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A retrospective observational study of real-time ultrasound-guided peripheral arterial cannulation in infants

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Abstract

Objective: To examine first attempt success and overall success of real-time ultrasound guided peripheral arterial cannulation in infants.

Study design: Retrospective review of 477 ultrasound guided peripheral arterial cannulations in infants less than 1 year of age. Procedural and patient characteristics were evaluated to better understand factors related to procedural success.

Results: Ultrasound guided peripheral arterial cannulation had a first attempt success rate of 65% and an overall success rate of 86%. Success rates significantly differed by arterial location ($p < 0.001$). First attempt success and overall success were highest in the radial artery (72%, 91%) and lowest in the posterior tibial artery (44%, 71%). Success was more likely with greater age and greater weight ($p = 0.006$, $p = 0.002$).

Conclusion: Success rates are high when using a real-time ultrasound-guided technique for peripheral arterial cannulation in infants. An infant's weight and selected artery are strong predictors of success when performing peripheral arterial cannulation. The use of procedural ultrasound may reduce unnecessary attempts and minimize procedure-related harm.

Keywords

Neonatal, infant, arterial, ultrasound, ultrasonography, NICU, cannulation, intensive care, neonate

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Introduction

Peripheral arterial cannulation is an important procedure in critically ill infants for blood sampling and hemodynamic monitoring.[1–3] Unfortunately, due to the small size of vessels in infants, success rates when using traditional techniques are low.[3–5] Peripheral arterial cannulation is commonly performed by pulse palpation and the use of anatomic landmarks to identify the appropriate location for needle insertion. Although this method has been used for many years in children, it is very frequently unsuccessful, with reported first attempt success rates ranging from 14% to 36%.[6–9] Following an unsuccessful first attempt, the procedure may become increasingly difficult due to arterial spasm and hematoma formation.[4,10]

The use of point-of-care ultrasound (POCUS) to guide invasive procedures has become more common in pediatric clinical practice. Ultrasound guidance is commonly used to aid in paracentesis, thoracentesis, pericardiocentesis, and placement of central venous catheters.[11–14] In children and adults, ultrasound guidance has improved the success rate and safety of central venous catheterization when compared to landmark techniques.[15,16] The use of ultrasound to guide central venous line placement is now the standard of care in adults and is endorsed by multiple medical societies.[17–19] Ultrasound guidance for arterial cannulation has resulted in improved success rates when compared to the traditional landmark techniques in older children and adults.[20–22] Although there is a growing body of evidence that supports the use of ultrasound guidance for arterial cannulation in a broader range of pediatric

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Table 1. Patient characteristics, median (IQR).

Characteristic	All ($n = 377$)
Gestational age at birth, weeks	36 (29–38)
Post-menstrual age at time of procedure, weeks	38 (34–41)
Weight at time of procedure, g	3190 (2370–4140)

Table 2. Patient and procedure characteristics by success, mean ± sd or *n* (%).

Characteristic	Success($n = 410$)	Unsuccessful($n = 67$)	*p*-Value
Post-menstrual age at time of procedure, weeks	38.3 ± 8.1	35.6 ± 7.2	0.006
Weight at time of procedure, g	3464.8 ± 1684.8	2753.5 ± 1451.9	0.002
Attempts	1.3 ± 0.6	2.6 ± 0.9	<0.001
Location			<0.001
Radial artery	266 (91)	27 (9)	
Dorsalis pedis artery	80 (85)	14 (15)	
Posterior tibial artery	64 (71)	26 (29)	

patients,[6–9,23] there are no publications reporting the efficacy of this technique in infants. Therefore, the objective of this study was to assess the feasibility of performing peripheral arterial cannulation under real-time ultrasound guidance and report first attempt success and overall success rates from a large cohort of critically ill infants.

Methods

This was a retrospective review of the success rates of peripheral arterial cannulation when using real-time ultrasound guidance. The primary aim of the study was to determine the first-attempt and overall success rates of ultrasound-guided peripheral arterial cannulation in critically ill infants. Secondarily, we sought to determine the effect of weight or selected artery as it pertains to success rates. The data was extracted from an existing POCUS quality improvement database for patients under 1 year of age who had a real-time ultrasound-guided peripheral arterial cannulation between January 2015 and April 2021. Demographic data including gestational age, birth weight, post-menstrual age, and weight at time of procedure were collected. Procedural data included overall success, number of attempts performed, and artery selected for cannulation. This study was conducted in a single academic, tertiary-care, urban newborn and infant intensive care unit. All ultrasound guided arterial line insertions were performed by neonatologists who had prior training and experience using POCUS. Ultrasounds were performed using a Philips CX50 (Philips, Andover, MA) or GE LOGIQ e R7 (GE, Wauwatosa, WI, USA) ultrasound machine and a L15-7io or L10-22-RS high frequency linear transducer. All cannulations were achieved using an over-the-needle technique with a 24-gauge catheter of various lengths with a short-axis ultrasound approach. The sample was summarized using simple frequencies and descriptive statistics and presented as proportions and mean ± standard deviation. The associations between procedure success rate and number of attempts with the independent variables of interest were assessed using Pearson's chi-square test for categorical variables and non-parametric Mann-Whitney *U* and Kruskal-Wallis tests for continuous variables. Nonparametric tests were used because the data did not meet assumptions to be considered normally distributed. A binary logistic regression model was used to predict procedure success adjusting for significant covariates. A *p*-value less than 0.05 was considered statistically significant for all tests. Analysis was completed using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armonk, N.Y., USA). The study was approved by the Institutional Review Board at the Children's Hospital of Philadelphia (IRB 19-016374, 2019).

Results

During the study period, a total of 477 arterial cannulations using ultrasound guidance were performed in 377 patients. Infants were diverse in gestational age, post-menstrual age, and weight at time of procedure (Table 1). The youngest infant was 23 weeks postmenstrual age and the smallest infant was 520 g. The first attempt success rate was 65%, success within two attempts was 81%, and overall success was 86%. There were no successful arterial cannulations performed when more than three attempts were made. Success rate was significantly higher with greater age and greater weight ($p = 0.006$ and $p = 0.002$, respectively) (Table 2, Figure 1). Weight at time of procedure was not significantly different among the procedures performed in the different selected arteries ($p = 0.143$). Of the vessels selected for cannulation, 293 (61%) were radial artery, 94 (20%) were dorsalis pedis artery, and 90 (19%)

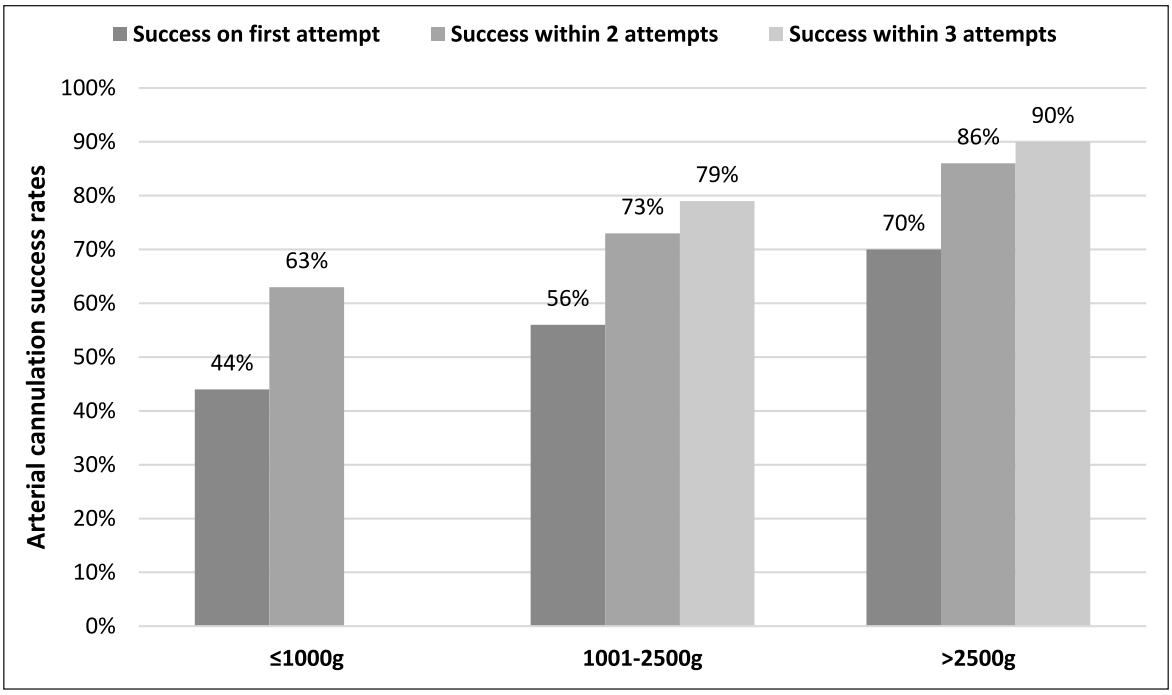

Figure 1. Cumulative success by weight.
Ultrasound-guided arterial cannulation success rates on first attempt, within two attempts, and within three attempts are shown in different weight ranges. Weight at time of procedure was significantly associated with success ($p = 0.002$).

were posterior tibial artery. Overall success rate significantly differed by location ($p < 0.001$) and was highest (91%) in the radial artery, followed by the dorsalis pedis artery (85%) and lowest in the posterior tibial artery (71%) (Tables 2 and 3, Figure 2). For successful procedures, the average number of attempts was 1.3 ± 0.6 and for unsuccessful procedures, the average number of attempts was 2.6 ± 0.9 ($p < 0.001$).

A binary logistic regression model was created to predict procedure success. Age and weight were strongly correlated (Spearman's rho = 0.591, $p < 0.001$) and therefore age was not included in the final model. No multicollinearity was detected for the final model.

The model indicates that weight and vessel location are significant predictors of procedure success (Chi-Square = 3.004, df = 3, and $p < 0.001$). These two predictors explain 11% of the variability of success. An increase in weight was associated with an increase in likelihood of success (OR = 1.0003, 95% CI (1.0001, 1.0005), $p = 0.003$). When compared to the radial artery, the posterior tibial artery location was associated with a decrease in likelihood of success (OR = 0.265, 95% CI (0.144, 0.489), $p < 0.001$), while the dorsalis pedis artery showed no significant difference ($p = 0.11$) (Table 4). The model correctly predicted 86% of successes.

Discussion

In situations where critically ill infants are too old for umbilical arterial access or attempts at this access are unsuccessful, peripheral arterial cannulation is often required to facilitate monitoring of real-time blood pressure and allow for frequent laboratory evaluation. Site selection depends on several patient factors, including age, size, perfusion, anatomy, vessel patency, and history of arterial access. Unfortunately, traditional approaches to this procedure often result in failure. The reasons for potential failure are numerous and may include provider training level, small size of patient vessels, cardiovascular instability, and prior arterial access attempts and hematoma formation. The use of ultrasound as an adjunct tool allows providers to overcome many of these challenges through visualization of a selected vessel and measurements of both diameter and depth. Additionally, providers can identify unfavorable conditions such as hematoma formation from prior procedural attempts and avoid accidental intravenous catheter placement by confirming an arterial blood supply using color and pulsed wave Doppler. While obtaining ultrasound imaging of vessels is straightforward, the use of real-time ultrasound guidance to observe needle advancement into a selected vessel is technically more challenging and the education required to obtain procedural competency provides an opportunity for future research.

This study is the first to provide evidence of high success rates for peripheral arterial cannulation in infants using real-time ultrasound guidance when performed by neonatologists. Our data demonstrate feasibility in neonates over a broad range of weights including premature infants as small as 520 g. It is our belief that there is no

Table 3. Success rate by attempt, *n* (%).

	First attempt success	Second attempt success	Third attempt success	Overall success
All events (*n* = 477)	312 (65)	77 (16)	21 (4)	410 (86)
Location				
Radial artery (*n* = 293)	211 (72)	47 (16)	8 (3)	266 (91)
Dorsalis pedis artery (*n* = 94)	61 (65)	10 (11)	9 (10)	80 (85)
Posterior tibial artery (*n* = 90)	40 (44)	20 (22)	4 (3)	64 (71)
Weight at time of procedure				
⩽1000 g (*n* = 27)	12 (44)	5 (19)	*	17 (63)
1001–2500 g (*n* = 114)	64 (56)	19 (17)	7 (6)	90 (79)
⩾2500 g (*n* = 336)	236 (70)	53 (16)	14 (4)	303 (90)

*No successful third attempts at this weight range.

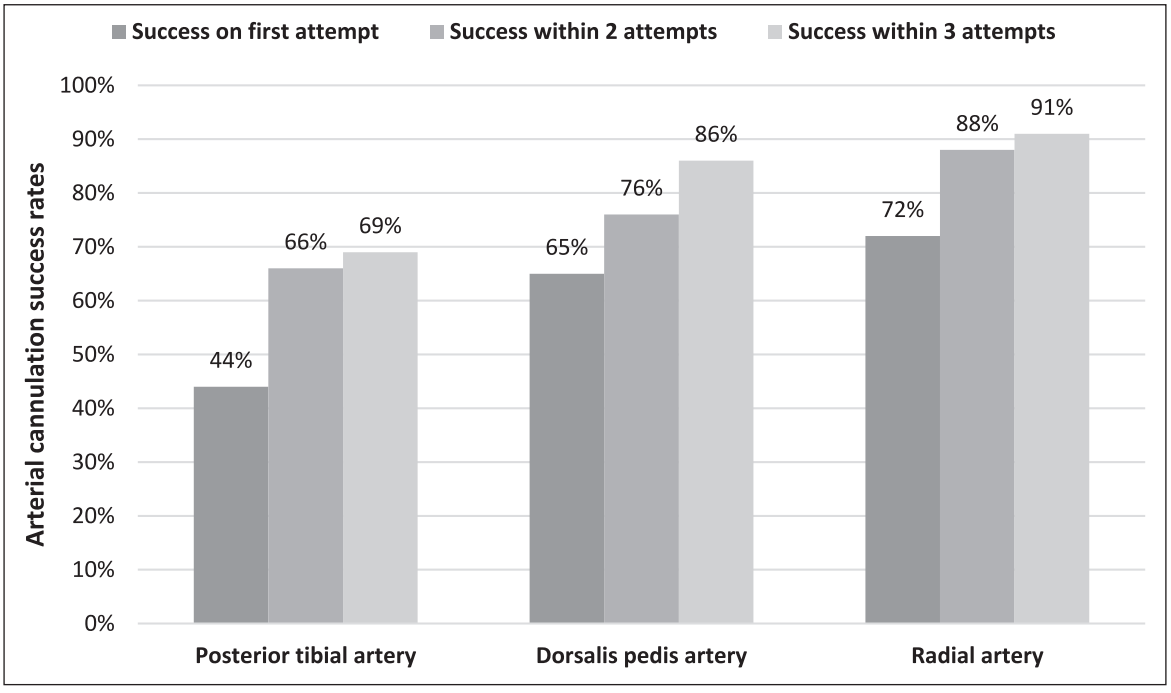

Figure 2. Cumulative success by vessel.
Ultrasound-guided arterial cannulation success rates on first attempt, within two attempts, and within three attempts are shown for selected vessels. Artery selected was significantly associated with success ($p < 0.001$).

upper or lower weight limit when performing peripheral arterial cannulation under ultrasound-guidance, however, probe selection and depth of field for a given ultrasound machine are important factors in image optimization and visualization of vessels.

Although sonographic windows can be excellent and may facilitate success in tiny premature infants, vessel size increases with increasing weight and post-menstrual age. This increase in vessel size may explain the data we observed of increased success rates as patients were older and weighed more at the time of procedure. Using a binary logistic regression model our data showed that an increase in 1 g was associated with an increase in likelihood of success by a factor of 1.0003. As such, an increase in weight by 100 and 500 g results in a 3% and 16% increase in likelihood of success, respectively. Interestingly we did not find a statistically significant difference between success rates when cannulating the radial artery and the dorsalis pedis artery. While the radial artery is often chosen as the first sight for evaluation and access attempts due to its familiarity among neonatologists, our data suggests that the dorsalis pedis artery may be a reasonable next choice and that the posterior tibial artery should be viewed as a last resort if no other suitable location is identified.

Although this is the only study describing the use of real-time ultrasound guidance to perform peripheral arterial cannulation in neonatal patients by neonatologists, there are limitations of this study. This cohort was limited

Table 4. Logistic regression predicting procedure success.

Characteristic	Univariate OR (95% CI)	Multivariate OR (95% CI)	Multivariate *p*-value
Weight	1.0003 (1.0001, 1.0005)	1.0003 (1.0001, 1.0005)	0.003
Radial artery	Ref	Ref	
Dorsalis pedis artery	0.58 (0.29, 1.16)	0.565 (0.28, 1.14)	0.11
Posterior tibial artery	0.25 (0.14, 0.46)	0.265 (0.144, 0.49)	<0.001

to a single center where all arterial cannulations were performed by neonatologists with experience in ultrasound-guided vascular access, using an over-the-needle technique. Thus, these success rates may not be generalizable to novice sonographers or to intensive care units that employ a Seldinger technique by performing arterial cannulation over a guidewire. Additionally, success rates may be dependent upon several additional factors such as quality of ultrasound equipment, patient illness severity, and patient history of vascular access. Lastly, this was a cohort of convenience and the retrospective design of this study may not have captured all patients in the study period. In addition, the observed correlation between success and body weight as well as success and chosen artery would need to be confirmed in a prospective study. An ideal approach to confirm the observed benefit of ultrasound-guidance would be to prospectively randomize neonates to a traditional peripheral arterial cannulation or a real-time ultrasound-guided peripheral arterial cannulation with matching by the experience of the proceduralist.

Conclusion

POCUS has become a powerful tool for improving procedural success, provider's performance, and patient safety. When trained neonatologists perform ultrasound-guided peripheral arterial cannulation, both first attempt and overall success rates are high. An infant's weight and selected vessel were strong predictors of procedural success. The use of procedural ultrasound may reduce unnecessary attempts and minimize procedure-related harm in critically ill infants. These findings support the routine use of ultrasound guidance for peripheral arterial cannulation and encourage the growing trend in training neonatal providers in the use of basic ultrasound. Research to determine the process of optimal ultrasound training and applied techniques is needed.

Declaration of conflicting interests

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References

1. Shiloh AL and Eisen LA. Ultrasound-guided arterial catheterization: a narrative review. *Intensive Care Med* 2010; 36: 214–221.
2. Imbrìaco G, Monesi A and Spencer TR. Preventing radial arterial catheter failure in critical care — factoring updated clinical strategies and techniques. *Anaesth Crit Care Pain Med* 2022; 41: 101096.
3. Biasucci DG, Disma NM and Pittiruti M (eds). *Vascular access in neonates and children*. Cham: Springer International Publishing, 2022.
4. Schindler E, Kowald B, Suess H, et al. Catheterization of the radial or brachial artery in neonates and infants. *Paediatr Anaesth* 2005; 15: 677–682.
5. Yildirim V, Ozal E, Cosar A, et al. Direct versus guidewire-assisted pediatric radial artery cannulation technique. *J Cardiothorac Vasc Anesth* 2006; 20: 48–50.
6. Schwemmer U, Arzet HA, Trautner H, et al. Ultrasound-guided arterial cannulation in infants improves success rate. *Eur J Anaesthesiol* 2006; 23: 476–480.
7. Ishii S, Shime N, Shibasaki M, et al. Ultrasound-guided radial artery catheterization in infants and small children. *Pediatr Crit Care Med* 2013; 14: 471–473.
8. Ueda K, Puangsuvan S, Hove MA, et al. Ultrasound visual image-guided vs Doppler auditory-assisted radial artery cannulation in infants and small children by non-expert anaesthesiologists: a randomized prospective study. *Br J Anaesth* 2013; 110: 281–286.
9. Ganesh A, Kaye R, Cahill AM, et al. Evaluation of ultrasound-guided radial artery cannulation in children. *Pediatr Crit Care Med* 2009; 10: 45–48.
10. Shiver S, Blaivas M and Lyon M. A prospective comparison of ultrasound-guided and blindly placed radial arterial catheters. *Acad Emerg Med* 2006; 13: 1275–1279.
11. Diacon AH, Brutsche MH and Solèr M. Accuracy of pleural puncture sites: a prospective comparison of clinical examination with ultrasound. *Chest* 2003; 123: 436–441.
12. Sekiguchi H, Suzuki J and Daniels CE. Making paracentesis safer: a proposal for the use of bedside abdominal and vascular ultrasonography to prevent a fatal complication. *Chest* 2013; 143: 1136–1139.
13. Moore CL. Ultrasound first, second, and last for vascular access. *J Ultrasound Med* 2014; 33: 1135–1142.
14. Fraga MV, Stoller JZ, Glau CL, et al. Seeing is believing: ultrasound in pediatric procedural performance. *Pediatrics* 2019; 144: e20191401.

15. Rando K, Castelli J, Pratt JP, et al. Ultrasound-guided internal jugular vein catheterization: a randomized controlled trial. *Heart Lung Vessel* 2014; 6: 13–23.
16. de Souza TH, Brandão MB, Nadal JAH, et al. Ultrasound guidance for pediatric central venous catheterization: a meta-analysis. *Pediatrics* 2018; 142: e20181719.
17. Lamperti M, Biasucci DG, Disma N, et al. European Society of Anaesthesiology guidelines on peri-operative use of ultrasound-guided for vascular access (PERSEUS vascular access). *Eur J Anaesthesiol* 2020; 37: 344–376.
18. Franco-Sadud R, Schnobrich D, Mathews BK, et al. Recommendations on the use of ultrasound guidance for central and peripheral vascular access in adults: a position statement of the society of hospital medicine. *J Hosp Med* 2019; 14: E1–E22.
19. Ultrasound guidelines: emergency, point-of-care and clinical ultrasound guidelines in medicine. *Ann Emerg Med* 2017; 69: e27–e54.
20. Gu W-J, Wu X-D, Wang F, et al. Ultrasound guidance facilitates radial artery catheterization: a meta-analysis with trial sequential analysis of randomized controlled trials. *Chest* 2016; 149: 166–179.
21. Bhattacharjee S, Maitra S and Baidya DK. Comparison between ultrasound guided technique and digital palpation technique for radial artery cannulation in adult patients: an updated meta-analysis of randomized controlled trials. *J Clin Anesth* 2018; 47: 54–59.
22. Moussa Pacha H, Alahdab F, Al-Khadra Y, et al. Ultrasound-guided versus palpation-guided radial artery catheterization in adult population: a systematic review and meta-analysis of randomized controlled trials. *Am Heart J* 2018; 204: 1–8.
23. Anantasit N, Cheeptinnakorntaworn P, Khositseth A, et al. Ultrasound versus traditional palpation to guide radial artery cannulation in critically ill children: a randomized trial. *J Ultrasound Med* 2017; 36: 2495–2501.