Therapeutics and Clinical Risk Management

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ORIGINAL RESEARCH

Optimizing Infusate Flow Patterns for Minimizing Vein Wall Trauma: An Exploratory Study with a Modified off-Axis Catheter Tip Opening

Amit Bahl[1], S Matthew Gibson[2], Alexis Walton[3]

[1]Department of Emergency Medicine, Oakland University William Beaumont School of Medicine, Rochester, MI, USA; [2]Vascular Access Consulting, Henderson, KY, USA; [3]Department of Emergency Medicine, Corewell Health William Beaumont University Hospital, Royal Oak, MI, USA

Correspondence: Amit Bahl, Oakland University William Beaumont School of Medicine, 586 Pioneer Drive, Rochester, MI, 48309, USA, Email Amit.bahl@corewellhealth.org

Objective: Modifying the PIVC tip to direct infusates toward areas of highest hemodilution may reduce vein wall damage. This study compared flow patterns between a traditional PIVC with a central opening and one with an off-axis aperture.

Methods: This was an exploratory observational analysis conducted at a tertiary care emergency department (ED) comparing flow patterns of two intravenous catheters: PIVC 1 (2.95 cm 20 gauge [Autoguard, Becton Dickinson]) and PIVC 2 (3.68 cm 20 gauge [Osprey, SkyDance Vascular]). Adult ED patients with PIVCs placed via traditional palpation/visualization method and with ultrasound capturing the flushing were eligible participants. Ultrasounds were reviewed to determine vein, catheter, and flow characteristics. The primary outcome was angle of the infusate leaving the catheter. Secondary outcomes included direction of catheter tip against vein wall, distance away from vein wall, vasospasm, and laminar/turbulent flow.

Results: Data from December 2023 included 28 catheters (10 PIVC 1, 18 PIVC 2). The average patient age was 53.7 years; 53.6% were female. Vein diameter/depth were similar: 0.35 cm/0.41 cm for PIVC 1 and 0.37 cm/0.47 cm for PIVC 2. The catheter tip pointed posteriorly towards the vein wall in 60% of PIVC 1 vs 11.1% in PIVC 2 ($P=0.018$). The angle of infusate flow away from the vein wall was 0.20° (SD 0.63) for PIVC 1 and 7.61° (SD 5.71) for PIVC 2 ($P<0.001$). Flow at 0° occurred in 90% of PIVC 1 vs 16.7% in PIVC 2 ($P<0.001$).

Conclusion: In this exploratory investigation, a peripheral vascular access device with an off-axis tip aperture of demonstrated a sharper infusate flow angle away from the vein wall compared to a traditional central opening device. This redirection may reduce vein wall trauma and complications, though further research is needed to pair clinical outcomes with this technology.

Keywords: peripheral intravenous access, hemodilution, flow pattern, infusates, modified catheter tip, catheter length

Introduction

Peripheral intravenous catheters (PIVC) are ubiquitous and essential to delivery of patient care.[1] With nearly 140 million emergency room visits and over 33 million hospital admissions per year,[2] 70–90% of the patients will need a PIVC.[3] With over half of PIVCs failing,[4] it is bewildering why the patients, hospitals and healthcare workers accept such poor performance. Common complications including phlebitis, infiltration, and thrombus formation lead to failure.[4] In order to make meaningful improvements in outcomes, it is necessary to explore the mechanisms that cause failure and develop solutions that target these causes.

One vulnerable structure that is prone to mechanical and chemical injury during and after the insertion of a PIVC is the fragile intimal venous wall. The wall is coated by the glycocalyx, a layer of complex carbohydrates that covers the luminal surface of endothelial cells.[5] This gel-like meshwork extends into the bloodstream from the endothelial cell membrane and functions as an insulator to protect the endothelium cells from damage.[6] The delicate and highly dynamic tissue can be damaged by the mechanical rubbing and flushing shear stress causing an inflammatory response where phlebitis and thrombosis begin.[7] Subsequent harm is compounded by the delivery of harsh infusates, some of which may

Received: 16 July 2024
Accepted: 26 August 2024
Published: 4 September 2024

be inappropriate for peripheral veins, flowing against the exposed endothelial cells that are no longer insulated by the glycocalyx resulting in the progression of complications and early PIVC failure.[8–10]

Typically, infusates exit the catheter parallel to the axis of the catheter shaft. The direction of the infusates flow is determined by the orientation of the catheter within the vein. If the catheter tip is directed towards the vein wall, the suboptimal direction can accelerate damage. Conversely, if the catheter tip is angled towards the vein lumen, the infusates will be channeled toward regions with heightened flow and more hemodilution will occur.[7,11] With any type of catheter, proper catheter placement and positioning are critical to ensure optimal infusion and minimize the risk of complications.[12]

Modification to the PIVC tip, such as an off-axis aperture, holds promise in redirecting infusions away from the susceptible intimal wall, channeling them toward regions with heightened flow and hemodilution. Therefore, it is the aim of this investigation to determine the flow pattern of infusates, comparing a traditional PIVC with a central opening and a PIVC with an off-axis aperture.

Methods

Study Design, Settings, Participants

This was an exploratory observational investigation conducted at a suburban, tertiary care center with 1100 hospital beds and 120,000 emergency department (ED) visits. Data were obtained as part of a quality improvement project and later retrospectively analyzed for research purposes. In December 2023, a convenience sample of adult patients who required a PIVC in the ED for diagnostics/treatment with a vascular access score (VAS) of 1 or 2 were eligible participants.[13] Patients with a VAS of 1 or 2 had palpable and visible veins appropriate for traditional visualization/palpation method of cannulation. The local institutional review board (IRB) approved the study. A waiver of informed consent was granted by the IRB as the study meets exemption based on design and objectives. Patient data was handled with the highest level of confidentiality and in full compliance with institutional and ethical guidelines.

Objectives

The primary objective was to compare the angle of flow of the flush as it left the catheter tip between PIVC 1 and PIVC 2. Secondary objectives included assessing for differences in flow pattern, flow type, retrograde direction, and evidence of vasospasm.

Sonography Definitions

Flow pattern was defined as parallel, posterior, or anterior based on the visible direction of the flush leaving the PIVC tip. Flow was considered laminar if the flush was traveling smoothly in a steady state with the greatest echogenicity of the fluid jet near the center of the vein. Flow was considered turbulent if it the flush was disturbed and heterogenous with echogenicity of the fluid jet spread across the vein. Retrograde flow was defined as majority flow tracking backwards towards the PIVC immediately after flush. Tip vasospasm was defined as narrowing of the vein after PIVC insertion at the level of the PIVC tip.

Procedures

Patients received either PIVC 1 (2.95 cm 20 gauge [Autoguard, Becton Dickinson]) or PIVC 2 (3.68 cm 20 gauge [Osprey, SkyDance Vascular]). Figure 1 illustrates the PIVC tip apertures. Placements were executed using the traditional visualization/palpation technique. Prior to insertion, ultrasound was used to assess the venous site. Ultrasound images were captured by clinical staff with extensive experience in vascular ultrasound imaging for procedural guidance. Vein diameter and vein depth were measured in short axis prior to insertion. After PIVC placement, functionality was confirmed by blood return and flushing without resistance. Still and video ultrasound images were obtained to obtain PIVC tip angle against nearest vein wall, distance of tip to closest wall, vein wall contact, and tip position. Next PIVCs were flushed with 10 cc of normal saline over 5 seconds with simultaneous ultrasound video imaging in long axis to

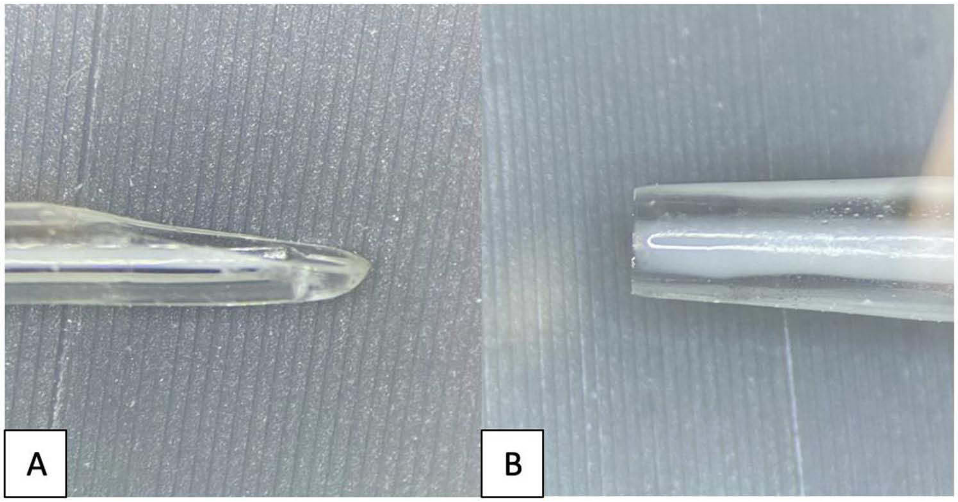

Figure 1 Peripheral Intravenous Catheter tip openings. (**A**) Modified tip with off-axis opening. (**B**) Traditional central opening.

capture flow quality and direction of the flush at the PIVC tip. All imaging was saved locally and later reviewed and analyzed by an ultrasound-fellowship trained emergency physician who was blinded to catheter type.

Data Source/Variables

Data sources included the electronic health record and the PIVC site ultrasound imaging. Demographic data included age, sex, race, and body mass index. PIVC data included vascular access score, laterality, location, number of attempts, gauge, length, and type. Ultrasound imaging included vein parameters of depth and diameter. Ultrasound PIVC variables included PIVC tip angle against nearest vein wall, distance of tip to closest wall, vein wall contact, and tip position. Dynamic flow imaging was reviewed to determine angle of infusate flow, flow quality and direction, and presence of vasospasm of the PIVC tip.

Statistical Analysis

Descriptive analysis was employed to summarize patient characteristics. Numerical variables were reported as means with standard deviations. Categorical variables were expressed as counts and frequencies (percentages). The Fisher's exact test was used for categorical variables and the Kruskal–Wallis (exact) test was used for numerical values. Analysis was performed using R-4.1.2 (R Foundation for Statistical Computing) and Excel (Microsoft).

Results

In December 2023, data from 28 catheters (10 PIVC 1 and 18 PIVC 2) were collected. Demographic data was similar between groups (P>0.05). Overall, average patient age was 53.7 years, 53.6% were female, 60.7% were White, and average BMI was 28.51.

All PIVCs were placed via traditional palpation/visualization method but certain vein parameters were assessed with ultrasound prior to insertion. (Figure 2) Vein diameter and vein depth were similar between groups: 0.35 cm and 0.41 cm for PIVC 1 and 0.37 cm and 0.47 cm for PIVC 2, respectively. All catheters were 20 gauge in diameter. Length was different between PIVC 1 (2.95 cm) and PIVC 2 (3.68 cm). The catheter tip direction was posterior towards the vein wall in 60.0% in PIVC 1 compared to just 11.1% in PIVC 2 (P=0.018) (Table 1).

The main outcome was angle of infusates flow. The angle of infusates flow away from the vein wall was 0.20 degrees (SD 0.63) in PIVC 1 and 7.61 degrees (SD 5.71) in PIVC 2 (P<0.001). The angle of infusates flow was 0 degrees in 90% of PIVC 1 compared to just 16.7% in PIVC 2 (P<0.001). Directional flow patterns were also different between groups. For PIVC 1 40% had posterior flow pattern while no PIVC 2 had posterior flow (P=0.000). The quality of flow was also different with 40% of PIVC 1 demonstrating retrograde flow compared to 16.7% of PIVC 2 (P=0.041) (Table 2).

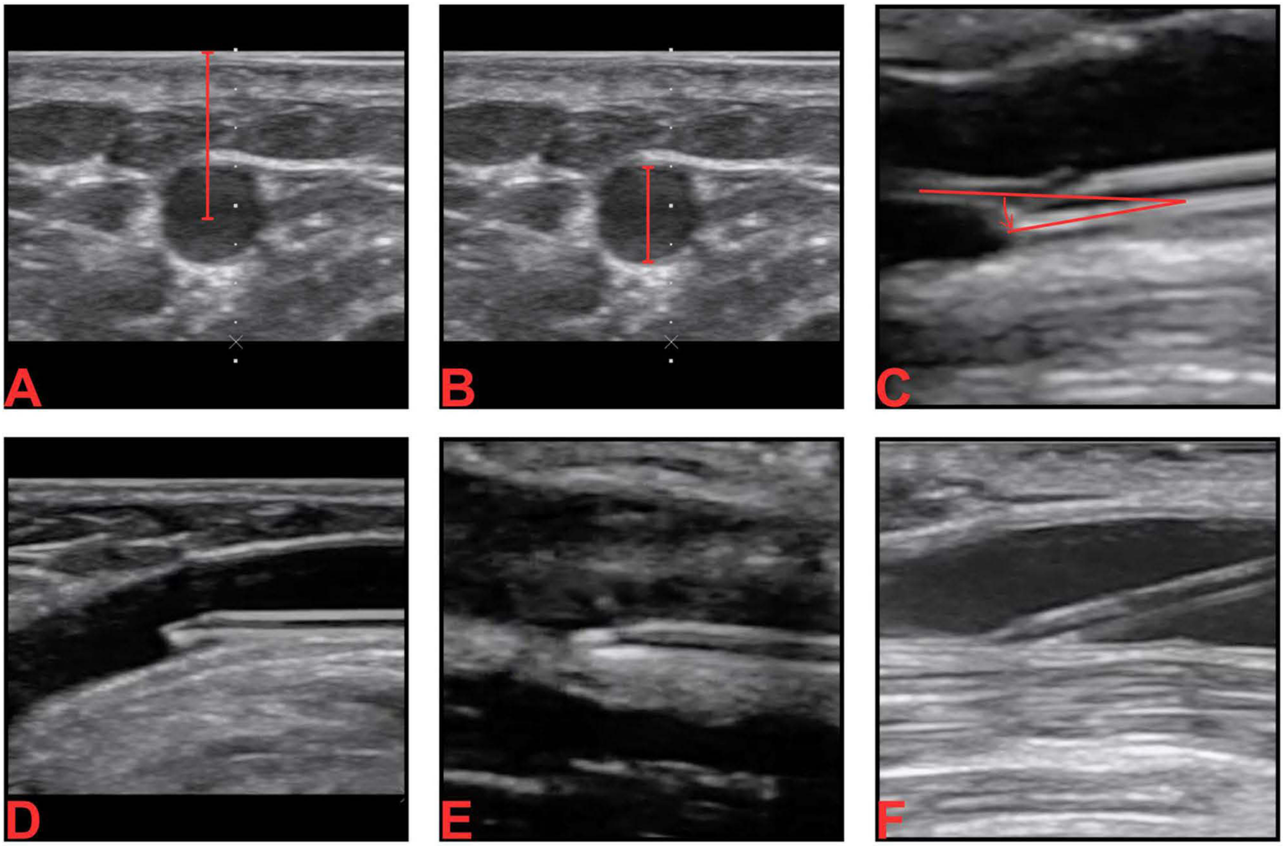

Figure 2 Example ultrasound images from study. (**A**) Short axis image demonstrating vein depth, measuring from top of image to middle of vein. (**B**) Short axis image demonstrating vein diameter. (**C**) Long axis image demonstrating angle of infusate. (**D**) Example image in long axis of catheter angled towards anterior wall. (**E**) Example image in long axis of catheter parallel in vein. (**F**) Example image in long axis of catheter angled towards posterior wall.

Discussion

This study found that the modified-tip PIVC redirects infusates away from the glycocalyx and intimal wall, contrasting with the standard-tip PIVC. In most cases (83.3%), flow patterns angled away from the vein wall with the modified tip, compared to only 10% with the standard tip. This redirection, facilitated by the off-axis catheter design, channels

Table 1 Demographics, PIVC Insertion-Related Characteristics, and PIVC Ultrasound Characteristics for PIVC #1 and PIVC #2

Variables*	All	PIVC #1	PIVC #2	P value
n	28	10 (35.7%)	18 (64.3%)	
Demographics				
Age, years				
Mean (SD)	53.71 (22.65)	52.60 (27.58)	54.33 (20.28)	0.701†
Sex				
Female	15 (53.6%)	5 (50.0%)	10 (55.5%)	1.000‡
Race				
White	17 (60.7%)	7 (70.0%)	10 (55.5%)	0.479‡
Black	9 (32.1%)	2 (20.0%)	7 (38.9%)	
Other	2 (7.1%)	1 (10.0%)	1 (5.6%)	
Body mass index, kg/m2				
Mean (SD)	28.51 (7.10)	27.12 (7.58)	29.28 (6.92)	0.388†

(*Continued*)

Table 1 (Continued).

Variables*	All	PIVC #1	PIVC #2	P value
PIVC Insertion-Related Characteristics				
Vascular access score				
1	11 (39.3%)	4 (40.0%)	7 (38.9%)	1.000‡
2	17 (60.7%)	6 (60.0%)	11 (61.1%)	
Laterality				
Right	19 (67.9%)	6 (60.0%)	13 (72.2%)	0.678‡
Location				
Antecubital	11 (39.3%)	5 (50.0%)	6 (33.3%)	0.444‡
Forearm	17 (60.7%)	5 (50.0%)	12 (66.7%)	
Number of attempts				
1	25 (89.3%)	8 (80.0%)	17 (94.4%)	0.284‡
2	3 (10.7%)	2 (20.0%)	1 (5.6%)	
Gauge				
20	28 (100.0%)	10 (100.0%)	18 (100.0%)	
Length, cm				
2.95	10 (35.7%)	10 (100.0%)	0 (0.0%)	N/A
3.68	18 (64.3%)	0 (0.0%)	18 (100.0%)	
PIVC Ultrasound Characteristics				
Vein diameter, cm				
Mean (SD)	0.37 (0.06)	0.35 (0.07)	0.37 (0.06)	0.349†
Vein depth, cm				
Mean (SD)	0.45 (0.14)	0.41 (0.15)	0.47 (0.13)	0.113†
Tip angle against nearest wall, degrees				
Mean (SD)	3.46 (4.99)	7.00 (3.31)	1.50 (3.31)	0.012†
Vein wall contact				
Yes	23 (82.1%)	10 (100.0%)	13 (72.2%)	0.128‡
Catheter tip direction				
Parallel	17 (60.7%)	4 (40.0%)	13 (72.2%)	0.018‡
Posterior	8 (28.6%)	6 (60.0%)	2 (11.1%)	
Anterior	3 (10.7%)	0 (0.0%)	3 (16.7%)	
Distance from catheter tip to nearest wall, cm				
Mean (SD)	0.02 (0.04)	0.00 (0.00)	0.03 (0.05)	0.045†

Notes: *Continuous variables represented by mean (standard deviation). †Kruskal–Wallis rank sum test. ‡Fisher's Exact Test.
Abbreviations: PIVC, peripheral intravenous catheter; SD, standard deviation.

infusions centrally toward the faster-flowing blood, reducing chemical insult and ensuing endothelial damage and thrombus formation.[7] Even when the modified tip angled posteriorly towards the wall, flow shifted towards areas of higher hemodilution, potentially reducing shear stress. Unexpectedly, significant retrograde flow was sonographically apparent in the standard-tip PIVC, likely due to its inherent disruption of flow dynamics. Studies show a 93% reduction in flow rates with peripherally inserted central catheters,[14] indicating the importance of solutions that counter the natural tendencies of catheters to reduce flow and induce vein wall injury.

Optimizing the flow of infusates involves refining the position of the PIVC tip. In this study, the modified-tip catheter had a less acute tip angle compared to the traditional catheter, allowing for more central distribution within the vessel. This positioning promotes greater hemodilution and reduces shear stress. Tip angle and proximity to the vein wall significantly influence wall shear stress, with higher angles and closer proximity increasing complication risk.[7] Studies have shown a 37% increase in phlebitis with a tip angle exceeding 5.8 degrees and a 4.39 times higher risk of thrombosis with a tip angle surpassing 5 degrees.[15–17] Controlling the position of the PIVC tip is crucial due to its common movement in clinical settings. Recent research utilizing ultrasound to evaluate PIVCs shows that external forces universally induce PIVC movement, often leading to

Table 2 Outcomes for PIVC #1 and PIVC #2

Variables*	All	PIVC #1	PIVC #2	P value
Primary Outcome				
Angle of infusate flow, degrees				
Mean (SD)	4.96 (5.81)	0.20 (0.63)	7.61 (5.71)	<0.001†
Angle of infusate flow				
0 degrees	12 (42.9%)	9 (90.0%)	3 (16.7%)	<0.001‡
>0 degrees	16 (57.1%)	1 (10.0%)	15 (83.3%)	
Secondary Outcomes				
Flow pattern				
Parallel	9 (32.1%)	5 (50.0%)	4 (22.2%)	0.000‡
Posterior	4 (14.3%)	4 (40.0%)	0 (0.0%)	
Anterior	15 (53.6%)	1 (10.0%)	14 (77.8%)	
Majority flow type				
Laminar	24 (85.7%)	8 (80.0%)	16 (88.9%)	0.602‡
Turbulent	4 (14.3%)	2 (20.0%)	2 (11.1%)	
Majority retrograde flow				
Yes	5 (17.9%)	4 (40.0%)	1 (16.7%)	0.041‡
Vasospasm at tip				
Yes	6 (21.4%)	3 (30.0%)	3 (10.7%)	0.635‡

Notes: *Continuous variables represented by mean (standard deviation). †Kruskal–Wallis rank sum test. ‡Fisher's Exact Test.
Abbreviation: PIVC, peripheral intravenous catheter; SD, standard deviation.

significant contact with the vein wall and failure.[18,19] As this movement contributes to mechanical vein wall injury, precise control of the PIVC tip position is essential for enhancing outcomes.

Enhancing the PIVC tip angle and tip position is achieved by selecting a longer catheter length. Longer catheters enable a more parallel alignment of the PIVC with the vessel, promoting smooth gliding along the vein wall compared to acute angling, which can cause the catheter to push into the vein wall. Studies by Bahl et al recommend that for ultrasound-guided insertions in deeper veins, a minimum of 2.75 centimeters of catheter should reside in the vein to reduce failure rates, adding an average of 44 hours of dwell time.[20] This principle likely extends to traditionally placed PIVCs, especially considering that in this study, the average vein depth was 0.45 cm. Consequently, approximately 60% of shorter, standard 2.95 cm PIVCs had tips projecting into the posterior wall due to inadequate length for parallel alignment, potentially increasing wall shear stress. Conversely, longer 3.68 cm modified-tip catheters offer better vein purchase, allowing for a lower tip angle and reducing the risk of catheter and chemical induced vein wall injury.

Limitations

This study has some limitations. First, it is an exploratory retrospective analysis that was conducted as part of a quality improvement project. While PIVCs were evaluated using a standard sonographic approach, there was no randomization or blinding and a small number of cases. Second, while there are theoretical advantages of an off-axis aperture, the downstream complications of catheters were not assessed for admitted patients so the clinical significance of the results needs further inquiry. Third, while this study focuses on modification of the PIVC tip to reduce vein wall injury, other strategies such as tissue adhesives, integrated catheters, or other changes to catheter composition may provide similar results.[21–23] Finally, the sonographic flow patterns assessed during flushing might not directly translate to the administration of other infusates, especially those administered at slower rates. A computational fluid dynamics study revealed increased wall shear stress with higher infusion rates.[7] Nevertheless, since flushing is a routine part of PIVC maintenance conducted multiple times daily, these findings hold relevance for everyday care.

Conclusions

In this exploratory investigation, a peripheral vascular access device with an off-axis aperture of the tip demonstrated a more acute angle of infusates flow away from the vein wall than a traditional device with a central opening. Shifting flow away from the vein wall may reduce mechanical insults to the vein and reduce complications. Further research is needed to pair clinical outcomes with this technology.

Data Sharing Statement

The data that support the findings of this study are available via a data access agreement. Please contact the corresponding author for this request.

Ethics Committee Statement

This research was conducted according to the guidelines of the Declaration of Helsinki. Corewell Health Institutional Review Board reviewed and approved this study. Informed consent was waived by the IRB given the retrospective nature of data collection.

Acknowledgments

The authors applaud Nicholas Mielke, MD, for his assistance in statistical analysis for this publication.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This research received no specific grant from any funding agency in public, commercial, or not-for-profit sectors.

Disclosure

AB has research grant support from B. Braun Medical, Becton-Dickinson, Teleflex, Adhezion, Medline Industries, and Moderna. AB is a paid consultant Lineus Medical, Skydance Vascular, and Fujifilm Sonosite. In addition, AB has a patent US 11,791,049 issued to A Little Cold Gel, LLC and a patent Operation STICK issued to Operation STICK, LLC. SMG is a paid consultant for Lineus Medical, Nexus Medical, PICC Excellence, and Fujifilm Sonosite. The authors report no other conflicts of interest in this work.

References

1. Kaphan K, Auypornsakul S, Somno J, et al. The Prevalence and Associated Factors of Peripheral Intravenous Complications in a Thai Hospital. *J Infusion Nurs*. 2024;47(2):120–131. doi:10.1097/NAN.0000000000000538
2. Statistics CNCfH. Emergency Department Visits: reviewed 5/13/2024. Available from: https://www.cdc.gov/nchs/fastats/emergency-department.htm. Accessed September 02, 2024.
3. Kache S, Patel S, Chen NW, et al. Doomed peripheral intravenous catheters: bad Outcomes are similar for emergency department and inpatient placed catheters: a retrospective medical record review. *J Vasc Acc*. 2022;23(1):50–56. doi:10.1177/1129729820974259
4. Helm RE, Klausner JD, Klemperer JD, et al. Accepted but unacceptable: peripheral IV catheter failure. *J Infusion Nurs*. 2015;38(3):189–203. doi:10.1097/NAN.0000000000000100
5. Reitsma S, Slaaf DW, Vink H, et al. The endothelial glycocalyx: composition, functions, and visualization. *Pflügers Archiv-Euro J Physiol*. 2007;454:345–359. doi:10.1007/s00424-007-0212-8
6. Lin C, Kaper HJ, Li W, et al. Role of endothelial glycocalyx in sliding friction at the catheter-blood vessel interface. *Sci Rep*. 2020;10(1):1–10. doi:10.1038/s41598-019-56847-4
7. Piper R, Carr PJ, Kelsey LJ, et al. The mechanistic causes of peripheral intravenous catheter failure based on a parametric computational study. *Sci Rep*. 2018;8(1):1–12. doi:10.1038/s41598-018-21617-1
8. Drouet M, Chai F, Barthélémy C, et al. Influence of vancomycin infusion methods on endothelial cell toxicity. *Antimi Agen Chem*. 2015;59(2):930–934. doi:10.1128/AAC.03694-14

9. Manrique-Rodríguez S, Heras-Hidalgo I, Pernia-López MS, et al. Standardization and Chemical Characterization of Intravenous Therapy in Adult Patients: a Step Further in Medication Safety. *Drugs R&D*. 2020;1–26.
10. Borgonovo F, Quici M, Gidaro A, et al. Physicochemical characteristics of antimicrobials and practical recommendations for intravenous administration: a systematic review. *Antibiotics*. 2023;12(8):1338. doi:10.3390/antibiotics12081338
11. Moureau NL Vessel health and preservation: the right approach for vascular access; 2019.
12. Nickel B, Gorski L, Kleidon T, et al. Infusion Therapy Standards of Practice. *J Infusion Nurs*. 2024;47(1S):S1–S285. doi:10.1097/NAN.0000000000000532
13. Bahl A, Mielke N, Diloreto E, et al. Operation STICK a vascular access specialty program for the generalist emergency medicine clinician. *J Vasc Acc*. 2024;1–10. doi:10.1177/11297298231222060
14. Nifong TP, McDevitt TJ. The effect of catheter to vein ratio on blood flow rates in a simulated model of peripherally inserted central venous catheters. *Chest*. 2011;140(1):48–53. doi:10.1378/chest.10-2637
15. Tanabe H, Murayama R, Yabunaka K, et al. Low-angled peripheral intravenous catheter tip placement decreases phlebitis. *J Vasc Acc*. 2016;17 (6):542–547. doi:10.5301/jva.5000601
16. Tanabe H, Takahashi T, Murayama R, et al. Using ultrasonography for vessel diameter assessment to prevent infiltration. *J Infusion Nurs*. 2016;39 (2):105–111. doi:10.1097/NAN.0000000000000159
17. Mielke N, Johnson S, Karabon P, et al. A prospective sonographic evaluation of peripheral intravenous catheter associated thrombophlebitis. *J Vasc Acc*. 2021;1–10. doi:10.1177/11297298211020150
18. Bahl A, Clement V, DiLoreto E, et al. Evaluating the impact of external forces on peripheral intravenous catheter movement using ultrasound: a randomized pilot study. *J Vasc Acc*. 2024;1–7. doi:10.1177/1129729823122205
19. Giustivi D, Celano R, Cattalani M, et al. Ultrasound assessment of short peripheral catheter failure. *J Vasc Acc*. 2024;11297298241261146. doi:10.1177/11297298241261146
20. Bahl A, Hijazi M, Chen N-W, et al. Ultralong versus standard long peripheral intravenous catheters: a randomized controlled trial of ultrasonographically guided catheter survival. *Ann Emerg Med*. 2020;76(2):134–142. doi:10.1016/j.annemergmed.2019.11.013
21. Bahl A, Gibson SM, Jankowski D, et al. Short peripheral intravenous catheter securement with cyanoacrylate glue compared to conventional dressing: a randomized controlled trial. *J Vasc Acc*. 2021;22:1–12. doi:10.1177/11297298211020150
22. Gidaro A, Quici M, Giustivi D, et al. Integrated short peripheral intravenous cannulas and risk of catheter failure: a systematic review and meta-analysis. *J Vasc Acc*. 2024;1–9. doi:10.1177/11297298231218468
23. Matthews R, Gavin NC, Marsh N, et al. Peripheral intravenous catheter material and design to reduce device failure: a systematic review and meta-analysis. *Infec Dis Health*. 2023;298–307. doi:10.1016/j.idh.2023.05.005