success rate of PICC placement in children is affected by the experience of the nurse performing the procedure. Since the same nurse performed all PICC insertions, the success rate may have been higher during the later stage of the study period than during the early stage due to the accumulation of experience. Further research is needed to confirm our findings and investigate approaches to improving the success of the first puncture attempt.

5.1. Conclusions

In conclusion, the first-attempt success rate in children undergoing PICC insertion is associated with the degree of cooperation, target vein diameter and depth, and catheter specification. We propose that administering appropriate analgesia and sedation could improve patient cooperation. Furthermore, we suggest that using the modified Seldinger technique with a 24G indwelling needle and both cross-sectional and longitudinal ultrasound views might improve the success rate of the first puncture attempt.

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Footnotes

Authors' Contribution: M.D. contributed to the study conception and design, data acquisition and interpretation, and manuscript drafting. X.F. contributed to the study design and manuscript drafting. H.Q. critically revised the manuscript. X.F. contributed to data analysis. M.F. contributed to data interpretation. All authors read and approved the final manuscript.

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Data Reproducibility: The dataset presented in the study is available on request from the corresponding author during submission or after its publication.

Ethical Approval: The Ethics Committee of the Children's Hospital of Zhejiang University School of Medicine approved this study (approval number: 2021-IRB-285). The requirement for informed consent was waived due to the retrospective nature of this research.

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