Identifying Predictors of Peripheral Intravenous Catheter Failure Using a Novel Combination of Clinical and Ultrasonographic Assessments

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Research Article

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Abstract

Objective:

Peripheral intravenous catheter (PIVC) failure occurs frequently, but the underlying mechanisms of failure are poorly understood. We aim to identify factors that predict premature PIVC failure.

Methods:

We conducted a single site prospective observational investigation at an academic tertiary care center. Adult emergency department (ED) patients who underwent traditional PIVC placement in the ED and required admission with an anticipated hospital length of stay greater than 48 hours were included. Ongoing daily PIVC assessments included clinical and ultrasonographic evaluations. The primary goal was to identify demographic, clinical, and PIVC related variables that predicted PIVC failure. Univariate and multivariate analyses were employed to identify risk factors for PIVC failure.

Results:

In July and August of 2020, 62 PIVCs were enrolled. PIVC failure occurred in 24 (38.71%) participants. Multivariate logistic regression demonstrated that the presence of subcutaneous edema [AOR 8.29 (1.50, 45.8) p = 0.0153], an above average neutrophil to lymphocyte (N:L) ratio [AOR 4.63 (1.06, 20.3) p = 0.0422], and the administration of an irritant/vesicant [10.3 (1.46, 72.6) p = 0.0.192] were associated with increased likelihood of premature PIVC failure.

Conclusions:

PIVC failure is related to clinical and ultrasonographic variables associated with inflammation: elevated N:L ratio, use of caustic medications, and presence of subcutaneous edema on ultrasound. Reducing inflammation of the vein may lead to better PIVC survival outcomes. Further large-scale randomized controlled trials are needed to validate and build upon the concepts in this study.

Introduction

The placement of peripheral intravenous catheters (PIVC) is the most commonly performed invasive procedure in the acute care clinical setting with over 300 million PIVCs inserted annually in the United States alone.[1–3] Up to 90% of hospitalized patients require a PIVC for therapy with many patients relying on functional vascular access for the delivery of life-saving fluids and medications.[1] Unfortunately, PIVCs have high failure rates ranging from 36% to 63% leading to significant patient safety and cost implications.[2–4] Patients may suffer a multitude of sequelae from PIVC failure including extravasation with skin necrosis, catheter associated bloodstream infections, interruption of medical therapies, and longer hospital stays.[5–7] Further, PIVC failure results in additional invasive procedures to obtain vascular access often requiring multiple needle sticks and reinsertions that may lead to venous depletion leaving

limited or no viable peripheral venous access options. Once venous depletion develops PIVC insertion becomes more difficult and it is estimated that up to 3% of patients require a central venous access device.[8]

A better understanding of the etiology of PIVC failure is critical to improve patient outcomes. Most of the existing literature highlights the various causes of PIVC failure (phlebitis, infiltration, occlusion) but as presence of these complications generally equates to need for catheter removal, once the complication is externally evident, little can be done to reverse course.[9] Prevention of these complications requires focusing on the changes beneath the skin that begin soon after PIVC insertion and progress over time.[10,11] Thus, investigating the anatomical changes at the subcutaneous level after PIVC insertion may unlock the secret to improved survivorship. Some recent exploratory data indicates that PIVC failure is due to ongoing inflammation of the vein.[12,13] Internally, venous changes can include narrowing of vein wall, wall thickening, and presence of thrombus even in the absence of any clinical signs and symptoms.[11] The incorporation of venous duplex ultrasonography to the site evaluation provides an objective means to characterize the ongoing changes underneath the skin and may help identify inflammatory variables that lead to PIVC failure.

The goal of this investigation is to create a predictive model for PIVC failure based upon our hypothesis that inflammation is the root cause of the problem. We aim to use demographic, clinical, and sonographic variables to identify risk factors associated with PIVC failure.

Materials And Methods

Study Design, Setting, and Selection of Participants

This study was a prospective observational investigation of PIVC failure. The study was conducted at a large 1100 bed tertiary care center with an annual ED census of greater than 130,000 visits. The Beaumont Institutional Review Board (IRB) approved this study.

Study investigators recruited a convenience sample of ED patients meeting inclusion criteria. Patients aged at least 18 years with anticipated hospitalization of greater than 48 hours and a PIVC placed using direct visualization and/or palpation in the ED were eligible participants. Patients admitted to the high acuity progressive and intensive care units were specifically targeted to increase the likelihood of meeting the minimum hospital length of stay goal of 48 hours. Patients were excluded if they voluntary withdrew or were cognitively impairment. Additionally, if the PIVC was inserted with ultrasound guidance or if the first sonographic assessment could not be conducted within 24 hours of PIVC placement then the patient was not eligible for enrollment. Informed consent was obtained for all subjects prior to enrollment in the study. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the Declaration of Helsinki.

Study Procedure

After patient enrollment, researchers performed an initial assessment of the patient. Pertinent demographic and clinical data was abstracted from the electronic medical record (EMR) and included age, body mass index, admission blood pressure, admission heart rate, gender, smoking history, pre-existing medical conditions (diabetes, deep vein thrombosis history, clotting disorder, cancer), and use of anticoagulant medications.

PIVC function was confirmed by clinical assessment (per institutional standard), in which a functional PIVC can be flushed without resistance and shows no external signs of unresolvable complication. PIVC complications include pain and/or tenderness, redness, and leaking or swelling around the PIVC site. PIVC failure was defined as failure of functionality based upon the clinical treatment team's impression. Next, the investigator performed a sonographic evaluation of the PIVC and surrounding area using a uniform scanning technique that has been previously described in the literature.[14] Study investigators trained in using ultrasound were responsible for obtaining images. The Mindray M7 Ultrasound Machine with a 14 MHz high frequency linear array transducer was used for all sonographic evaluations. After a small amount of sterile gel was placed on the non-bordered transparent dressing proximal to the PIVC insertion site, the PIVC and surrounding tissue was scanned proximally (towards the heart) 10 cm (length) x 5 cm (width) in short axis extending from the hub of the PIVC. Similar scanning was performed over the same area in the long axis. Appendix A demonstrates scan area. Adequate placement of the PIVC within the vein was confirmed using ultrasound. Gel was wiped off the dressing and skin after the imaging took place.

A series of cine clips (five seconds duration) of the scan area were recorded. All ultrasound images were saved and archived in QPath, a secure and Health Insurance Portability and Accountability Act (HIPPA) compliant storage warehouse for review and interpretation by the Emergency Ultrasound Director. The following measurements were made by post-processing of the original images: catheter-to-vein ratio, length of catheter in vein, angle of insertion, angle of distal tip against vessel wall, vein wall thickness, distance of catheter tip to vessel wall, degree of catheter kinking, and size of thrombus formation (Appendix B).

Investigators performed follow-up ultrasound and clinical assessments on all catheters daily for the life of the PIVC. At each follow-up interval, the researcher documented the time of evaluation and performed a sonographic assessment using the identical method as described above for the initial assessment. These images were also saved and archived similar to the index evaluation.

Clinical staff documents functional status of PIVCs in the EMR as a standard of care measure within our institution. Daily assessment of catheter function was accomplished by reviewing this documentation in the EMR for any notation of catheter failure and complications. If the investigators had any questions or concerns regarding the functionality of the PIVC, clinical staff was brought to the bedside to reassess functionality the PIVC. If the catheter failed or was removed prior to a follow-up assessment, the PIVC failure time, assessment of failure, and reason for line removal was obtained though EMR review and discussion with the nursing staff when possible.

Within 24 hours of PIVC placement, researchers used ultrasound to assess the PIVC site by measuring the diameter of the vein, length of the catheter in the vein, the angle of PIVC insertion, and the angle of the distal tip of the catheter to the vessel wall (Appendix B). After initial assessment of the PIVC, researchers continued to monitor the PIVC and surrounding tissue on a daily basis to follow the progression of the complication. Daily measurements included vein wall thickness, distance of catheter tip to vessel wall, degree of catheter kinking, as well as the assessment of thrombus or subcutaneous edema (Appendix C).

During every ultrasound evaluation, the insertion site was examined by the researcher and assessed using a standardize visual phlebitis scale.[9] The participant was considered symptomatic if they received a score of grade 1 or greater based on a standardized phlebitis scale, which includes the presence of erythema, pain, and/or edema at the access site.[9] All medications administered through each catheter was queried and cross referenced against known irritants and vesicants, as defined by the Infusion Nursing Society.[15] Frequency of administration and dosages were recorded. Beyond vesicants and irritants, the number of overall catheter events were recorded. A catheter event was defined as any instance where fluid was administered through the catheter, including administration of a bolus, initiation of a drip, non-irritant medication administration. Flushing was considered a component of routine care and PIVC maintenance and was not considered an independent event.

Outcome Measures

The primary endpoint was to identify risk factors associated with premature PIVC failure.

Statistical Rationale and Analysis

Continuously measured variables were displayed in terms of mean/average with standard deviation while categorical variables were displayed as frequencies with percentages in parentheses. Univariate, or unadjusted, analysis was performed. Continuous variables were stratified by catheter failure and compared using a Two Samples Independent T-Tests. Categorical variables also were stratified by catheter failure and compared using Chi-Square tests. Odds Ratios (OR) with corresponding 95% Confidence Intervals (95% CI) also were displayed for categorical variables. In addition, univariate logistic regression models were used and results were displayed in terms of Odds Ratios (OR) with corresponding 95% CI and P-Values. Kaplan-Meier Curves were graphically generated to show the difference in time-to-event outcomes in selected characteristics.

Multivariate/adjusted models also were generated as part of this study. Variables included in these models were chosen by all authors based on clinical rationale and the univariate/unadjusted findings. Firth's Penalized Likelihood was employed to mitigate the potential bias caused by the relatively small sample.[16] A multivariate logistic regression model was used. Effect sizes were shown in terms of Adjusted Odds Ratios (AOR) with 95% CI and P-Values for the logistic model.

P-Value < 0.05 indicates a statistically significant finding. All significant findings represent associations as no formal attempts were made to identify cause-and-effect, or causal, relationships. All analysis was

performed in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

In July and August of 2020, 77 patients were consented for the study, of these, 15 participants were excluded. 11 of these patients were lost to follow up (5 PIVCs failed and 7 patients were discharged prior to the first ultrasound evaluation), 3 PIVCs were excluded as two had incomplete PIVC documentation in the chart and one patient voluntarily withdrew from the study. Of the remaining 62 PIVCs, 24 (38.7%) met criteria for premature failure and 38 (61.2%) survived to completion of therapy. The mean catheter dwell time was 76.42 hours (SD = 66.60).

Patient characteristics and comorbidities were similar between the catheters that failed and survived to completion of therapy (all $P \geq 0.05$). Among the 62 patients in the final cohort, 53 had available complete blood count with differential data from admission and were assessed for neutrophil and lymphocyte. The average neutrophil count in failed PIVCs was 10.77 (SD = 4.15), vs 5.41 ($P < 0.0001$) in PIVCs that survived to treatment completion. Similarly, the average Neutrophil to Lymphocyte (N:L) ratio was 12.12 (SD = 8.52) in the failed PIVC group, compared to 5.29 (SD = 4.44) in the group of PIVCs that survived to completion of therapy (P = 0.0018) (Table 1).

Our analysis showed a significant association between subcutaneous edema and catheter failure; while 57.14% of PIVC's that had subcutaneous edema failed, only 14.81% of PIVC's without subcutaneous edema failed (P = 0.0020) (Figure 1A). There is also a significant association between premature catheter failure and the administration of vesicants/irritants (P = 0.0064) (Figure 1B). There also are findings linking catheter failure to usage of the PIVC. The number of catheter events that occurred during the life of the catheter in the survival group was 3.39, which was significantly less than the failure group at 5.58 (P = 0.0011). In terms of the number of days the catheter is idle, the average percent of days idle for the survival group was 38%, compared to just 6% in the failure group ($P < 0.0001$) (Table 2).

Unadjusted for other factors, logistic regression analysis demonstrated that subcutaneous edema was associated with 6.91-fold greater odds of catheter failure (P = 0.0020). At the time of admission, those with an N:L ratio of ≥ 8.1 demonstrated 6.85-fold greater odds of catheter failure (P = 0.0029). Patients with more than one PIVC present throughout their hospital course were associated with greater odds of catheter failure (OR = 6.53; P = 0.0044). In regards to IV infusates, the administration of vesicants/irritants was linked to 8.95-fold greater odds of premature catheter failure (P = 0.0064) (Table 3).

Multivariate logistic regression analysis, which was adjusted for other factors, demonstrated subcutaneous edema was independently associated with 8.29-fold greater odds of premature catheter failure (P = 0.0153). Additionally, those with N:L ratio of ≥ 8.1 had 4.63-fold greater odds of premature catheter failure (P = 0.0422). Furthermore, administration of a vesicant/irritant to the PIVC was associated with 10.3-fold greater odds of premature PIVC failure (P = 0.0192) (Table 3).

Discussion

We found that the presence of subcutaneous edema, a N:L ratio of ≥8.1, and administration of vesicants/irritants were predictive of PIVC failure. These results supported our hypothesis that inflammation is a major contributor to poor PIVC survivorship. Our study added to the growing body of literature that has identified subcutaneous edema, a marker of inflammation, as a relevant variable in PIVC outcomes. Further, to our knowledge, this is the first investigation that identifies subcutaneous edema as a major predictor of PIVC failure. Additionally, we discovered that an increased neutrophil to lymphocyte ratio increased the risk of PIVC failure, suggesting further investigation is needed to better understand these mechanisms on a cellular level.

Existing prediction models for PIVC failure are sparse. In one multivariate analysis, traditional inserter-related variables such as catheter diameter and site of insertion were linked to PIVC failure.[1] The authors concluded that smaller catheter diameters and forearm placement were associated with the best PIVC survival rates. As the wrist and hands have the worst outcomes and no catheters in our study were placed in these locations, this variable was not a relevant predictor in our cohort.[4] Additionally, a catheter to vein ratio of less than 0.33 has been identified as a risk factor for catheter failure. In our study over 80% of the catheters were 20-gauge in diameter and the average catheter to vein ratio was 0.36, suggesting that the impact of catheter diameter on PIVC failure was also likely minimal in our cohort.[17] Despite what would appear as optimal PIVC conditions according to prior research, we still noted a high failure rate of 38.7% highlighting the need for further investigation.

Other trials have recently implicated mechanical irritation of the vein wall as a strong predictor of catheter-induced inflammation. In an analysis on the location of catheter tip position within the vein, Murayama et al. found that contact of the tip against the vein wall was associated with subcutaneous edema on ultrasound.[14] Another study in an animal model found that modification of the catheter with the goal of reducing contact against the vein wall led to a 40% reduction in subcutaneous edema.[18] In our study, not only did we identify that subcutaneous edema existed in the majority of our insertions, but we also found that subcutaneous edema on ultrasound was a significant predictor of PIVC failure, a key clinical outcome measure. However, unlike previous investigations, we tracked onset and progression of subcutaneous changes using an innovative methodology inclusive of daily ultrasound site assessments. Serial tracking helped identify that the location of the tip of the catheter was not a static condition, but rather a variable that potentially changed daily. In 44 (71%) cases, the catheter tip to wall distance varied among serial ultrasound evaluations. In 87% of cases, the catheter tip contacted the vein wall at least once during its lifespan illustrating that irritation from the tip likely occurs in more PIVCs than previously reported.[14] It also highlights that PIVC tip position is not a static variable and natural ebbs and flows in the degree of inflammation caused by mobility of the catheter should be considered when seeking solutions to the PIVC failure problem.

We identified that ultrasonographic changes began very early after PIVC insertion.

Indeed, laboratory models have demonstrated that the release of inflammatory and pro-thrombotic markers begins as early as the initial IV needlestick.[19] We found that thrombosis was a nearly universal occurrence with 87% of PIVCs having some degree of catheter-associated thrombosis. This is likely due to the initial cascade of inflammatory markers that is released during PIVC insertion.[14] We noted that in many cases, thrombus formation occurred rapidly, with 52% of patients developing thrombosis within 24 hours of PIVC placement. However, not all thrombosis was clinically significant. We noticed that a subset of patients had no progression or change in the ultrasonographic site assessment, while a larger group had significant progression and eventual development of subcutaneous edema. These findings suggest that while initial release of inflammatory and pro-thrombotic markers is likely inevitable, their continued release is a key step in premature PIVC failure. Therefore, to improve PIVC survival methods to reduce continued inflammatory marker release are needed. While reducing continued inflammatory marker release is likely achievable by mechanical modification of the PIVC position, our research also elucidated another potential target to help reduce the rate of PIVC failure.

Cellular models show that significant ongoing inflammatory marker release results in local neutrophil recruitment, activation, and neutrophil extracellular trap (NET) formation. NET formation has recently been implemented in a variety of pathologic, pro-thrombotic, conditions such as stroke, myocardial infarction, and deep venous thrombosis.[20] Thrombosis in the presence of NETs is resistant to normal mechanisms of clot degradation.[20] We found that increased neutrophil to lymphocyte N:L ratio as well as a higher circulating neutrophil count was predictive of PIVC failure. In multivariate analysis, we found that N:L ratio of $\geq$ 8.1 had 4.63-fold greater odds of premature catheter failure. Our data confirms that while thrombus was almost universal, only once significant signs of inflammation were present did premature PIVC failure occur. Therefore, ongoing inflammatory marker release resulting in local neutrophil activation which leads to “inflammatory NET thrombus” is likely a key component of premature catheter failure. Thus, in addition to modifying mechanical PIVC factors to reduce ongoing inflammation, another strategy to increase PIVC survival may be prevention of NET thrombosis formation, rather than simple antithrombogenic coatings that have been recommended previously.

This study took place during the COVID pandemic, thus only a small sample size was obtained due to personal protective equipment limitations and research regulations within the hospital. Given the small sample size, effects of certain variables on PIVC failure may be underestimated, particularly factors with marginal significance. Further, the findings may not be generalized to all settings as the study was conducted at a large academic tertiary care center with a unique population. Additionally, if the PIVC failed or patients were discharged during off hours, the final determination of whether a PIVC was considered a success or failure was based on documentation within the study participant’s medical record. In some instances, the researchers found PIVCs with sonographic signs of severe inflammation, but clinical staff was not available to perform bedside functionality assessment of the catheter. It is possible that there may have been a delay in the recognition of PIVC complication and failure in some cases.

This study's findings demonstrate that the presence of subcutaneous edema, an increasing N:L ratio, and the administration of vesicants/irritants increase the risk of premature PIVC failure. Inflammation plays a key role in precipitating PIVC failure and solutions targeting reduction in inflammation may substantially improve PIVC outcomes. Additional larger, prospective research investigations are needed to validate and build upon these findings.

Declarations

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Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: AB, NM; data collection: AB, SJ, NM; analysis and interpretation of results: AB, SJ, NM, PK; draft manuscript preparation: AB, SJ, NM, PK. All authors reviewed the results and approved the final version of the manuscript.

Additional Information

The authors declare no competing interests.

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Tables

Table 1: Patient Characteristics, Comorbidities, Vital Signs, Lab Values, & IV Insertion Characteristics

	All PIVCs (n = 62)	Failed (n = 24)	Survived (n = 38)	P-Value
Patient Characteristics				
Age of Patient (Years)				
Mean (Standard Deviation)	67.18 (19.25)	65.79 (18.12)	68.05 (20.12)	0.6561
Gender				
Male	32 (51.61%)	14 (43.75%)	18 (56.25%)	
Female	30 (48.39%)	10 (33.33%)	20 (66.67%)	0.4178
Body Mass Index (BMI) of Patient				
Mean (Standard Deviation)	28.22 (6.82)	29.22 (7.26)	27.58 (6.56)	0.3632
Comorbidities				
History of Smoking				
No	32 (51.61%)	13 (40.63%)	19 (59.38%)	
Yes	30 (48.39%)	11 (36.67%)	19 (63.33%)	0.7588
History of Diabetes				
No	45 (72.58%)	15 (33.33%)	30 (66.67%)	
Yes	17 (27.42%)	9 (52.94%)	8 (47.06%)	0.1735
History of Active Cancer				
No	54 (87.10%)	22 (40.74%)	32 (59.26%)	
Yes	8 (12.90%)	2 (25.00%)	6 (75.00%)	0.4820
History of Previous DVT				
No	55 (88.71%)	20 (36.36%)	35 (63.64%)	
Yes	7 (11.29%)	4 (57.14%)	3 (42.86%)	0.3243
Personal History of Clotting Disorder				
No	54 (87.10%)	19 (35.19%)	35 (64.81%)	
Yes	8 (12.90%)	5 (62.50%)	3 (37.50%)	0.1774
Currently on Anticoagulant Medication				
No	45 (72.58%)	18 (40.00%)	27 (60.00%)	
Yes	17 (27.42%)	6 (35.29%)	11 (64.71%)	0.7676
Vital Signs at Time of Admission				

Systolic Blood Pressure at Admission				
Mean (Standard Deviation)	131.95 (20.82)	126.08 (18.68)	135.66 (21.47)	0.0775
Heart Rate at Admission				
Mean (Standard Deviation)	84.56 (22.14)	98.75 (22.01)	75.61 (17.15)	< 0.0001
Lab Values at Time of Admission				
Neutrophils	**(n = 53)**	**(n = 22)**	**(n = 31)**	
Mean (Standard Deviation)	7.64 (4.36)	10.77 (4.15)	5.41 (2.94)	< 0.0001
NL Ratio	**(n = 53)**	**(n = 22)**	**(n = 31)**	
Mean (Standard Deviation)	8.12 (7.23)	12.12 (8.52)	5.29 (4.44)	0.0018
NL Ratio ≥ 8.5	**(n = 53)**	**(n = 22)**	**(n = 31)**	
Yes	17 (32.08%)	12 (70.59%)	5 (29.41%)	0.0066
No	36 (67.92%)	10 (27.78%)	26 (72.22%)	
Lymphocytes	**(n = 53)**	**(n = 22)**	**(n = 31)**	
Mean (Standard Deviation)	1.31 (0.72)	1.20 (0.77)	1.38 (0.69)	0.3726
IV Insertion Characteristics				
Laterality of Successful Cannulation				
Left	27 (43.55%)	12 (44.44%)	15 (55.56%)	0.4282
Right	35 (56.45%)	12 (34.29%)	23 (65.71%)	
Location of IV				
Antecubital	47 (75.81%)	20 (42.55%)	27 (57.45%)	
Forearm	15 (24.19%)	4 (26.67%)	11 (73.33%)	0.3180
>1 IV Placed During Hospital Course				
No	47 (75.81%)	13 (27.66%)	34 (72.34%)	
Yes	15 (24.19%)	11 (73.33%)	4 (26.67%)	0.0044
Catheter Gauge (including diameter in mm)				
18: 1.27 mm	12 (19.35%)	5 (41.67%)	7 (58.33%)	0.7951
20: 0.91 mm	50 (80.65%)	19 (38.00%)	31 (62.00%)	
Diameter of Catheter (cm)				
Mean (Standard Deviation)	0.10 (0.01)	0.10 (0.01)	0.10 (0.01)	0.8185

Vein Diameter (short axis) (cm)				
Mean (Standard Deviation)	0.32 (0.13)	0.32 (0.14)	0.33 (0.13)	0.6888
Catheter-to-vein ratio				
Mean (Standard Deviation)	0.36 (0.15)	0.37 (0.16)	0.35 (0.15)	0.5999
Length of Catheter in Vein (long axis) (cm)				
Mean (Standard Deviation)	1.98 (0.37)	1.95 (0.44)	2.00 (0.32)	0.5949
Angle of Insertion (long axis) (degrees)				
Mean (Standard Deviation)	15.38 (6.47)	15.00 (4.58)	15.61 (7.43)	0.6953
Angle of Distal Tip Against Vessel Wall (long axis) (degrees)				
Mean (Standard Deviation)	6.10 (5.13)	5.67 (5.28)	6.37 (5.09)	0.6039

Table 2: Daily IV Characteristics, Clinical Symptoms, Sonographic Findings, IV Infusate Administration, and IV Usage Characteristics

	All Lines (n = 62)	Failed (n = 24)	Survived (n = 38)	P-Value
Daily IV Characteristics				
Vein Wall Thickness (short axis) (cm)				
Mean (Standard Deviation)	0.04 (0.01)	0.04 (0.02)	0.05 (0.01)	0.5931
Distance of Catheter Tip to Vessel Wall (cm)				
Mean (Standard Deviation)	0.04 (0.04)	0.03 (0.03)	0.04 (0.05)	0.0561
Degree of Catheter Kinking (long axis) (degrees)				
Mean (Standard Deviation)	4.17 (3.31)	4.36 (3.28)	4.06 (3.37)	0.7316
Clinical Symptoms				
Phlebitis Scale (0-5)				
0	36 (58.06%)	12 (33.33%)	24 (66.67%)	
1	20 (32.26%)	9 (45.00%)	11 (55.00%)	0.5963
2	6 (9.68%)	3 (50.00%)	3 (50.00%)	
Phlebitis	**(n = 54)**	**(n = 22)**	**(n = 32)**	
Symptomatic	22 (40.74%)	11 (50.00%)	11 (50.00%)	0.2682
Asymptomatic	32 (59.26%)	11 (34.38%)	21 (65.63%)	
Sonographic Findings				
Presence of subcutaneous edema				
No	27 (43.55%)	4 (14.81%)	23 (85.19%)	
Yes	35 (56.45%)	20 (57.14%)	15 (42.86%)	0.0020
Time to Edema	**(n = 35)**	**(n = 20)**	**(n = 15)**	
Mean (Standard Deviation)	46.92 (52.32)	39.17 (34.61)	57.25 (69.44)	0.3660
< 24 Hours	8 (22.86%)	6 (75.00%)	2 (25.00%)	
24 - 48 Hours	18 (51.43%)	10 (55.56%)	8 (44.44%)	0.5333
> 48 Hours	9 (25.71%)	4 (44.44%)	5 (55.56%)	
Presence of Thrombus	**(n = 54)**	**(n = 22)**	**(n = 32)**	
Yes	40 (74.07%)	17 (42.50%)	23 (57.50%)	0.6941
No	14 (25.93%)	5 (35.71%)	9 (64.29%)	
Time to Thrombus	**(n = 54)**	**(n = 22)**	**(n = 32)**	

Mean (Standard Deviation)	26.22 (19.88)	23.57 (14.94)	28.05 (22.71)	0.3862
< 24 Hours	28 (51.85%)	12 (42.86%)	16 (57.14%)	
24 Hours +	26 (48.15%)	10 (38.46%)	16 (61.54%)	0.7535
IV Infusate Administration				
IV fluid bolus or continuous drip administered				
Yes	49 (79.03%)	21 (42.86%)	28 (57.14%)	0.2450
No	13 (20.97%)	3 (23.08%)	10 (76.92%)	
IV Medication Administration				
No	11 (17.74%)	1 (9.09%)	10 (90.91%)	
Yes	51 (82.26%)	23 (45.10%)	28 (54.90%)	0.0661
IV Vesicant/Irritant Administration				
No	11 (17.74%)	9 (81.82%)	2 (18.18%)	0.0064
Yes	51 (82.26%)	15 (29.41%)	36 (70.59%)	
IV Usage Characteristics				
Catheter Dwell Time (Hours)				
Mean (Standard Deviation)	76.42 (66.60)	66.85 (44.34)	82.47 (77.42)	0.3171
Number of Catheter Events				
Mean (Standard Deviation)	4.24 (2.65)	5.58 (2.41)	3.39 (2.47)	0.0011
Percent of Days Idle (%)				
Mean (Standard Deviation)	26% (31%)	6% (17%)	38% (32%)	< 0.0001

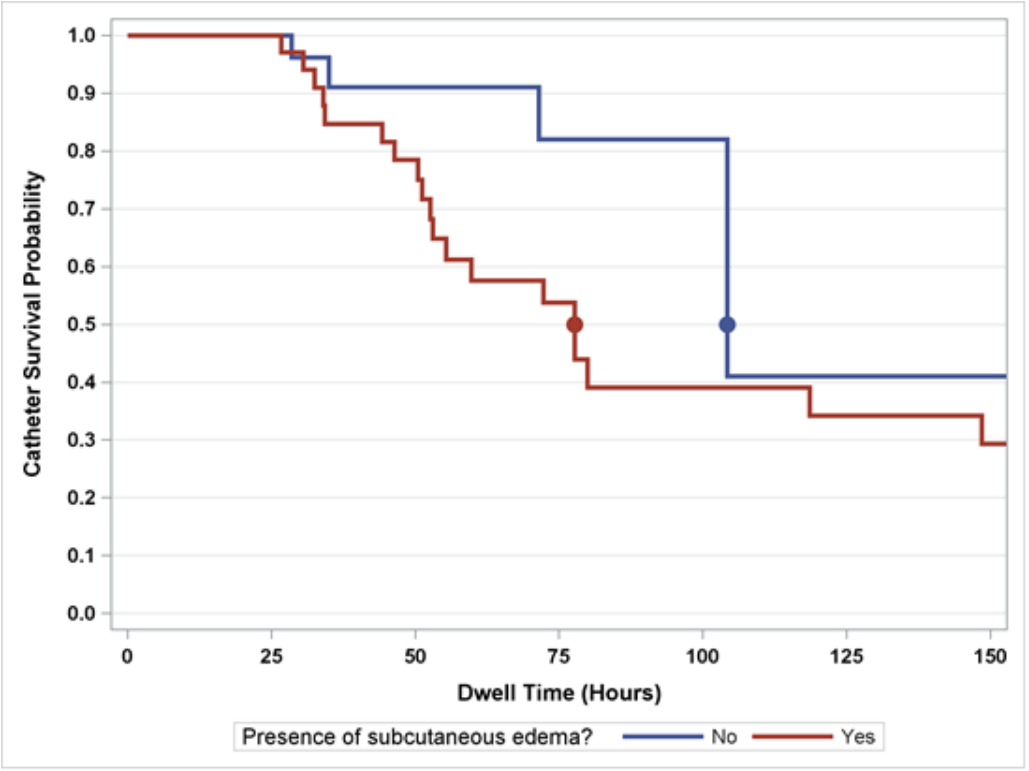
Table 3: Univariate and Multivariate Analysis

	Univariate		Multivariate	
	OR (95% CI)	P-Value	AOR (95% CI)	P-Value
Patient Characteristics				
Gender				
Male	Reference Group			
Female	0.65 (0.23, 1.83)	0.4178		
Comorbidities				
History of Smoking				
No	Reference Group			
Yes	0.85 (0.31, 2.37)	0.7588		
History of Diabetes				
No	Reference Group			
Yes	2.20 (0.71, 6.85)	0.1735		
History of Active Cancer				
No	Reference Group			
Yes	0.56 (0.11, 2.86)	0.4820		
History of Previous DVT				
No	Reference Group			
Yes	2.23 (0.45, 10.9)	0.3243		
Personal History of Clotting Disorder				
No	Reference Group			
Yes	2.86 (0.62, 13.2)	0.1774		
Currently on Anticoagulant Medication				
No	Reference Group			
Yes	0.84 (0.27, 2.67)	0.7676		
Lab Values at Time of Admission				
NL Ratio $\geq$ 8.1				
Yes	6.85 (1.93, 24.3)	0.0029	4.63 (1.06, 20.3)	0.0422
No	Reference Group		Reference Group	

N:L Ratio	1.19 (1.05, 1.34)	0.0052		
IV Insertion Characteristics				
Laterality of Successful Cannulation				
Left	1.52 (0.54, 4.25)	0.4282		
Right	Reference Group			
Location of IV				
Antecubital	Reference Group			
Forearm	0.53 (0.15, 1.86)	0.3180		
>1 IV Placed During Hospital Course				
No	Reference Group			
Yes	6.53 (1.79, 23.8)	0.0044		
Catheter Gauge (including diameter in mm)				
18: 1.27 mm	1.19 (0.33, 4.26)	0.7951		
20: 0.91 mm	Reference Group			
Catheter-to-Vein Ratio				
Ratio ≥ 33%	1.23 (0.44, 3.42)	0.6935	0.91 (0.21, 3.97)	0.8996
Ratio < 33%	Reference Group		Reference Group	
Daily IV Characteristics				
Distance Catheter Tip to Vein Wall				
0 only	Reference Group		Reference Group	
0 and > 0	0.80 (0.25, 2.50)	0.6962	0.34 (0.07, 1.81)	0.2076
> 0 only	0.48 (0.08, 2.89)	0.4187	1.13 (0.09, 14.2)	0.9267
Clinical Symptoms				
Phlebitis Scale (0-5)				
0	Reference Group			
1	1.62 (0.53, 4.96)	0.3987		
2	1.96 (0.34, 11.2)	0.4495		
Phlebitis				
Symptomatic	1.87 (0.62, 5.66)	0.2682		

Asymptomatic	Reference Group			
Sonographic Findings				
Subcutaneous Edema				
Yes	6.91 (2.03, 23.5)	0.0020	8.29 (1.50, 45.8)	0.0153
No	Reference Group		Reference Group	
Time to Edema				
< 24 Hours	Reference Group			
24 - 48 Hours	0.48 (0.08, 2.89)	0.4190		
> 48 Hours	0.32 (0.04, 2.40)	0.2642		
Presence of Thrombus				
Yes	1.29 (0.37, 4.51)	0.6941		
No	Reference Group			
Time to Thrombus				
< 24 Hours	Reference Group			
24 Hours +	0.84 (0.28, 2.49)	0.7535		
IV Infusate Administration				
IV Fluid Bolus or Continuous Drip Administered				
Yes	2.26 (0.57, 8.97)	0.2450		
No	Reference Group			
IV Medication Administered				
No	Reference Group			
Yes	5.77 (0.89, 37.5)	0.0661		
Vesicant/Irritant Administered				
Yes	8.95 (1.85, 43.2)	0.0064	10.3 (1.46, 72.6)	0.0192
No	Reference Group		Reference Group	

Figures



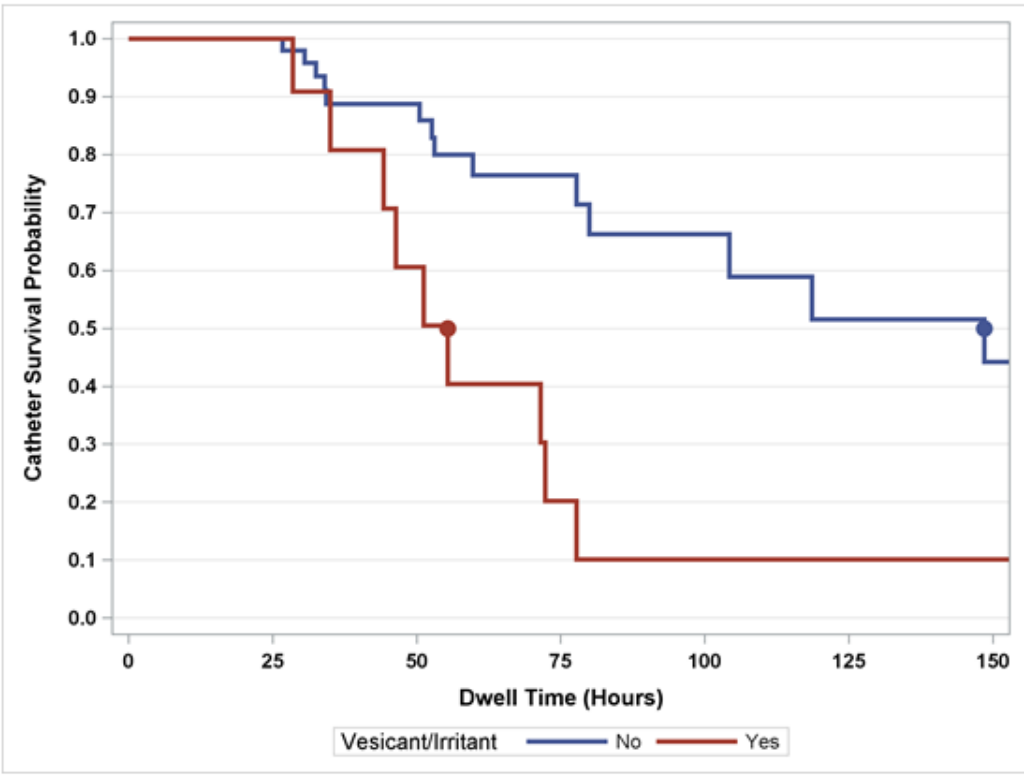


Figure 1

Kaplan-Meier survival curve estimates for PIVC survival. Each plot indicates the survival probability of 0.5 with its corresponding median dwell time. A. The median survival time was 77.69 hours (95% CI: 52.60 hours, 148.50 hours) for participants with subcutaneous edema and 104.23 hours (not enough data to compute a CI for the median) for participants without subcutaneous edema. B. The median survival time was 55.37 hours (95% CI: 35.00 hours, 72.27 hours) for subjects who were administered

vesicants/irritants and 148.50 hours (not enough data to compute a CI for the median) for subjects who were not administered any vesicants/irritants.