What You See (Sonographically) Is What You Get: Vein and Patient Characteristics Associated With Successful Ultrasound-guided Peripheral Intravenous Placement in Patients With Difficult Access

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Abstract

Objectives: Ultrasound (US) has been shown to facilitate peripheral intravenous (IV) placement in emergency department (ED) patients with difficult IV access (DIVA). This study sought to define patient and vein characteristics that affect successful US-guided peripheral IV placement.

Methods: This was a prospective observational study of US-guided IV placement in a convenience sample of DIVA patients in an urban, tertiary care ED. DIVA patients were defined as having any of the following: at least two failed IV attempts or a history of difficult access plus the inability to visualize or palpate any veins on physical exam. Patient characteristics (demographic information, vital signs, and medical history) were collected on enrolled patients. The relationships between patient characteristics, vein depth and diameter, US probe orientation, and successful IV placement were analyzed.

Results: A total of 169 patients were enrolled, with 236 attempts at access. Increasing vessel diameter was associated with a higher likelihood of success (odds ratio [OR] = 1.79 per 0.1-cm increase in vessel diameter, 95% confidence interval [CI] = 1.37 to 2.34). Increasing vessel depth did not affect success rates (OR = 0.96 per 0.1-cm increase of depth, 95% CI = 0.89 to 1.04) until a threshold depth of 1.6 cm, beyond which no vessels were successfully cannulated. Probe orientation and patient characteristics were unrelated to success.

Conclusions: Success was solely related to vessel characteristics detected with US and not influenced by patient characteristics or probe orientation. Successful DIVA was primarily associated with larger vessel, while vessel depth up to >1.6 cm and patient characteristics were unrelated to success. Clinically, if two vessels are identified at a depth of <1.6 cm, the larger diameter vessel, even if comparatively deeper, should yield the greatest likelihood of success.

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Peripheral intravenous (IV) access is often a vital component of emergency department (ED) patient care. In 2005 there were 115 million U.S. ED visits.[1] Many of these visits require a combination of phlebotomy, IV volume resuscitation, and administration of IV medications. Peripheral IV access is traditionally achieved by visual inspection and palpation of the target vessel. However, several commonly encountered impediments, including morbid obesity, chronic disease, IV drug abuse, and dehydration, can make traditional IV access technically challenging.[2,3] Failure to obtain peripheral IV access can cause a drain on health care provider resources, delay diagnosis and treatment, and expose the patient to risks associated with central venous access.

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Ultrasound (US) guidance has been shown to improve peripheral IV placement success rates in patients with difficult access.[2–6] US-guided peripheral IVs can be successfully placed by emergency medical providers, require less time than non–US-guided placement in patients with difficult IV access (DIVA), and are associated with higher patient satisfaction.[2–4,7] However, it is unknown how patient characteristics, US probe orientation, and the anatomic features of the vein may influence the success of US-guided peripheral IV access. This information may help guide the choice of vein, reduce the rate of unsuccessful attempts, limit time spent in obtaining access, and minimize the use of external jugular or central venous access.[2]

The primary goal of this study was to determine how vessel depth and diameter affect successful US-guided IV placement. Additionally, we sought to determine how patient characteristics and US probe orientation influence success.

METHODS

Study Design

This study was a prospective cohort study of a convenience sample of ED patients. All patients who were enrolled in the study gave consent for their participation. This study was approved by the institutional review board at the University of Pennsylvania.

Study Setting and Population

The study was conducted between December 2007 and May 2008 in a single urban tertiary care university ED with 55,000 annual visits. The study ED has a 4-year emergency medicine (EM) residency program and an US fellowship.

Patients were enrolled when one of the four study sonographers (three EM residents and one US fellow) was available. Patients were eligible for enrollment if they were 18 years or older, were able to provide informed consent, required an IV as determined by the treating team, and had DIVA. DIVA patients were defined as having either of the following: more than two failed peripheral IV attempts or a history of difficult access plus the inability to visualize or palpate any veins on physical exam. Patients requiring immediate central venous access were excluded.

Study Protocol

After consenting to the procedure, background demographic, historical, and physical examination information was recorded by the study sonographer. Study data were recorded directly onto paper forms, which were then entered into a Microsoft Access (Microsoft Corp., Redmond, WA) database.

Prior to study initiation, all study sonographers met the training requirements for emergency US as delineated in the 2001 guidelines of the American College of Emergency Physicians, including 16 hours of didactic lectures and over 150 technically adequate scans.[8] Residents were postgraduate year (PGY) 2 level or higher and had completed a 4-week rotation in emergency US during their PGY 2 year. Prior to enrolling patients, study sonographers demonstrated competence through the successful placement of at least 10 US-guided peripheral IVs. During the first week of data collection, and periodically afterward, images and data collection forms were reviewed by the director of emergency US or the emergency US fellow to ensure quality and consistency.

All IVs were placed by a study sonographer using a Sonosite Micromaxx (Sonosite Inc., Bothell, WA) with a high-frequency L38/13-6MHz linear array transducer. All catheters were 20 gauge and 48 mm long (Angiocath Autoguard, BD Medical Systems, Sandy, UT). The region of the target vein was prepped with a chlorhexidine swab. A sterile sheath was applied to the transducer. Lidocaine anesthesia was injected into the subcutaneous tissues above the target vein based on either operator preference or patient request. Once the target vessel was identified, the operator obtained a still image in transverse plane and measured depth (distance from the skin surface to the middle of the near wall of vessel) and diameter (distance from middle of near wall to middle of far wall; Figure 1). After obtaining the still image, an attempt to cannulate the vein was made using the single-operator technique in which the sonographer, holding both the transducer and the IV needle, attempted to visualize the needle pass through the tissues and enter the vein using dynamic real-time scanning. The transducer was oriented in longitudinal or transverse plane, depending on the operator's preference (Figures 2 and 3).

The primary study outcome was successful placement of an US-guided IV. This was defined as aspiration of 5 mL of blood and the placement of a working IV line. The procedure was deemed a failure after three separate sites had been attempted without success. A new site was defined as any change in vessel location. Redirection or withdrawal from the skin did not constitute a new site if the target vessel location remained the same.

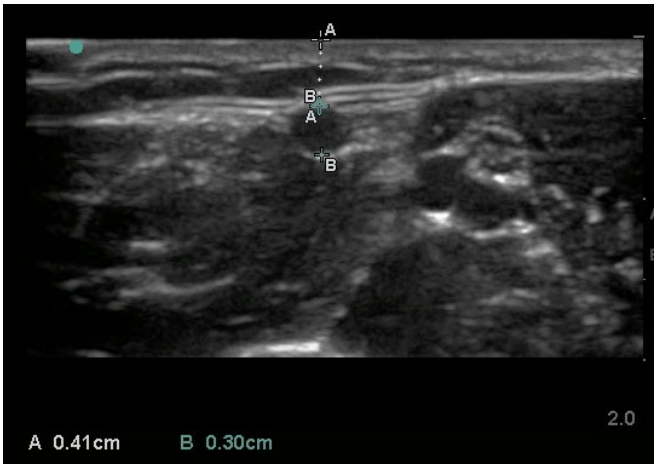

Figure 1. Still ultrasound image of a peripheral vein in transverse plane with caliper measurements. Caliper A represents vessel depth (0.41 cm). Caliper B represents vessel diameter (0.30 cm).

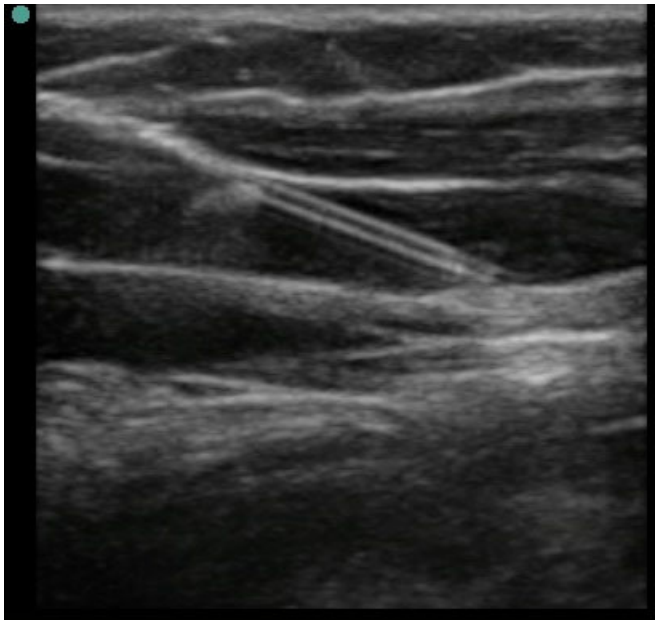

Figure 2. Still ultrasound image of a peripheral vein in longitudinal plane with an IV catheter within the lumen of the vessel.

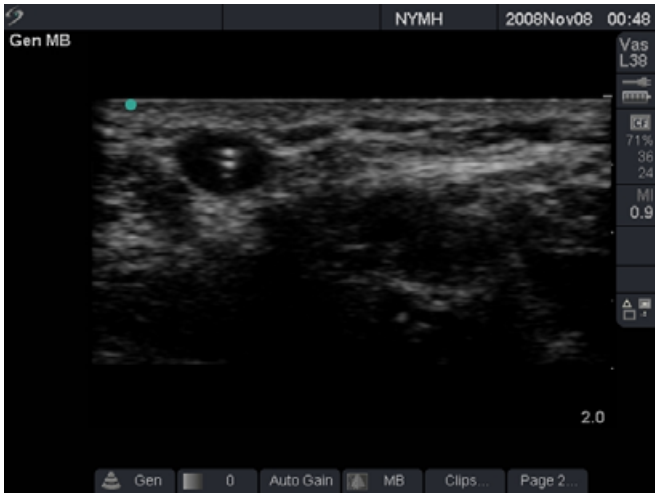

Figure 3. Still ultrasound image of a peripheral vein in transverse plane with an IV catheter within the lumen of the vessel.

Data Analysis

The outcomes of the study were analyzed with respect to patient characteristics, vein parameters, and a combination of both. For analysis of the relationship between patient characteristics and success, t-tests and Fisher's exact tests were used. The data were analyzed to determine if there was a significant difference in patient characteristics among those with successful versus unsuccessful first site US-guided IV placement. We divided vein depth into 0.2-cm increments and vein diameter into 0.1-cm increments. Fisher's exact test was used to assess if there were differences among increments of depth and diameter and success rates.

An adjusted analysis was then performed using logistic regression to determine the effect of vein depth and diameter together along with the following covariates: age category (18–34, 35–54, 55–64, and ≥65 years), sex, race (African American vs. other races), body mass index as a continuous variable, history of IV drug use, diabetes, previous chemotherapy, sonographer, and probe orientation (transverse or longitudinal). These covariates were determined a priori as potentially being related to successful IV placement. The total number of covariates included in the model was restricted so that more than 10 outcomes were present for each covariate included in the adjusted model. In the multivariable analysis, we divided both depth and diameter into 0.1-cm increments to permit the comparison of the relative impact of changing each parameter by the same distance. Multivariable analysis was performed with clustering on the patient to account for patients who had been enrolled on two or more visits. To determine whether a significant interaction between vessel depth and diameter existed, a combined variable ''diameter/depth'' (diameter divided by depth) was added to the model. This interaction term was chosen to be this quotient because success rates were expected, a priori, to be directly correlated with diameter and inversely correlated with depth. No significant interaction was identified, so we have reported our results as adjusted odds ratios (ORs) without an interaction term. Stata 10 was used for the analysis (StataCorp, College Station, TX). A p-value of <0.05 was considered significant.

RESULTS

Characteristics of Study Subjects and Overall Success Rates

During the study period, 169 patients were enrolled, with a total of 236 US-guided peripheral IV attempts. The mean age was 52 years (SD ± 18 years). One-hundred sixteen patients (69%) were female and 135 (80%) were African American. Successful IV placement was achieved after three attempts in 152 patients (90%). One-hundred seventeen patients (69%) had successful IVs at the first site, 26 patients (15%) at the second site, and nine (5%) patients at the third site. There were no significant differences in the patient characteristics of the group that had first site success when compared to the group that did not (Table 1). Of the 236 attempts at US-guided peripheral venous access, 153 (65%) resulted in successful cannulation.

Bivariable Analysis

Measurements of 236 individual vessels were grouped into 0.2-cm increments by depth and 0.1-cm increments by diameter. In the Fisher's exact test, depth was significantly associated with success. On examination of the data, success rates were fairly consistent until a depth of 1.6 cm was reached, after which no lines were successfully placed. We therefore divided the data to examine this threshold effect, where vessels less than 1.6 cm had a 67% rate of success (95% confidence interval [CI] = 60% to 72%) compared to 0% when greater than or equal to 1.6 cm (95% CI = 0 to 37%; Table 2).

Table 1
Demographic Characteristics of ED Patients Who Had an Attempted US-guided IV in the ED, Divided by Those Who Received Successful First Site IVs vs. Unsuccessful First Site IV Placement (total *n* = 169)

Demographic	% Successful First-site IV, *n* = 117 (95% CI)	% Unsuccessful First-site IV, *n* = 52 (95% CI)
Age, yr		
18–34	21 (14–29)	20 (10–32)
35–54	38 (29–47)	25 (14–38)
55–64	25 (17–37)	29 (17–42)
≥65	17 (10–25)	28 (16–40)
Female	63 (54–72)	75 (62–86)
Race		
African American	76 (67–83)	82 (70–91)
White	21 (13–29)	14 (6–26)
Body mass index	29 (27–30)	29 (27–31)
History		
Prior history of difficult IV access	84 (76–90)	88 (76–95)
IV drug use	17 (11–25)	11 (4–21)
Chemotherapy	11 (6–18)	7 (2–18)
Dialysis	14 (8–21)	16 (7–28)
Diabetes	34 (26–44)	32 (20–46)

US = ultrasound.

Table 2
US-guided IV Success Rates at Various Vessel Depths and Diameters (*n* = 236)

	Success Rate
Vessel diameter (cm)	
≤0.3	24/43 (56%)
>0.3–0.4	56/88 (64%)
>0.4–0.5	45/73 (62%)
>0.5–0.6	17/20 (85%)
>0.6	11/12 (92%)
Vessel depth (cm)	
≤0.2	4/6 (67%)
>0.2–0.4	20/31 (64%)
>0.4–0.6	35/49 (71%)
>0.6–0.8	26/41 (63%)
>0.8–1.0	26/39 (67%)
>1.0–1.2	17/28 (61%)
>1.2–1.4	17/22 (77%)
>1.4–1.6	8/12 (67%)
>1.6	0/8 (0%)

Values represent the number of successful IVs placed by category. The calculated proportion is in parentheses.
US = ultrasound.

Using the Fisher's exact test, vessel diameter and success rates were significantly different. When diameter was <0.3 cm, the success rate was 56% (95% CI = 40% to 71%); when the diameter was >0.6 cm, the success rate was 92% (95% CI = 62% to 100%; Table 2). No threshold effect was identified.

Probe orientation (transverse vs. longitudinal) had no significant effect on US-guided peripheral IV placement success (Table 3). In the transverse plane 133/206 (65%) were successful, versus 20/30 (67%) in the longitudinal plane (two-sided Fisher's exact = 0.82).

Table 3
Probe Orientation (Transverse vs. Longitudinal) and US-guided Peripheral IV Attempt Success Rates (*n* = 236)

Probe Orientation	Successful US-guided IV Placement
Transverse	133/206 (65%)
Longitudinal	20/30 (67%)

Two-sided Fisher's exact = 0.82. The calculated proportion is in parentheses.
US = ultrasound.

Multivariable Analysis

In the adjusted analysis with respect to the patient, depth and diameter were each independently associated with success. For each 0.1-cm increase in diameter, the odds of successful IV placement increased by 1.79 (95% CI = 1.36 to 2.34). When considering all observations, there was a weak relationship between depth and success, with the OR of successful IV placement decreasing by 0.89 (95% CI = 0.82 to 0.97) per 0.1-cm increase in depth. None of the a priori covariates were significant in the adjusted model. The Hosmer-Lemeshow goodness-of-fit test does not suggest lack of fit for this model (p = 0.89). However, in view of the previously noted threshold, an additional analysis was performed. Testing the 228 patients in a model that excluded the eight outliers of >1.6 cm, the adjusted OR of success was found to be 0.96 (95% CI = 0.89 to 1.04) per 0.1-cm increment of depth, which was not significant.

DISCUSSION

The goal of this study was to discover what factors predict the greatest likelihood of US-guided peripheral IV success in patients with DIVA. Our data revealed that larger vessel diameter was most predictive of success and that depth had no effect until a threshold of >1.6 cm was reached where success rates dropped to 0%. Further, patient characteristics were not predictive of success; thus, the patient characteristics that make traditional methods of IV placement difficult do not persist when using US guidance. Knowing this, we believe that clinicians can simply focus on what they see when they look with ultrasound, rather than being discouraged by various patient characteristics.

When assessing venous access options with US, most patients will have multiple vessels from which to choose. With greater understanding of the patient and vein characteristics that affect success, a clinician can rapidly identify the optimal target vessel. Further, if no suitable vessels are visualized, potentially deferring to an alternate vascular access strategy might avoid painful and ultimately futile access attempts, as well as be time-saving.

Our data revealed that vessel larger diameter was most predictive of success and that depth had no effect until a threshold of >1.6 cm was reached, where success rates dropped to 0%. Anecdotally, study sonographers reported that they were able to target vessels

at extreme depths, but the 48-mm angiocatheter length was too short to successfully cannulate the vessel. Basic trigonometry may explain our findings. If a vessel is 16 mm deep, and one takes a 45° angle to the vein, then a minimum 23-mm catheter is needed to reach the vessel. At a 30° angle, a catheter would have to be 32 mm to touch the anterior vessel wall. These calculations assume that the needle is placed immediately adjacent to the probe as it pierces the skin, where in reality, one often starts a few millimeters proximal to the probe. Nor do they include the additional catheter length that must reside within the vessel lumen for the line to be functional. As vessel depth increases, a progressively steeper ''angle of attack'' is required to reach the vessel. This increasingly obtuse angle between the catheter and the vessel has several adverse effects. First, it makes it increasingly likely that the tip of the introducer needle pierces the back wall of the vessel prior to full introduction of the plastic catheter. Second, if the back wall of the vessel is successfully avoided, once the lumen is entered, either the catheter gets caught up on the back wall or serious irreparable kinking occurs. A study by Mills et al.[3] describes cannulating a vessel using a standard length catheter (32 mm) and then inserting a 15 cm catheter over a wire with good success. This technique may ameliorate the difficulties described above.

The effect of probe orientation on US-guided peripheral IV success has been discussed in the literature; however, there is no consensus as to whether long axis (longitudinal) or short axis (transverse) is more effective.[3,5,9–11] Central line literature often describes obtaining access in short access because of the ability to visualize the artery relative to the vein;[9,12] however, Karakitsos et al.[13] describe improved visualization of the internal jugular vein and surrounding structures when both the longitudinal and transverse axes were employed. A study by Blaivas et al.[10] reported that novice sonographers obtain vascular access faster in the short-axis orientation on an inanimate arm model. In our study, the sonographer was free to choose whichever orientation he or she found more comfortable, with the majority of vessels being cannulated in transverse axis (206 short axis vs. 30 long axis). We found that probe orientation was unrelated to success. It is the first author's preference to use a combined approach, starting in short axis to target the vessel in relation to surrounding structures and then rotating the transducer into long axis just prior to piercing the vessel to observe the needle and catheter enter fully into the vein. However, this approach takes a fair amount of hand–eye coordination and may not be appropriate for the novice sonographer. Ultimately, we believe that clinicians should utilize the access technique with which they are most familiar and comfortable.

No study, to our knowledge, has examined the effect of vessel diameter on successful US-guided peripheral IV placement; however, it has been investigated in central line research. The authors of the third Sonography Outcomes Assessment Program (SOAP-3) trial,[14] based on their findings, recommend that cannulation of central veins <5 mm in diameter not be attempted without dynamic US guidance because of a high likelihood of failure. In a study of 493 punctures of the internal jugular vein, poor patient compliance and a vessel diameter smaller than 7 mm had a negative influence on the success rate.[15]

Little research on US-guided peripheral IV placement has been conducted on pediatric patients in whom IV access is frequently both life-saving and challenging. Anecdotally in the current study, several of the patients in whom successful cannulation could not be obtained even after three attempts were those who were unable to stay still for the procedure. This is a problem that is commonly encountered in pediatric patients and may limit the utility of US in this population. Future studies may look at the feasibility of US-guided peripheral IV access in children, particularly how age, height, body mass index, and vessel characteristics affect success.[16]

LIMITATIONS

The generalizability of this study's results may be limited by the single study site and the use of a single brand of US machine and angiocatheter. Although several demographic and patient characteristics were analyzed, it is possible that a different population or ED setting might give rise to a different outcome.

The decision to design the study using four dedicated study sonographers was made to ensure a relatively consistent level of skill in investigating the primary questions; however, it may have limited generalizability in several ways. First, since the sonographers in most cases were available to enroll patients without other clinical responsibilities, they had more time than might typically be available during a clinical shift. Second, although the sonographers had completed the specialty requirements for proficiency in US-guided IV access before the outset of the study, it is possible that continued practice gave them a level of skill not enjoyed by most emergency physicians.[7] Third, it is possible that the ready availability of the study sonographers may have led the ED staff to have an abnormally low threshold for requesting an US-guided peripheral IV attempt, resulting in an abnormally ''easy'' cohort of patients for the study.

The fact that the study sonographers were not blinded to the study aims also exposes the results of the study to several potential biases. First, it may have biased the study sonographer's choice of target vessel. We assume that in clinical practice, a sonographer would select the vessel that he or she thought offered the best chance of success. However, it is conceivable that the study sonographers chose a variety of depths and sizes (when there were easier alternatives available) to answer the study's questions.

We chose to allow study sonographers to orient the probe in the plane they were most comfortable with when placing the IV. Had we randomized the technique, we may have found a significant difference in success rates. However, having an individual perform a procedure in a way that he or she finds uncomfortable would have put the study protocol in conflict with clinical practice. Further study in this topic is needed to better elucidate whether there is a significant difference in success rates in longitudinal versus transverse axis and between experienced versus novice sonographers.

CONCLUSIONS

The success of ultrasound-guided peripheral IV placement was related to vessel characteristics detected with ultrasound but was not influenced by patient characteristics or probe orientation. Knowing this, we believe that clinicians can focus on the sonographic image, rather than being discouraged by patient characteristics. Successful difficult IV access was primarily associated with larger vessel size, while vessel depth up to >1.6 cm and patient characteristics were unrelated to success. Clinically, if two vessels are identified at a depth of <1.6 cm, the larger diameter vessel, even if comparatively deeper, should yield the greatest likelihood of success.

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