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Utility of color flow Doppler ultrasound to identify peripheral intravenous catheter position in adult surgical patients

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Abstract

Objective: To evaluate color flow Doppler flow ultrasound compared to standard clinical techniques, to detect the intravascular position of peripheral intravenous catheters in adult surgical patients.

Methods: A prospective study was conducted in adult (>18 years old) patients scheduled to undergo elective surgery. Peripheral intravenous catheter position was evaluated with standard clinical techniques (free flow of fluid from a hanging bag, easy saline injection, and aspiration of blood), and with color flow Doppler ultrasound proximal to the insertion site to identify intravascular catheter position. Comparative test performance was carried out.

Results: In total, 174 patients were enrolled. The venous catheter was deemed to be intravascular in 92.53% (n = 161) and 90.23% (n = 157) based on clinical evaluation and color flow Doppler, respectively (p = 0.206). Moderate to substantial agreement between the two approaches was found. Cohen's kappa was 0.64 (95% CI 0.43–0.83). Specificity of clinical judgment to detect catheter extravascular position was only 58.82%, when the color flow Doppler technique was set as the gold standard. Free flow from a hanging bag method showed the best agreement with color flow Doppler to determine intravascular position of a catheter (p = 0.3173, kappa = 0.68), with sensitivity of 98.09% and specificity of 64.71%.

Conclusion: Color flow Doppler is a specific tool complementary to sensitive clinical indicators to detect peripheral venous catheter infiltration. The ability of color flow Doppler to accurately determine the position of a peripheral venous catheter depends on experience and familiarity with the tool by providers, who can master the technique with education and training.

Keywords

Color flow Doppler, infiltration, extravasation, peripheral intravenous catheters, general anesthesia

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Introduction

Intravenous catheters are ubiquitous and are part of the standard of care in modern medicine. They are the lifeline in perioperative surgical patient care. Parenteral administration of fluids and medications via intravenous cannulation is an integral part of anesthetic practice. Complications associated with indwelling peripheral intravenous catheters include phlebitis, local infection, skin irritation, and inadvertent infiltration and extravasation.[1] Infiltration is defined as extravascular accumulation of a parenteral solution intended to remain in the intravenous compartment. Extravasation, defined as damage caused by the efflux of a solution from a blood vessel to surrounding tissues,[2] can lead to a host of adverse effects, in a spectrum ranging from minor discomfort to skin necrosis and sloughing requiring surgical debridement and grafting or even amputations in severe cases.[3] Of note, during anesthetic procedures, a wide variety of pharmacological solutions and intravenous fluids with particular physicochemical properties

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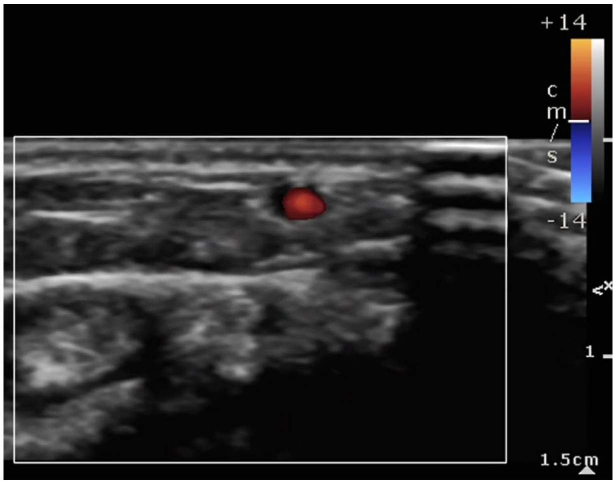

Figure 1. Cephalic vein with color flow Doppler imaging during saline infusion evidencing flow.

are administered. Peripherally administered medications such as propofol and vasopressors have been associated with local tissue injury of varying severity.[4–6]

Confirmation of adequate peripheral intravenous catheter placement should be determined before using the parenteral route; however, there is no gold standard universally accepted for this purpose. Determination of the correct position of freshly inserted peripheral intravenous catheters and already established intravenous lines depends largely on subjective clinical signs such as visual evidence of swelling around the insertion site, low resistance to infusion, and free back-flow of blood. Ultrasound-guided cannulation of peripheral veins has gained popularity in recent years and is standard of practice in some institutions.[7] Primarily used in guiding central line placement, the applications of ultrasound for vascular access continue to expand in the perioperative setting, thanks to its easy use, non-invasiveness, and safety profile. On the contrary, utilization of color flow Doppler technology with flow injection test has been shown to be a valuable tool for early recognition of malfunctioning intravenous catheters.[8] The color flow Doppler flow technique is both safe and reliable, and aids in identification of correct intravascular position of venous catheters in children.

This study aims to test the hypothesis that the color flow Doppler flow technique is superior to standard clinical techniques to detect the correct position of peripheral intravenous catheters in adult surgical patients.

Methods

After approval by the Institutional Review Board of Augusta University, we prospectively evaluated adult patients older than 18 years old scheduled to undergo elective surgical procedures during the month of August 2018. This was a non-randomized, cross-sectional clinical study. The study was registered in the Clinicaltrials.gov registry, with a trial number NCT03889678. Patients with open wounds in the vicinity of the intravenous line insertion site or scar tissue on the extremity, as well as those with dressings, bandages, or casts on the extremity precluding adequate use of ultrasound were excluded. We evaluated intravascular position of peripheral venous lines by three clinical methods to test superiority of the color flow Doppler flow technique over standard clinical indicator methods: free flow from a hanging intravenous fluid bag, aspiration of venous blood with a syringe, and hand injection of 2 mL of normal saline in adult surgical patients. Informed consent was waived. The intravenous catheters had been inserted before the study measurements were made. None of the catheters was inserted with ultrasound guidance. Although the techniques used in this study are widely used in clinical practice, none of them has been validated in the literature.

After admission to the preoperative suite in the operating room area, in situ intravenous lines were evaluated with the four methods under study in the following sequence: (1) Examination of the peripherally placed intravenous line to evaluate for obvious signs of infiltration, (2) identification of free flow from a hanging intravenous fluid bag located 30 cm above the cannula insertion site, (3) aspiration of venous blood through the catheter with a 3-mL syringe, (4) unobstructed injection of 2 mL of preservative free normal saline through the catheter, and (5) color flow Doppler evaluation with the linear probe on cross-sectional axis set at medium scale, placed 4 cm proximal to catheter insertion site along the venous system, after injection of 2 mL of preservative-free normal saline over 2 s. The evaluation of the five methods took less than a minute in total. We employed a 13 MHz linear probe (Sonosite®, Bothell, WA, USA). The change in color flow pattern on the proximal draining veins was the primary end point of the study (Figure 1). A positive test means identification of intravascular position of the catheter. Absence of flow in proximal vein was evidence of distal vein infiltration (Figure 2). A test was deemed positive for each technique as follows: (1) Sustained dripping of intravenous fluid, (2) positive aspiration of blood with a 3-mL syringe or spontaneous blood return from the catheter, (3) easy injection of 2 mL normal saline with absence of swelling around insertion site, (4) identification of color pattern change due to turbulence with color flow Doppler in proximal veins. In our study, vascular infiltration is described as lack of intravascular color pattern, and presence of extravascular color mosaic around the area of insertion of the intravenous catheter, as a result of flow and accumulation of a parenteral solution in the tissues surrounding a peripheral vein.

Demographic variables (age, gender) and catheter-related variables (extremity location, time after insertion) were recorded. Sensitivity and specificity of tests was determined based on the results of the four techniques reported as positive or negative.

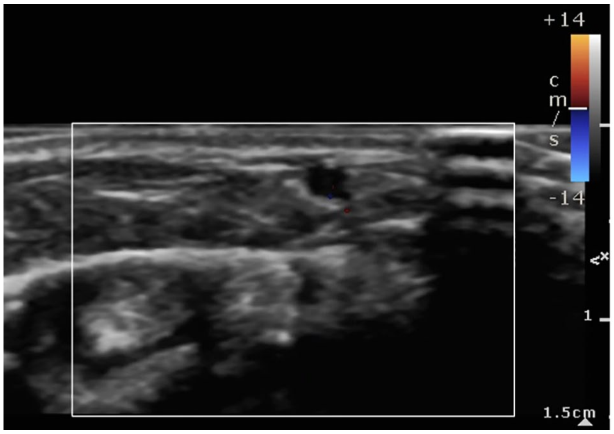

Figure 2. Basilic vein with color flow Doppler imaging during saline infusion. No flow is visualized indicating proximal infiltration.

Table 1. Demographic and catheter variables.

Variable	Mean	SD
Age (years)	54.6	16.47
Variable	Level	*n* (%) (*n* = 174)
Gender	Female	98 (56.32%)
	Male	76 (43.68%)
Injection sites	Forearm	27 (15.52%)
	Antecubital	23 (13.22%)
	Foot	1 (0.57%)
	Hand	123 (70.69%)
Time of injection	After surgery	116 (66.67%)
	Before surgery	58 (33.33%)
Gauge	22	26 (14.94%)
	18	12 (6.90%)
	20	136 (78.16%)

Statistical analysis

Sample size was based on convenience and feasibility, and on a prior experience with the color flow Doppler evaluation of peripheral intravenous catheters in a pediatric population.[8] We calculated a sample size of 150 patients that was increased to 174 to account for possible cases with incomplete information. All statistical analyses were performed using SAS 9.4 and statistical significance was assessed using an alpha level of 0.05. Appropriate descriptive statistics (frequencies and percentages or means, standard deviations) were calculated for all variables overall and by locations. The McNemar's test was performed, and the Cohen's Kappa was calculated to determine the agreement between the different evaluation methods for successful injection. Sensitivity and specificity of the different approaches used in standard confirmatory tests were also determined using the color flow Doppler results as definitive.

Results

A total of 174 patients were enrolled in the study. Demographic variables and details of intravenous catheters are shown in Table 1. The mean age of the patients was 54.6 ± 16.47 years old. Based on clinical indicators (blood aspiration, fluid dripping from hanging bag, and easy saline flush injection), the venous catheter was deemed to be intravascular in 92.53% of cases ($n = 161$). Based on the color flow Doppler technique, the catheter was deemed to be in intravascular position in 90.23% of patients ($n = 157$; Table 2). Figure 3 shows the distribution of patients based on catheter position detected by clinical methods and color flow Doppler. The catheter was removed when there was indication of extravascular position by any of the methods. The intravascular position of the catheter was not evaluated with two-dimensional ultrasound, as we acknowledged that in some situations where the vein is collapsed, the position of the catheter may be difficult to visualize and would not add information. No patients exhibited signs of local vein thrombosis on ultrasound examination before the color flow Doppler evaluation. A McNemar's test comparing the two methods (ultrasound versus clinical indicators) showed a *p*-value of 0.206, suggesting similar outcomes. Furthermore, the value of Cohen's kappa was 0.64 (95% CI 0.43–0.83) suggesting a moderate to substantial agreement between the two approaches. However, the specificity of clinical judgment to detect catheter extravascular position was only 58.82%, when the color flow Doppler technique was set as the gold standard, which indicates that the clinical methods may miss some infiltrated injections. The three standard clinical indicator tests were also evaluated separately using the color flow Doppler technique results as gold standard. The data show that the aspiration method yields the lowest rate of identification of intravascular position of the catheter (32.18%), as confirmed by color flow Doppler visualization ($p < 0.0001$ and kappa = 0.10). Sensitivity of the aspiration method for intravascular catheter detection was unsatisfactory (35.67%). In addition, the result of easiness of saline flush injection test does not exhibit agreement with the color flow Doppler technique ($p = 0.0005$ and kappa = 0.43). The sustained dripping method appears to have the best agreement with the Doppler flow method to determine intravascular position of an intravenous catheter ($p = 0.3173$ and kappa = 0.68), with the sensitivity being 98.09% and specificity 64.71%. Finally, different injection sites may result in different rates of infiltration (Table 3). Except for a case of successful foot catheter location, hand location appears to be the injection site with highest intravascular successful position rate (93.50%), followed by the antecubital location (91.30%).

Discussion

Our study shows that when compared with color flow Doppler, the clinical assessment of intravascular position of a peripheral venous catheter, by means of a combination

Table 2. Evaluation of standard confirmatory tests based on color Doppler flow technique results.

Tests	Color Doppler test		*p* value	Cohen's kappa	Sensitivity (%)	Specificity (%)
	Working	Infiltrated				
Sustained dripping						
Yes	154	6	0.3173	0.68 (0.49–0.88)	98.09 (94.52–99.60)	64.71 (38.33–85.79)
No	3	11				
Positive aspiration						
Yes	56	0	<0.0001	0.10 (0.05–0.15)	35.67 (28.19–43.70)	100 (80.49–100)
No	101	17				
Easy injection						
Yes	157	12	0.0005	0.43 (0.17–0.69)	100 (97.68–100)	29.41 (10.31–55.96)
No	0	5				
Three clinical methods						
Yes	154	7	0.206	0.64 (0.43–0.84)	98.1 (94.52–99.6)	58.82 (32.92–81.56)
No	3	10				

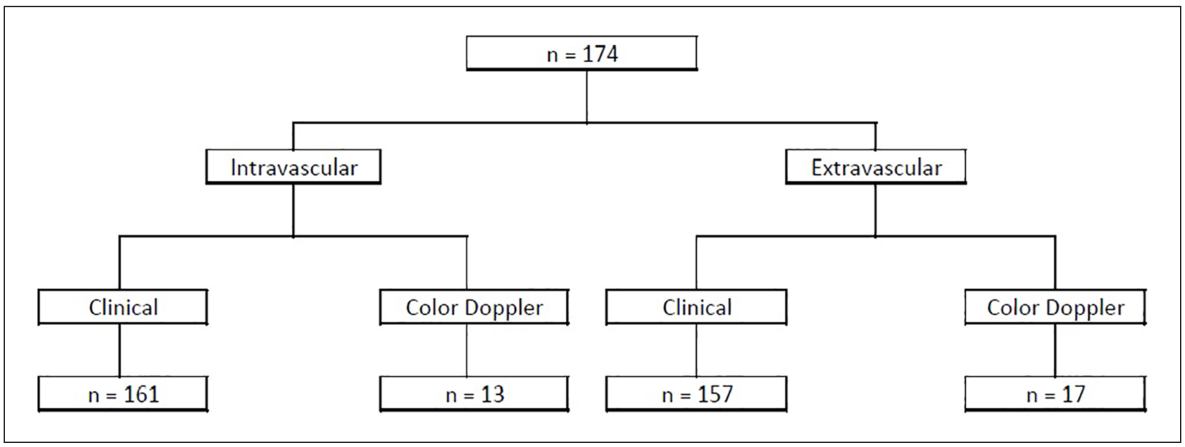

Figure 3. Patient distribution for catheter position based on clinical methods and color flow Doppler examination.

of free flow of a hanging fluid bag, easy saline flush injection, and blood aspiration, yield similar results. However, when vein infiltration is confirmed by color flow Doppler, the specificity of a clinical assessment is rather unsatisfactory, indicating that the use of clinical methods alone may lead the clinician to miss some cases of extravascular position of the catheter. In addition, out of the three clinical methods evaluated in this study, free fluid flow from a hanging bag exhibits the best agreement with color flow Doppler to diagnose intravascular position of the catheter.

The incidence of venous extravasation and infiltration ranges between 0.1% and 6.5% in pediatric hospital patients.[9] On the contrary, although peripheral intravenous infiltration rates are frequently underreported, it is estimated to occur in as many as 20%–30% of adult inpatients.[10] An analysis of the American Society of Anesthesiologists Closed Claims database revealed that 2% of all claims was related to peripheral venous catheterization, and more than half of these were due to extravasation.[11] Our study shows that clinical evaluations including free flow from a hanging bag, free saline flush and blood aspiration, are poor indicators of vein infiltration. A similar finding was documented by Gautam et al.[8] in pediatric patients, with detection of 100% of 27 venous catheters by color flow Doppler. Inadvertent extravascular position of a venous catheter is associated with deleterious outcomes. The effective delivery of total intravenous general anesthesia (TIVA) depends on the intravascular position of the venous catheter throughout the procedure. The fifth National Audit Project in the United Kingdom, identified that TIVA was associated with twice the incidence of awareness after general anesthesia.[12] Causes of awareness in this context include disconnection of the intravenous catheter and extravasation of the anesthetic to surrounding tissue due to cannula malposition.[13] Some authors propose measurement of peripheral venous pressure to detect extravasation as a means to prevent awareness during TIVA.[13,14] However, widespread use of this technique may be cumbersome and impractical in the perioperative period. Color flow Doppler to detect infiltration as an early stage of extravasation is a safe, easy to use

Table 3. Results of standard confirmatory tests and color Doppler flow technique.

Methods	Overall ($n = 174$)	Injection sites			
		Forearm ($n = 27$)	Antecubital ($n = 23$)	Foot ($n = 1$)	Hand ($n = 123$)
Standard confirmatory tests					
Sustained dripping	160 (91.95%)	20 (74.07%)	23 (100%)	1 (100%)	116 (94.31%)
Positive aspiration	56 (32.18%)	8 (29.63%)	14 (60.87%)	1 (100%)	33 (26.83%)
Easy injection	169 (97.13%)	25 (92.59%)	23 (100%)	1 (100%)	120 (97.56%)
Combination of three methods	161 (92.53%)	19 (70.37%)	23 (100%)	1 (100%)	118 (95.93%)
Color Doppler flow technique					
Visibility	102 (58.62%)	9 (33.33%)	9 (39.13%)	1 (100%)	53 (43.09%)
CFI	157 (90.23%)	20 (74.07%)	21 (91.30%)	1 (100%)	115 (93.50%)
Doppler confirmed injection	157 (90.23%)	20 (74.07%)	21 (91.30%)	1 (100%)	115 (93.50%)

CFI: contrast flow index.

technique, especially when ultrasound machines are ubiquitous in operating rooms and preoperative settings. Training is necessary to develop the competency to identify venous flow patterns. Standardization can be obtained by implementation of simulation training sessions.[15] Training is also an important tool to document the patency of venous lines. In a multidisciplinary team care model, relaying information between professional taking care of patients is a powerful tool to reduce adverse outcomes.[16] Ball et al.[17] demonstrated the lack of a standard for management and documentation of peripheral intravenous lines in the operating room, among anesthesia providers in academic institutions in the United States. This represents an opportunity for the development and implementation of quality improvement projects in surgical services.

Although clinical indicators are comparable to color flow Doppler ultrasound in terms of detection of intravascular position of a venous catheter, the latter technique is better at detecting infiltration. Unfortunately, there are no gold standard techniques used in routine clinical practice to detect intravenous catheter position. However, we consider that since we are able to detect clear flow patterns with color flow Doppler, and because the outcome of intravascular position was comparable between the two methods, we could argue that color flow Doppler is a good reference method to detect peripheral vein infiltration. Diagnosis of vascular infiltration is clinically more relevant than the intravascular catheter detection. In other words, when there is doubt about infiltration, clinical indicators fall short and a more specific technique becomes necessary. The clinical relevance of our finding of a better performance of color flow Doppler over clinical signs lies in the decision to avoid the administration of medications that can cause serious local tissue damage.[4–6] In addition, systemic and local unwanted effects of medications may be the result of a missed diagnosis of vein infiltration. Prolonged neuromuscular block has been reported secondary to accidental subcutaneous deposit of a muscle relaxant.[18] We may argue that clinical indicators (free flow of fluid from a hanging bag, easy saline flush and blood aspiration) can be used as screening tools to rule out extravascular position of venous catheters, whereas color flow Doppler might find its application as a confirmatory tool to rule-in venous infiltration in surgical patients. We recommend the use of an algorithm using clinical methods followed by color flow Doppler evaluation to confirm cases of infiltration would provide maximum sensitivity and specificity.

Our study has limitations. The study was performed by anesthesiologists with experience in the use of ultrasound and color flow Doppler techniques, which may limit generalizability of results when operators with less experience use the technique for the purpose of identifying venous catheter position. Although inter-operator variability will always be problematic in relation to ultrasound studies, such variance can be minimized by means of training programs, either in simulated or real-patient settings. Although ultrasound is being widely used in anesthesia over the last decade, there are still locations where equipment is either not readily available or has to be shared by multiple providers. This situation may limit the application of our results; however, using a stepwise approach with the use of clinical indicators to screen patients with infiltration, therefore limiting the use of color flow Doppler to those patients with positive clinical signs of possible infiltration, would be an efficient system. Future research should focus on the evaluation of quality improvement programs integrating the documentation of intravenous line status with the use of color flow Doppler ultrasound in surgical patients.

Conclusion

Color flow Doppler is a specific tool complementary to sensitive clinical indicators to detect peripheral venous catheter infiltration. The ability of color flow Doppler to accurately determine the position of a peripheral venous catheter depends on experience and familiarity with the tool by providers, who can master the technique with education and training.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

Ethical approval for this study was obtained from Institutional Review Board of Augusta University. Protocol Number: 1237593. Date of approval: 6 December 2018. The study was considered exempt from IRB review.

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Informed consent

Informed consent process was waived by IRB because this research has no more than minimal risks. The procedures routinely used to rule out IV infiltration are standard. Although ultrasound is used in some instances to assess intravascular catheter position, it is not routinely used in every patient. However, this is a non-invasive technique virtually devoid of side effects.

Trial registration

Name of the trial registry is Clinicaltrials.gov. and the trial registration number is NCT03889678.

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Data accessibility statement

Research data are available upon request.

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