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Original Contribution

Ultrasound-guidance vs. standard technique in difficult vascular access patients by ED technicians☆

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Abstract

Purpose: We evaluated the efficacy and safety of emergency department technicians' (EDT) use of ultrasound (US) guided peripheral intravenous (PIV) access compared to the traditional approach on a subset of patients with difficult IV access.

Methods: We enrolled a convenience sample of 75 ED patients with difficult IV access (at least 2 failed PIV attempts). During phase I, EDTs used the standard technique. EDTs then attended a didactic session on ultrasound guided PIV access of the upper extremity. In phase II, the EDTs used US guidance for PIV access. Outcome measures were successful PIV cannulation by an EDT, time to cannulation, medical doctor (MD) or registered nurseRN intervention, complications, patient satisfaction, and number of skin punctures.

Results: Successful cannulation rates were similar (US: 33/41, 80.5%; traditional technique: 24/34, 70.6%) (difference: 9.9%; 95% confidence interval (CI): -9.3%, 29.1%). US was 2.0 times faster (CI 1.3, 3.1), required less MD/RN intervention (7.3% vs. 20.6%) (difference: 13.3%; CI: -2.5, 30.2%), had fewer complications (41.5% vs. 64.7%, difference: 23.3%; CI 0.6%, 42.7%) and skin punctures (1.6 vs. 3.6; difference: 2.0; CI: 1.6, 2.7), and improved patient satisfaction from 4.4 to 7.7 cm (*P*-value = .0001).

Conclusions: Following a brief US training for PIV access, EDTs showed similar success rates but US had significantly improved speed and patient satisfaction with fewer skin punctures and complications.
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1. Introduction

Peripheral intravenous (PIV) access is a common procedure in the emergency department (ED). Traditionally, patients with difficult PIV access have been subjected to repeated attempts by multiple practitioners, external jugular vein cannulation or central line placement. Subsequently, these patients often experience delays in diagnosis and treatment. Ultrasound (US)-guidance for central venous access has been well documented to increase success and decrease complications [1-5]. Physician performed US-guided PIV access has been shown to increase successful cannulation and patient satisfaction and decreases time to

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cannulation and number of skin punctures [6]. Additionally, Brannam et al. demonstrated that ED nurses can be trained to use US-guided PIV access with high success rates and few complications [7]. In many EDs, PIV access is performed by ED technicians (EDT), however, the efficacy and safety of EDTs use of US-guided PIV access is unknown. EDTs trained in US-guided PIV access may speed diagnosis and treatment while freeing physicians and nurses for different patient care tasks. We evaluated the efficacy (success, time, number of skin punctures), safety and patient satisfaction of US-guided PIV access by EDTs in patients with difficult PIV access compared to the traditional technique of palpation and landmark identification.

2. Methods

2.1. Patients

Our facility is a 350 bed urban, university teaching hospital and regional trauma center with an annual census of over 70,000 emergency patient visits and supports an ACGME accredited Emergency Medicine residency program.

2.2. Design

We enrolled a convenience sample of ED patients with difficult vascular access in a two-phase prospective systematically allocated non-blinded cohort study from September 2006 to January 2007. The Institutional Review Board provided expedited review and approved the study.

Experienced EDTs (EMT-Paramedic or EMT-Intermediate with at least 1 year experience in the ED) were recruited to participate in the study. Informed consent was obtained from all study EDTs, per IRB request. No study EDTs had prior experience with US-guided PIV access. Patients with at least two failed traditional PIV attempts were screened for inclusion and exclusion criteria and enrolled by study EDTs when they were on duty. The inclusion criterion was difficult-to-obtain PIV access, defined as two failed traditional palpation and landmark attempts, defined as skin puncture with inability to draw 5ml of blood or extravasation of initial infusion. We excluded patients if they needed central line access (defined by treating physician), were less than age 18 years old, did not speak English, were incarcerated or were critically ill (defined as patients requiring the resuscitation suite). EDTs obtained informed consent from all subjects.

In phase I (weeks 1-7), after subjects met the definition of difficult PIV access, 2 failed traditional attempt, and were enrolled by study EDTs, data were collected on the course of acquiring their PIV access using the standard practice. Standard practice for PIV access at our facility is loosely hierarchical and consists of initial EDT use of traditional palpation and landmark technique (sometimes by multiple EDTs). If unsuccessful EDTs may use external jugular (EJ) vein cannulation with physician order or enlist RNs to use traditional technique, including EJ cannulation, and finally physician intervention including EJ, US-guided PIV access and central venous cannulation. All study EDTs then attended a one-hour didactic sessions on upper extremity transverse view single operator technique ultrasonography emphasizing confirmation of the needle tip in transverse view by fanning off the end of the needle and visualization of the needle tip deforming the target vessel prior to cannulation (see Fig. 1). The didactic included: basic ultrasound image acquisition, still images and hands on practice with a vascular access model (a phantom). In phase II (weeks 8-14), trained EDTs used a 5–10 MHz linear probe from either a Sonosite (Seattle, WA) Micromax or Titan model grey-scale ultrasonographic machine for US-guided PIV access in subjects with difficult vascular access and recorded data for comparison.

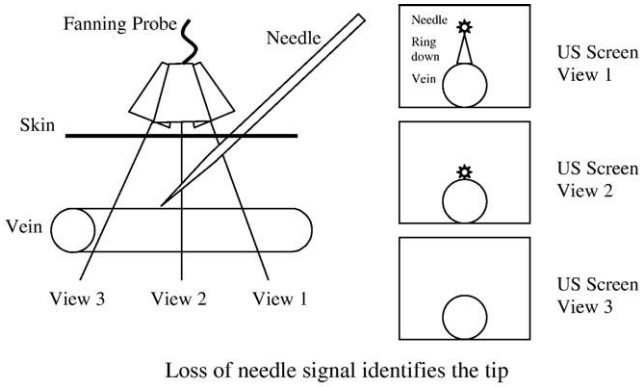

Fig. 1 Fanning technique for needle tip identification.

A one person transverse view technique was used during the US-guided phase as previous studies have shown no difference in success between the one and two person techniques [8,9] and the transverse view has been demonstrated to be superior to the longitudinal view in the novice user [10]. We used a semi-sterile technique (non-sterile probe) for US-guided cannulation, which was equivalent to standard PIV insertion. An 18 gauge 2.5 inch angiocath (B Braun Medical, Bethlehem, PA) was used for all basillic and brachial vein cannulations. No limitations were placed on needle selection for other sites.

2.3. Data collection and processing

Successful venous cannulation was defined as withdrawal of 5 ml non-pulsatile blood or infusion of 5 ml of saline without evidence of extravasation. Failure of EDT PIV access was defined as extravasation with initial infusion, inability to draw 5 ml of blood, physician or nurse intervention for access or EDT's inability to obtain access. Failure criterion for phase II also included three US-guided attempts without success. No limits were placed on the number of traditional attempts by EDTs as this reflects our standard practice. Time was recorded in minutes in real time by the EDTs with time zero during phase I defined as the first skin puncture after enrollment in the study. During phase II, time zero was chosen as the time the US probe first touched

the patient's skin as availability and proximity of US machines varies by department. The end time was marked by success or when failure criteria were met. We also recorded the level of training (EDT, nurse, physician) of the individual ultimately obtaining successful cannulation.

Complications were defined as hematoma and arterial puncture. EDTs were also able to record additional complications using free text. EDTs were instructed to report any complications other than hematoma to the attending physician on duty and to the investigator. Patient satisfaction was recorded by the subject as a mark on a 100 mm visual analog scale, anchored at zero by "very unsatisfied" and 100 by "very satisfied," after the EDT asked "How satisfied are you with the procedure?" Skin punctures were counted after enrollment and excluded the initial two failed attempts required for enrollment until success or failure was met. Demographic data and the reasons for difficult vascular access, as assessed by the EDT, were recorded. We predefined reasons for difficult access and included: obesity, injection drug use, end stage renal disease, chronic disease and other. EDTs were allowed to offer free text.

We conservatively estimated a 50% success rate via the traditional technique in difficult access patients based on previous studies [6,11] demonstrating a 33-46% success. We also estimated a 90% success rate with US-guidance based on previous studies [6,7,12] with 87-92% success. We calculated a sample size of 15 subjects in each arm to achieve 80% power with 95% confidence intervals. To permit subset analyses, we doubled this number and planned to enroll about 30 subjects per arm.

EDTs participating in the study recorded data on a preprinted data collection forms in real time. The raw data were then entered into Microsoft Excel (Microsoft Corporation, Redmond, WA) with double entry verification and imported into S-Plus Version 6.2 (Insightful Corporation, Seattle, WA) for analysis.

2.4. Data analysis

Successful PIV cannulation, need for physician or nurse intervention and presence of any complication are presented as proportions within each phase. Statistical significance was assessed using 95% confidence intervals about the difference between the two phases using the Newcombe-Wilson Hybrid Score [13]. Time, patient satisfaction, and number of punctures were summarized using mean, median and interquartile range measures. For time and puncture data, we used the natural logarithmic function to transform the data to improve normality and to stabilize variance. Unpaired t-tests were used to compare the two phases. Due to the logarithmic transformation, the difference in transformed values represented the ratio of means after back transformation. Thus, the presented values represent the relative difference of traditional and US-guided data. For satisfaction data, no suitable transformation produced adequate normally distributed data for analysis, thus a Wilcoxon Rank-Sum test was performed for tests of statistical significance, using a two tailed Type I error rate of 5%.

3. Results

We enrolled 75 subjects during the study period, 34 in phase I and 41 in phase II (Table 1). There were fewer injection drug users in phase I (12%) than phase II (24%) and more unspecified reasons for difficult vascular access in phase I (32%) compared to phase II (17%).

3.1. Success rates

Using the traditional technique, EDTs successfully cannulated 24 of 34 subjects (70.6%) while EDTs using US-guidance successfully cannulated 33 of 41 subjects (80.5%) (Table 2). Success rates did not significantly differ (difference: 9.9%, 95% confidence interval (CI): -9.3%, 29.1%). However, in a post hoc analysis using greater than three skin punctures as the failure criterion for both arms, US-guidance was significantly more successful (80.5%) compared to the traditional technique (44.1%, 15/34) (difference: 33.4%; CI: 14.5%, 54.2%). Most US-guided PIVs were placed in the brachial (48%) or basilic (26%) vein while most traditional technique cannulations were placed in forearm (33%), hand (29%) or antecubital fossa (25%) veins.

3.2. Time to cannulation, skin punctures and satisfaction

US-guidance was 2.0 times faster (CI: 1.3, 3.1), requiring significantly less time for vascular access compared to the

Table 1 Subject characteristics and reason for difficult access, by group

	Traditional		US-Guided	
Number of subjects	34		41	
Gender				
Male	12	35.3%	9	22.0%
Female	22	64.7%	32	78.0%
Missing	–		–	
Age				
Mean (SD)	45.9	13.5	48.2	12.6
Median	46		51	
IQR	35 – 54		39 – 57	
Missing	–		–	
Reason for difficulty				
Obesity	10	29.4%	10	24.4%
Injection Drug Use	4	11.8%	10	24.4%
ESRD	3	8.8%	5	12.2%
Other chronic disease	6	17.6%	9	22.0%
Unspecified	11	32.4%	7	17.1%

Abbreviations: SD, standard deviation; IQR, interquartile range.

Table 2 Primary and secondary outcomes, by group

	Traditional		US-Guided		Difference	95% CI	
Number of subjects	34		41				
Successful IV Start							
Yes	24	70.6%	33	80.5%	9.9%	-9.3%	29.1%
No	10	29.4%	8	19.5%			
Number of skin punctures							
Mean (SD)	3.6	2.2	1.6	0.7	2.0	1.6	2.7*
Median	3		1				
IQR	2 – 5		1 – 2				
Missing		0.0%		0.0%			
Time to completion (minutes)							
Mean (SD)	74.8	76.0	26.8	19.8	2.0	1.3	3.1*
Median	45		20				
IQR	21.3 – 95		15 – 30				
Missing		0.0%	1	2.4%			
Satisfaction (mm)							
Mean (SD)	44	36	79	24			
Median	33		91				
IQR	12 – 80		67 – 98				
Additional professional							
Nursing	3	8.8%	3	7.3%			
Physician	4	11.8%	–				
Any	7	20.6%	3	7.3%	–13.3%	–30.2%	2.6%
Complications							
None	12	35.3%	24	58.5%	23.2%	0.6%	42.7%
Hematoma	22	64.7%	12	29.3%			
Arterial puncture	–		4	9.8%			
Nerve pain	–		1	2.4%			

Abbreviations: IV, intravenous; SD, standard deviation; IQR, interquartile range.
* Differences are relative in these instances.

traditional technique (mean 74.8 vs. 26.8 minutes). There was one instance of arterial puncture for which time data were not recorded; this subject was excluded from the time calculations only.

There were twice as many skin punctures in the traditional technique group (mean 3.6) compared to the US-guided group (mean 1.6) (ratio: 2.0; CI: 1.6, 2.7).

US-guidance had higher patient satisfaction (mean: 79 mm, median: 91) compared to the traditional technique (mean: 44 mm, median: 33 mm) (*P*-value <.0001).

3.3. Physician and nurse intervention

US-guidance had fewer instances of physician and nurse intervention (7.3%) compared to the traditional technique (20.6%) but did not differ significantly (difference: 13.3%; CI: -2.6, 30.2%). In the traditional technique group there were four physician interventions and three nurse interventions. Of the three patients requiring intervention in the US-guided group, all were nurse interventions. In the traditional technique group there were three failures that did not result in physician/nurse intervention. In the US-guided group there were five failures not requiring physician/nurse intervention.

3.4. Complications

The US-guidance group had fewer complications (41.5%) compared to the traditional technique group (64.7%) (difference: 23.2%; CI: 0.6%, 42.7%). In the US-guidance group, however, there were four arterial punctures (9.8%) whereas the traditional technique group had none. None of the arterial punctures were associated with distal vascular compromise or bleeding after five minutes of compression. The most common complication was hematoma accounting for 100% of traditional group complications and 71% of US-guided complications. One US-guided subject (2.4%) experienced transient "nerve pain" without objective neurologic deficits.

4. Discussion and Limitations

PIV access is routinely required for the diagnosis and treatment of many ED patients. Patients with difficult PIV access frequently require multiple attempts by multiple providers and perhaps central venous access amounting to a significant time and resource use in the ED. US-guidance for PIV access by experienced physicians has been shown to

have a high success rate, few complications and is rapid to perform [6,11,12]. Brannam, et al. found similar results with emergency nurses using US-guidance for PIVs [7]. In many EDs, including ours, EDTs are the initial provider responsible for PIV access. Our study suggests that EDTs with no prior experience and minimal training can use US for PIV access in difficult to access patients.

Our success rate for the traditional method in difficult-to-access patients was considerably higher than previously reported data (70.6% vs. 33-46%) [6,11]. This may represent a more strict definition of failure in previous studies (such as greater than three attempts), a more difficult level of venous access amongst subjects or less skilled PIV starters compared to ours. In the post hoc analysis using greater than three skin punctures as the failure criterion for both arms, US-guidance was significantly more successful as the traditional technique success rate drops to 44%, similar to previously reported data. Our US-guided PIV success rate was comparable to previously reported data (80.5% vs. 86-92%) [6,11,12] demonstrating that EDTs are capable of using US with near equal efficacy as emergency physician sonographers.

US-guidance was twice as fast as the traditional technique. There also was a trend toward decreased physician and nurse intervention, which holds the potential to improve ED patient flow. Our emergency department is typical in that there is more patient need than resources and any improvement in throughput may improve overall care. Despite the overall improvement in time to IV access, both groups required a substantial time investment (traditional technique mean 74 minutes, US-guided mean 26 minutes). The US-guided mean is much longer than previous studies, which have reported mean times to cannulation of 2-4 minutes [6,12,14]. This delay may have been a result of EDTs inexperience with the machine, the technique or locating a suitable site for US-guided puncture as time zero began with the US probe touching the skin. The previously mentioned studies all used residents and attending EPs with considerable US experience.

US-guidance also significantly decreased number of skin punctures, which likely led to the significantly improved patient satisfaction. The study was not blinded so patients may feel use of technology in and of itself is good which may skew satisfaction date toward the US intervention. There were three instances in the traditional technique arm where high satisfaction scores were seen with failure of the traditional technique. These were observed in cases where a physician obtained "rescue" vascular access with US, possibly representing satisfaction with physician intervention.

An important advantage to the use of US-guided PIV access in difficult-to-access patients is not exposing the patient to the risks of central venous cannulation such as; pneumothorax, carotid artery puncture and deep-venous thrombosis. In our study, US-guidance was associated with decreased number of total complications; however, there were four (10%) arterial punctures in the US group compared to none in the traditional group. Previous studies found arterial puncture rates of around 2% [7,12]. Our higher incidence may be secondary to EDT inexperience. Of the arterial punctures, two were on the technician's very first attempt, and two did not directly visualize the catheter compressing the vein prior to cannulation, a key point in the technique discussed in the training. One arterial puncture occurred when the EDT incorrectly interpreted a blue Doppler signal as definitive for a vein. Another arterial puncture occurred when the EDT attempted a vein on top of artery configuration. This configuration poses a higher risk of arterial cannulation, as frequently the posterior wall of the vein is punctured, and the artery is entered. Direct proctoring of initial US-guided attempts, strict adherence to protocols for vein selection and inclusion of Doppler US in the training module could minimize the risk of arterial puncture. We also found one incident (2%) of "nerve pain" resulting in stopping the procedure. Keyes et al. found the incidence of nerve injury in 1% of patients with US-guided PIV access [12]. There was no specific follow-up mechanism in this study thus delayed complications may have been missed. Additionally, rare complications, such as phlebitis and venous thrombosis could not be assessed with this relatively small sample.

The longevity of US-guided PIV access, specifically in regards to delayed extravasation, is an unanswered question. The authors believe that catheter length and venous depth are likely the major factors in extravasation rates. As the depth of tissue prior to venous cannulation increases so does the mobility of the catheter. If the catheter is secured to the skin 2 cm superficial to the site of venous puncture there is considerable translation of the overlying tissue and thus movement of the catheter in and out of the vessel and potential for extravasation. Our study did not find any instances of extravasation, although there was no specific follow-up mechanism to detect delayed extravasation. Previous studies have found extravasation rates of 8%, at 1 hour with 1.8 or 2 inch catheter [12], and 4%, in 15 minutes using a 15 cm catheter [14], in patients after US-guided PIV placement. A longer catheter should decrease the incidence of infiltration. We chose to use 2.5 inch catheters exclusively for US-guided PIV access of the brachial and basilic veins. Sandu chose a length of less than 2.5 cm of cannula inside the vein as inadequate and in that study replaced it with a 15 cm catheter by a Seldinger technique [15]. A 2.5 inch catheter is 6.35 cm thus allowing approximately 3.5 cm of tissue prior to cannulation and still allowing "adequate" length of catheter in the vein. Limiting attempts with a 2.5 inch catheter to veins <3 cm deep may be prudent to decrease extravasation. Further study is warranted to clarify the relationship between venous depth, catheter length and US-guided PIV access longevity.

5. Conclusion

Following a brief training program, emergency department technicians, without prior ultrasound experience, can

attain peripheral intravenous access on patients with difficult intravenous access using single operator transverse view ultrasound-guidance technique with improved speed, less skin punctures and greater patients patient satisfaction than traditional techniques, though at higher risk of arterial puncture.

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