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Ultrasound assessment of peripheral intravenous catheters by nurses in the pediatric intensive care unit

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Abstract

Objective: Establish the feasibility of pediatric intensive care unit (PICU) nurse-directed ultrasound assessment (UA) of peripheral intravenous (PIV) catheters, compare the results of UA to traditional assessment (TA), and determine PIV survival after UA.

Design: Prospective observational cohort study.

Setting: PICU within a children's hospital.

Patients: PICU patients with a PIV.

Interventions: None.

Measurements and main results: Eight nurses performed UA on 131 PIVs in 85 patients. Median age was 3.0 years (IQR 1.0–13.8) and median weight was 15.0 kg (IQR 9.6–59.3). The most common PIV location was the arm (43%) and extravasation occurred in 15% of PIVs. Agreement between TA and UA was moderate with a Kappa of 0.47 (95% CI 0.28–0.66). Nursing confidence in the UA was significantly higher than TA (92% vs 21% very confident, $p < 0.0001$). In 106 PIVs with a UA that indicated the PIV was intravascular (i.e. negative UA), the median survival was 50.0 h (IQR 21.8–100.3).

Conclusions: Nurses can perform UA of PIV status in PICU patients and express greater confidence in the findings of UA than TA. Further study is necessary to determine the impact of UA on the rate of PIV complications.

Keywords

Critical care, catheters, pediatrics, ultrasonography, veins

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Introduction

Peripheral intravenous (PIV) catheters allow for the provision of life-saving medications and are commonly utilized for patients admitted to the pediatric intensive care unit (PICU). PIVs are at risk for failure and complications including extravasation with local tissue injury, especially in critically ill children.[1–4] While most PIV complications are mild, severe extravasations can lead to significant morbidity including compartment syndrome.[5,6] To minimize the risk of complications, PIVs must be assessed routinely to determine whether they remain intravascular. Implementation of hourly PIV assessment by nurses decreased the rate of extravasation at one pediatric hospital.[7] The "Touch, Look, Compare" approach remains best practice for PIV assessment but is subjective and labor intensive. Unnecessary removal of PIVs may lead to delays in therapy and need for additional painful procedures, including central line placement if peripheral access is difficult.[8,9]

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More reliable PIV assessment techniques may decrease the rate of PIV complications and unnecessary PIV replacement. Ultrasound (US) has been utilized to evaluate the location of central lines through direct visualization of the catheter tip or appearance of spontaneous contrast after saline flush.[10–12] A similar technique has been demonstrated for PIV assessment in children using both color flow doppler (CFD) and spontaneous contrast.[13,14] In these studies, ultrasound assessment (UA) of PIVs performed by physicians had a sensitivity and specificity of 100% for determining if a PIV remained intravascular. In the PICU, nurses routinely perform PIV assessment, but training and utilization of US by nurses remains uncommon. Recent studies have shown that nurses with minimal US experience can learn the skills necessary for US-guided PIV placement, a skill closely related to UA of PIV status.[15,16]

The purpose of this study was to demonstrate the feasibility of PICU nurse-directed UA of PIV status and compare the results of UA to traditional assessment (TA).

Materials and methods

We conducted a prospective observational cohort study in the PICU at Children's Hospital Colorado between October 2019 and April 2020. The study was approved by the Colorado Multiple Institution Review Board with a waiver of written consent.

Nurse training

PICU nurses who regularly perform PIV placement and assessment were recruited to participate. None of the nurses had any previous experience using US. Training included an independent pre-work module on US guided PIV placement that had been previously developed, followed by a 1-h hands on session led by one of the authors highly experienced in bedside US (RG) with demonstration of UA of a PIV including both CFD and spontaneous contrast techniques.[13–15] Findings of UA indicate whether or not flow between the PIV and the vein visualized by US is continuous. Steps of UA included: (1) identification of a vein proximal to the PIV site, (2) flushing 5–10 cc of normal saline through the PIV. The CFD box was centered over the vein of interest and US probe angled to not be perpendicular to the vein trajectory. Either proximal or central veins could be used for UA depending ease of identification. Nurses demonstrated the ability to perform UA of a PIV on a healthy volunteer with observation and confirmation of accuracy by expert observation prior to participation in the study. Nurses were also encouraged to perform their first 5 UA under expert supervision, though this was not mandated due to limitations of availability, especially during night shift. Nurses in the study received regular education on TA of PIV status as part of their normal clinical training.[7] Nurses were also certified to perform US-guided PIV placement by completing the training.

Patient selection

After training, nurses recruited a convenience sample of PICU patients with a PIV. Routine PIV assessment is performed hourly at our institution according to the "Touch, Look, Compare" protocol.[7] Patients with multiple different PIVs that underwent UA were included in the study but for repeat UA of the same PIV, only the first UA was included. Patients under 1 month of age are not routinely admitted to the PICU at our institution.

Study protocol

Nurses first performed TA of the PIV which included (1) ability to flush, (2) ability to aspirate, (3) presence of swelling, (4) comparison to the contralateral side. The presence or absence of each component of the TA was recorded and used to make a determination of PIV status. The TA was considered negative if the nurse concluded that the PIV was intravascular based on the above 4 criteria. The TA was considered positive if the nurse concluded that the PIV was not intravascular.

Next, UA was performed with a GE Venue US (General Electric Company, Waukesha, WI, USA) and GE L12n-SC linear probe with a frequency range of 8.0–13.0 MHz. Venous access settings were preset for a depth of 3.0 cm and Doppler velocity scale of 2.0 kHz. Nurses could perform CFD, spontaneous contrast, or both techniques throughout the study period. The UA was considered negative if CFD or spontaneous contrast were visualized in the proximal vein and positive if CFD or spontaneous contrast were not visualized (Figure 1).

After assessment, nurses recorded patient and PIV characteristics, findings of TA and UA and their confidence with each assessment in REDCap.[17] PIVs were removed as determined by nurses who were not blinded to the results of the UA. UA images were not routinely stored for quality assurance purposes though selected images saved by nurses underwent review by the lead investigator. Standard PIV catheter length at our institution is 25 mm, but some PIVs in the study may been placed at outside facilities with different catheter lengths.

Statistical analysis

Data were summarized using descriptive statistics. Concordance between TA and UA findings was calculated using Cohen's kappa. Nursing confidence in TA and UA findings was compared using a Fisher's exact test. A p-value <0.05 was considered statistically significant. Kaplan–Meier survival analysis was performed for PIV survival from time of placement and time of UA.

Results

Eight nurses performed a UA on 131 PIVs in 85 patients. The median number of UA performed by each nurse was

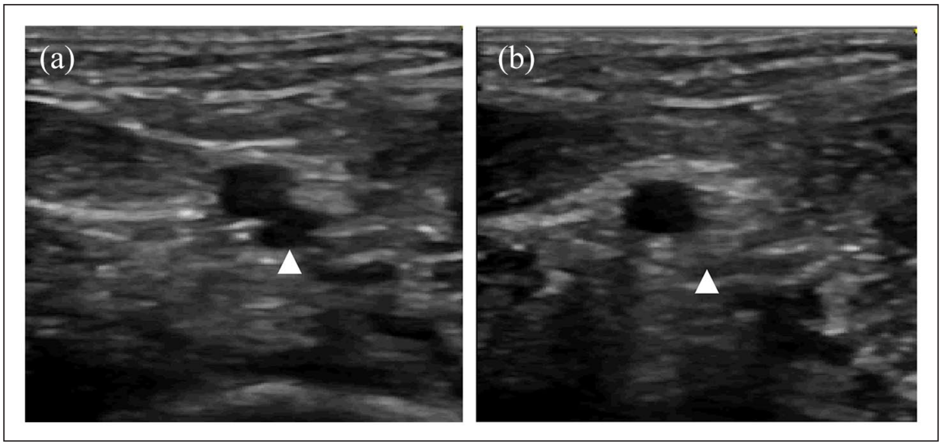

Figure 1. Representative image of a negative ultrasound assessment of a PIV performed by nursing during the study: (a) before normal saline flush and (b) during normal saline flush; white arrow: vein proximal to PIV.

10 (IQR 4.5–17). The median patient age was 3.0 years (IQR 1.0–13.8) and median weight was 15.0 kg (IQR 9.6–59.3). Most patients (60.0%) had a primary respiratory diagnosis with 40/85 (47%) on mechanical ventilation and 33/85 (39%) on sedation infusions. PIV characteristics are summarized in Table 1. Median total PIV survival was 77.6 h (IQR 38.7–140.4) after placement.

UA and TA agreed in 83% of assessments, and concordance was moderate with a Kappa of 0.47 (95% CI 0.28–0.66; Table 2). Nursing confidence in the UA was significantly higher than TA (92% vs 21% very confident, $p < 0.0001$) and remained high throughout the study period with no notable change over time. Nursing confidence was lower (0% very confident) in a small subset of seven patients with a negative UA and survival <3 h from UA.

All PIVs with a positive UA ($n = 25$) were removed within 1 h of UA. In 106 PIVs with a negative UA, the median survival was 50.0 h (IQR 21.8–100.3) and 11 were removed for leaking, occlusion or infiltration within 24 h. Among this subgroup, TA was negative in 10 and positive in only 1. For PIVs with negative UA and negative TA, median PIV survival was 51.0 h (IQR 21.8–102.0, $n = 94$). For PIVs with negative UA and positive TA, median survival was 34.2 h (IQR 5.5–80.0, $n = 12$) after UA (Figure 2).

Discussion

In this study, we present the first attempt at implementing UA of PIV status by nurses in the PICU as a potential alternative to traditional PIV assessment methods. We found that nurses rapidly gained confidence in the UA technique and that few PIVs failed in the hours immediately after UA findings supported intravascular location of the PIV. Previous work demonstrated similar findings among nurses trained in US guided PIV placement, which is a more challenging skill than UA.[15,18] Despite most nurses in our study performing UA relatively infrequently during the study period, confidence in the findings of UA were higher than for TA. Increased confidence in UA likely reflects the more objective nature of UA compared to TA but is surprising since nurses had minimal US experience before the study.

Any technique for PIV assessment must be feasible for nurses to perform given the number of patients who require PIVs and the frequency of PIV assessment.[4,7] Nurses in our study were able to perform UA in a wide variety of patients, including small children who were not sedated. UA using the CFD was previously performed on anesthetized children but interpretation of CFD is difficult or impossible in a moving subject.[14] Including the option of a spontaneous contrast technique that did not require CFD allowed nurses in our study to perform UA on awake, moving children, thus increasing the potential practical application of UA to settings outside of the PICU. Importantly, nurses in our study performed UA in many patients in the 1–3 year old age group despite the fact that given their developmental stage, these patients are unlikely to cooperate with any PIV assessment technique.

Gautam et al.[14] first described the use of UA for PIV status using CFD in anesthetized children in the operating room. Shortly after, Takeshita et al.[13] described the use of a spontaneous contrast technique of UA among PICU patients. In both studies, physicians with experience in US performed the UA, and the test characteristics reported were excellent, with 100% sensitivity and specificity for determination of PIV location for each technique. However, the remarkable performance of UA in these studies should be interpreted with caution as the follow-up time was short, and both relied on subjective criteria of PIV failure as a “gold standard.” Similar to these studies, we found moderately strong concordance between UA and TA, though we did not calculate test characteristics given the lack of blinding to UA results in our study.

Table 1. Peripheral intravenous catheter characteristics.

Characteristic	Peripheral intravenous catheters (*N* = 131)
PIV location, *n* (%)	
Arm	56 (42.7)
Hand	44 (33.6)
Foot	26 (19.8)
Other	5 (3.8)
PIV laterality, *n* (%)	
Right	77 (58.8)
Left	54 (41.2)
PIV gauge, *n* (%)	
24	17 (13.0)
22	84 (64.1)
20	27 (20.6)
18	3 (2.3)
Reason for UA, *n* (%)	
Bedside RN concern	76 (58.0)
Routine PIV check	30 (22.9)
Post PIV placement	25 (19.1)
Location UA performed, *n* (%)	
Axilla	40 (30.5)
Upper arm	31 (23.7)
Forearm	16 (12.2)
Antecubital fossa	13 (9.9)
Lower leg	17 (13.0)
Groin	9 (6.9)
Other	5 (3.8)
Reason for PIV removal, *n* (%)	
Leaking	32 (24.4)
No clinical need/ planned removal	27 (20.6)
Extravasated/infiltrated	19 (14.5)
Occluded	13 (9.9)
Phlebitis	7 (5.3)
Other	16 (12.2)
Not documented	11 (8.4)

PIV: peripheral intravenous catheter; UA: ultrasound assessment; RN: registered nurse; IQR: interquartile range.

Table 2. Concordance of ultrasound and traditional assessment.

	Traditional assessment	
	Negative	Positive
Ultrasound assessment		
Negative	94	12
Positive	10	15

The overall PIV longevity of just over 3 days in our study was similar to previous studies.[2,3,19] After negative UA, average PIV survival was over 2 days and few PIVs failed within 24 h of a negative UA, a result which supports the accuracy of nursing interpretation of the UA findings. The rate of extravasation in our study was higher than recently reported but PICU patients are likely at higher risk for PIV complications due to their severity of illness and need for frequent medication administration.[7,20] Decreasing the rate of extravasation by removing PIVs not deemed intravascular by TA must be balanced against unnecessary PIV removal. Interestingly, we found that PIVs that would have been removed using TA survived for a median of 34 additional hours and as long as 3 days if the UA was positive. Though this subset of PIVs was small, these results suggest a potential benefit of UA in reducing unnecessary PIV removal that merits further study.

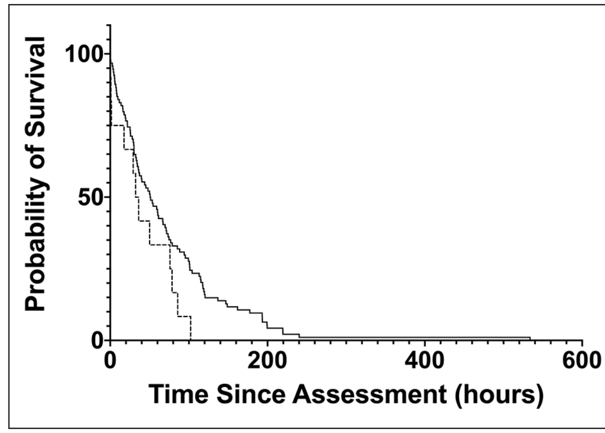

Figure 2. Kaplan-Meier peripheral intravenous catheter survival curves from the time of ultrasound assessment. Solid line: traditional assessment and ultrasound assessment negative ($n = 94$). Dashed line: traditional assessment positive and ultrasound assessment negative ($n = 12$).

Our study has several limitations. It was performed at a single center with a convenience sample of patients which limits generalizability. Training in UA did not include a formalized credentialed program to ensure continued nurse accuracy with UA in a clinical environment. Nurses in our study were not blinded to UA findings when determining PIV status which impacted the longevity of PIVs in our study. Only one nurse performed each UA, so we could not determine inter-rater reliability, and nurse studies were not routinely saved or reviewed for quality assurance. Few neonates were included in the study which limits evidence for the feasibility of UA in that age group. Finally, PIV removal indications were not independently verified by study personnel so the rate of extravasation may be under-reported.

Conclusions

Nurses express greater confidence in the findings of UA than TA when assessing PIV status in PICU patients, and correlation of UA and TA is moderately good. Further study is necessary to determine the impact of UA on complications of PIV failure.

Declaration of conflicting interests

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Ethical approval

The study was approved by the Colorado Multiple Institution Review Board (Protocol Number 19-2068).

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