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Original Research

DEEP VEIN THROMBOSIS

Risk of Symptomatic DVT Associated With Peripherally Inserted Central Catheters

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Background: **Previous studies undertaken to identify risk factors for peripherally inserted central catheter (PICC)-associated DVT have yielded conflicting results. PICC insertion teams and other health-care providers need to understand the risk factors so that they can develop methods to prevent DVT.**

Methods: **A 1-year prospective observational study of PICC insertions was conducted at a 456-bed, level I trauma center and tertiary referral hospital affiliated with a medical school. All patients with one or more PICC insertions were included to identify the incidence and risk factors for symptomatic DVT associated with catheters inserted by a facility-certified PICC team using a consistent and replicated approach for vein selection and insertion.**

Results: **A total of 2,014 PICCs were inserted during 1,879 distinct hospitalizations in 1,728 distinct patients for a total of 15,115 days of PICC placement. Most PICCs were placed in the right arm (76.9%) and basilic vein (74%) and were double-lumen 5F (75.3%). Of the 2,014 PICC insertions, 60 (3.0%) in 57 distinct patients developed DVT in the cannulated or adjacent veins. The best-performing predictive model for DVT (area under the curve, 0.83) was prior DVT (odds ratio [OR], 9.92; $P < .001$), use of double-lumen 5F (OR, 7.54; $P < .05$) or triple-lumen 6F (OR, 19.50; $P < .01$) PICCs, and prior surgery duration of > 1 h (OR, 1.66; $P = .10$).**

Conclusions: **Prior DVT and surgery lasting > 1 h identify patients at increased risk for PICC-associated DVT. More importantly, increasing catheter size also is significantly associated with increased risk. Rates of PICC-associated DVT may be reduced by improved selection of patients and catheter size.** ***CHEST 2010; 138(4):803–810***

Abbreviations: EMR = electronic medical record; ICD-9 = *International Classification of Diseases, 9th Edition*; OR = odds ratio; PICC = peripherally inserted central catheter

Peripherally inserted central catheters (PICCs) are a relatively safe and cost-effective method to provide long-term IV access for extended antibiotic therapy, chemotherapy, and total parenteral nutrition.[1-3] Many PICCs are inserted at the bedside by specially trained nurses using sterile technique, ultrasonography, and measured estimation for catheter tip placement.[4] Chest radiographs confirm placement of the catheter tip in the vena cava. DVT is a complication of PICC use; can be painful; and require anticoagulation therapy, early PICC removal and replacement, and extended hospitalization.[5,6] Postthrombotic syndrome may ensue following DVT.[7] Moreover, upper-extremity thrombosis may result in asymptomatic pulmonary embolism in as many as one-third of cases and symptomatic pulmonary embolism in as many as 9% of cases.[8-10] Pulmonary embolism complicating upper-extremity DVT carries a mortality rate as high as 25%.[11]

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DVT risk reduction strategies among patients receiving PICCs require an accurate understanding of DVT risk factors that currently are ill defined. Previous studies undertaken to identify risk factors for PICC-associated DVT have used varying study designs among variable patient populations with differing insertion methods and found conflicting results.[12-17] A more clear delineation of risk factors for DVT is needed to assist clinicians in weighing the risks and benefits of PICC insertion and to identify risk factors that may be amenable to modification. Central catheter diameter has been proposed to correlate with risk for DVT.[18] Although one study reported PICC diameter to be predictive of DVT,[14] two others found no relationship between PICC diameter and DVT.[16,17] We report risk factors for DVT among general tertiary referral hospital patients receiving PICC placement by certified nurses using a standardized protocol.

Materials and Methods

Intermountain Medical Center is a 456-bed teaching hospital affiliated with the University of Utah School of Medicine (Salt Lake City, UT) and replaced LDS Hospital in October 2007 as Intermountain Healthcare's level I trauma center. The hospital information system consists of two Health Evaluation through Logical Processing platforms, the first of these implemented > 30 years ago.[19,20] A key feature of the information system is the integrated electronic medical record (EMR) that contains most clinical information, including bedside charting of all PICC team insertions and daily documentation of line care and removal. EMR-coded data facilitate the development and use of clinical decision-support programs to analyze the data and constantly monitor patient care. PICC-associated DVT is diagnosed with the assistance of ultrasound performed by the Peripheral Vascular Laboratory. Although peripheral vascular study dictation reports are not coded and are stored as free-text documents, they can be reviewed through the information system or analyzed with natural language processing. In 2006, a computerized tool was created at LDS Hospital that used natural language processing for analysis of all venous duplex ultrasonography reports. This tool was validated and found to provide a dependable and consistent method for identifying PICC-associated DVT.[21]

PICC Insertion

More than 90% of PICCs at Intermountain Medical Center are inserted by the PICC team, which reports through the Nutrition Support Service, and these insertions were included in our study. We excluded the 9% of PICCs inserted by interventional radiology and the few that were inserted before hospital admission. The PICC team comprises 10 nurses with special training and internal certification.

During this study, a protocol using portable ultrasonography equipment at the bedside to verify candidacy for PICC team insertion was used. The vein of first choice was the right basilic. If the right basilic vein was not compressible with the ultrasound assessment, the left arm was examined. If the right basilic vein compressed but was too small for the size of the intended catheter, the right-upper-brachial vein was examined. The protocol stipulated that if the right-upper-brachial vein was not appropriate, veins in the left arm were examined starting with the basilic and then the brachial. The cephalic veins were used as a last choice. If a triple-lumen catheter was clinically indicated, the vein must have had at least a 0.5-cm diameter for the insertion of a 6F triple-lumen catheter. Other criteria for arm selection included presence of an arteriovenous fistula, mastectomy, paralysis, cellulitis, previous upper-extremity DVT, concurrent subclavian central venous catheter, or concurrent PICC. Patients who fell outside this protocol were referred to interventional radiology for venous access. The size of the inserted catheter was based on the number of lumens needed for the specific patient and was a multidisciplinary decision, including input from the PICC team. All PICCs were inserted proximal to the antecubital fossa.

All single-lumen PICCs used in this study were size 4F; double-lumen PICCs, 5F; and triple-lumen PICCs, 6F. All but six catheters were polyurethane with reverse taper design. All PICCs were inserted using a modified Seldinger technique. Catheter tip placement was confirmed by chest radiograph. PICC placement was considered optimal if the tip of the catheter was located at the cavoatrial junction and acceptable if located anywhere in the superior vena cava. Any catheter tips found to be in the subclavian or brachiocephalic veins were repositioned. A sterile occlusive dressing was used to cover the insertion site and changed according to a prespecified protocol to reduce risk of infection. Bedside nurses charted routine patient care, such as dressing status, line patency of the PICCs, and anticoagulation administration, in the EMR during each shift.

Study Design

A prospective observational study was performed in all patients with PICCs inserted during 2008 by the PICC team at Intermountain Medical Center. Each patient was monitored for symptomatic DVT using the computerized surveillance of venous duplex ultrasonography dictation reports[21] and PICC nurse adjudication based on a PICC presence in the same vein as the thrombosis. Patients with DVT symptoms prior to PICC placement and insertion difficulty were noted in the PICC placement documentation. A member of the PICC team followed up on the daily computer alerts of PICC-associated DVT and reviewed pertinent patient information not included in the routine bedside charting, such as location of DVT, exact catheter tip location, and use of anticoagulation therapy.

Assessment for DVT occurred only in symptomatic patients. Venous duplex ultrasonography was ordered based on provider observation of clinical manifestations, such as swelling in the upper extremity, pain, or leaking at the PICC site. The PICC team also recommended vascular studies based on the presence of noncompressible veins during ultrasound assessment associated with evaluation for PICC placement. DVT events were identified from analysis of dictated ultrasound reports performed by the hospital Peripheral Vascular Laboratory. The definition of DVT for this study was noncompressibility of the relevant vein using the ultrasound probe during direct visualization. Doppler modality was used for supplemental information and to assist the technician in locating relevant veins and distinguishing venous from arterial anatomy. Although Kearon et al[22] defined upper-extremity DVT as involving the subclavian, axillary, and brachial veins, we also report DVT involving the basilic and cephalic veins because clinically overt DVT in these veins reflect significant events that complicate PICC placement, although thrombi in these veins may have a lower risk of embolism or postthrombotic syndrome.

A study database was created to store pertinent patient information extracted from patient demographics, nurse charting and medication therapy data in the EMR, PICC team insertion documentation, and PICC team follow-up of all patients with documented PICC-associated DVT. Other potential DVT risk factors, such as previous upper- or lower-extremity DVT, previous cancer,

hypercoagulability status, and use of hormone replacement or oral contraceptives, were extracted from the enterprise data warehouse for each patient with a PICC. These data were imported into a relational database and loaded into a statistical software package for analysis.

Twenty-one putative risk factors for DVT were examined: PICC size, length, duration, and final tip location; reason for PICC insertion; accessed arm and vein; patient sex and age; insertion nurse; insertion division; previous DVT; previous cancer; hypercoagulability; surgery duration >1 h; bed rest; BMI >29 kg/m^2; receiving hormone replacement or oral contraception; admission diagnosis, use of anticoagulants; and use of pressors. Patients were considered hypercoagulable based on a record of prior positive test results for the factor V Leiden gene mutation, prothrombin gene 20210 A/G mutation; elevation of anticardiolipin IgG; abnormally low levels of antithrombin, functional protein C or functional protein S; elevated homocysteine, or prolonged dilute Russell viper venom time. Hormone replacement therapy included active prescriptions for estrogens, progestins, or progesterone. Hospital admission diagnoses were collected from the *International Classification of Diseases, 9th Revision* (ICD-9), diagnostic codes and grouped into logical clinical categories of oncology, cardiology, neurology, infectious diseases, and so forth. PICC duration was calculated from the day of insertion until the removal date or the patient discharge date. Major surgery was classified as surgery lasting >1 h. Final tip location was documented by the PICC team nurses and based on their ability to confirm through chest radiograph that the tip was within the superior vena cava. Bed rest was determined through nurse computerized charting codes of "bed rest," "unable to move," "moved only with assistance," and so forth. Anticoagulant use included heparin, warfarin, enoxaparin, argatroban, or bivalirudin administered at the bedside and excluded pre- and intraoperative doses. IV vasopressor use included epinephrine, norepinephrine, vasopressin, and dopamine administered at the bedside. The primary end point was presence of symptomatic DVT as diagnosed with the assistance of venous duplex ultrasonography. Patients were followed for this outcome until 5 days after PICC removal or hospital discharge. All patients with identified DVT were followed for 90 days for subsequent venous duplex ultrasonography and CT pulmonary angiography and ICD-9 codes for pulmonary embolism.

Statistical Analysis

Because individual patient factors are known to contribute to DVT, and most (87%) patients received a single PICC in 2008, we randomly selected a single PICC placement for patients with more than one placement (1,728 PICC placements) for analysis. Sensitivity analysis was conducted to ensure that neither the variable selection nor the parameter estimates were affected by the selected PICC placement. Descriptive statistics and univariate logistic regression models were generated to provide basic summaries of the data. Variable selection was conducted using a forward-selection process, with inclusion based on the area under the curve in a bootstrap framework.[23] Parameter estimates and 95% CIs for included variables were estimated using logistic regression, and its predictive power estimated with the bootstrap sample using 1,000 replicates. All statistical analyses were conducted with R, version 2.9.0 (R Foundation for Statistical Computing; Vienna, Austria). This study was approved by the Intermounatain Institutional Review Board.

Results

In 2008, the PICC team at Intermountain Medical Center successfully inserted 2,014 PICCs in 1,879 distinct patient hospitalizations and 1,728 distinct patients (Table 1). Thus, some patients had multiple PICCs inserted during the same hospitalization, and some of the same patients had PICC insertions during different hospitalizations. There were 1,768 patients with one PICC inserted during the same hospitalization, 98 with two, seven with three,

Table 1—*Demographic Characteristics of Patients With PICCs at Intermountain Medical Center During 2008*

Characteristic	Value
Total PICCs inserted, No.	2,014
Total unique PICC patient hospitalizations, No.	1,879
PICC insertions, No.	
1	1,768
2	98
3	7
4	5
9	1
Total unique PICC patients, No.	1,728
Total PICC days, No.[a]	15,115
Average PICC duration, d (range)[a]	7.5 (<1-78)
Average length of hospitalization, d (range)	14.5 (<1-161)
Average age of patients, y (range)	59.5 (12-94)
Percent female	48
Right arm insertion, No. (%)	1,548 (76.9)
Catheter size, No. (%)	
Single-lumen 4F	338 (16.8)
Double-lumen 5F	1,516 (75.3)
Triple-lumen 6F	160 (7.9)
Insertion vein, No. (%)	
Basilic	1,490 (74)
Brachial	462 (23)
Cephalic	62 (3)
Reason for PICC, No. (%)[b]	
Venous access	482 (23.9)
Antibiotics	588 (29.2)
Total parenteral nutrition	147 (7.3)
Chemotherapy	12 (0.6)
Medications	789 (39.2)
Blood products	17 (0.8)
Hydration	9 (0.4)
Replacement	42 (2.1)
Other[c]	73 (3.6)
Not documented	8 (0.4)
Medical condition, No. (%)	
Cardiology	321 (15.9)
Neurology	114 (5.7)
Infectious diseases	662 (32.9)
Gastroenterology	253 (12.6)
Trauma	87 (4.3)
Pulmonary	198 (9.8)
Oncology	124 (6.2)
Vascular	51 (2.5)
Orthopedics	53 (2.6)
Renal	67 (3.3)
Other	84 (4.2)

PICC = peripherally inserted central catheter.
[a]PICC insertion to removal or discharge.
[b]PICCs could be inserted for more than one reason.
[c]Reason was entered as free-text comment.

and five with four. One patient hospitalized for 149 days had nine insertions. The PICC team maintained an insertion success rate of 97%, placing 338 (16.8%) single-lumen 4F catheters, 1,516 (75.3%) double-lumen 5F catheters, and 160 (7.9%) triple-lumen 6F catheters. The PICCs were inserted for a total of 15,115 days, with an average of 7.5 days (SD, 7.6; range, < 1-78 days). The average length of hospitalization for the 1,879 patients was 14.6 days (SD, 16.9; range, < 1-161 days). The patients ranged in age from 12 to 94 years, with an average age of 59.5 years. Slightly fewer women (48%) had PICCs inserted than men, and 74% of the PICCs were placed in the right basilic vein. The most common reasons for PICC insertion were charted as medication administration, antibiotic delivery, and venous access. The patients were grouped into a number of different medical conditions, with infectious disease and cardiovascular, pulmonary, and GI conditions being the most common diagnoses.

Fifty-seven distinct patients experienced 60 (3.0% of insertions) PICC-associated DVT events documented by venous duplex ultrasonography (Table 2). Two patients had two separate DVTs documented during the same hospitalization, and one patient experienced DVT during different hospitalizations. The mean duration from PICC insertion to DVT diagnosis was 9.5 days (SD, 11.6; range, 1 to 64 days). DVT could affect multiple veins, with the thrombus involving the axillary vein 49 times; subclavian, 26 times; basilic, 10 times; brachial, three times; and cephalic, 3 times. The DVT rate was 0.6% for single-lumen 4F PICCs compared with 2.9% for double-lumen 5F PICCs and 8.8% for triple-lumen 6F PICCs (Fig 1). At least one vascular study was ordered for 16.9% of patients with 6F PICCs compared with 9.4% and 1.8% for 5F and 4F PICCs, respectively. Fifty-two percent of the vascular studies for 6F PICCs were positive for PICC-associated DVTs compared with 31% and 33% for 5F and 4F vascular scans, respectively. Process review indicated that vascular studies were ordered based on clinical manifestations of DVT and not on PICC size. A search of ICD-9 codes in the 90 days following PICC insertion revealed that six (11%) of the 57 patients with DVT also received a diagnosis of pulmonary embolism. Of these six, three also were diagnosed with DVT of the lower extremities. One patient with a hospital course complicated by a history of antiphospholipid antibody syndrome and heparin-induced thrombocytopenia also had a thrombosis in the brachial and radial arteries. The remaining two patients had no other thrombosis identified.

Table 2—*Characteristics of Patients With PICC-Associated DVT at Intermountain Medical Center During 2008*

Characteristic	No.
Total PICC insertions with DVT (%)	60 (3.0)
Total distinct patients with DVT	57
Patients with two DVTs during same hospitalization	2
Patients with two DVTs during different hospitalizations	1
Mean duration from PICC insertion to DVT diagnosis, d (range)	9.5 (1-64)
Veins affected by DVT[a]	
Axillary	49
Subclavian	26
Basilic	10
Brachial	3
Cephalic	3

See Table 1 legend for expansion of abbreviation.

[a]Multiple veins could be involved during the same incidence of DVT.

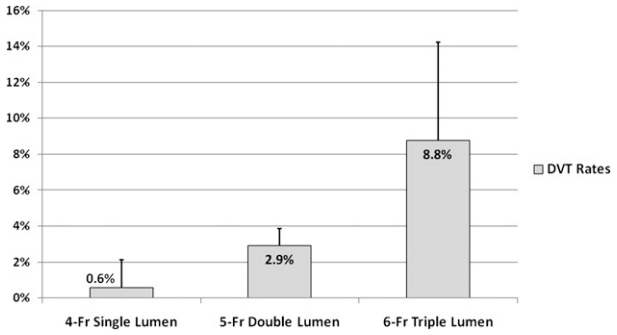

FIGURE 1. Rates and upper 95% CIs of symptomatic DVT associated with peripherally inserted central catheter diameter (PICC).

Risk Factor Analysis

Eight different risk factors were found to have an unadjusted $P < .05$ in univariate logistic regression models (Fig 2). Previous DVT had the lowest P value ($P < .001$) and was the best discriminator of a DVT associated with a PICC, followed by PICC size. Other risk factors identified included use of anticoagulants, use of IV vasopressors, surgery duration > 1 h, bed rest, length of stay, and PICC duration. The best multivariable predictive model achieved a moderate area under the curve of 0.83 and included previous DVT, PICC size, and surgery > 1 h (Fig 3). DVT risk increased with prior DVT (odds ratio [OR], 9.92; 95% CI; 5.08-21.25; $P < .001$), surgery > 1 h (OR, 1.66; 95% CI, 0.91-3.01; $P < .1$), use of double-lumen compared with single-lumen PICC (OR, 7.54; 95% CI, 1.61- > 100; $P < .05$), and use of triple-lumen compared with single-lumen PICC (OR, 19.50; 95% CI, 3.54- > 100; $P < .01$) (Fig 3). No other variables tested significantly contributed to the discriminatory power of the model or achieved a $P < .05$ in the multivariable model.

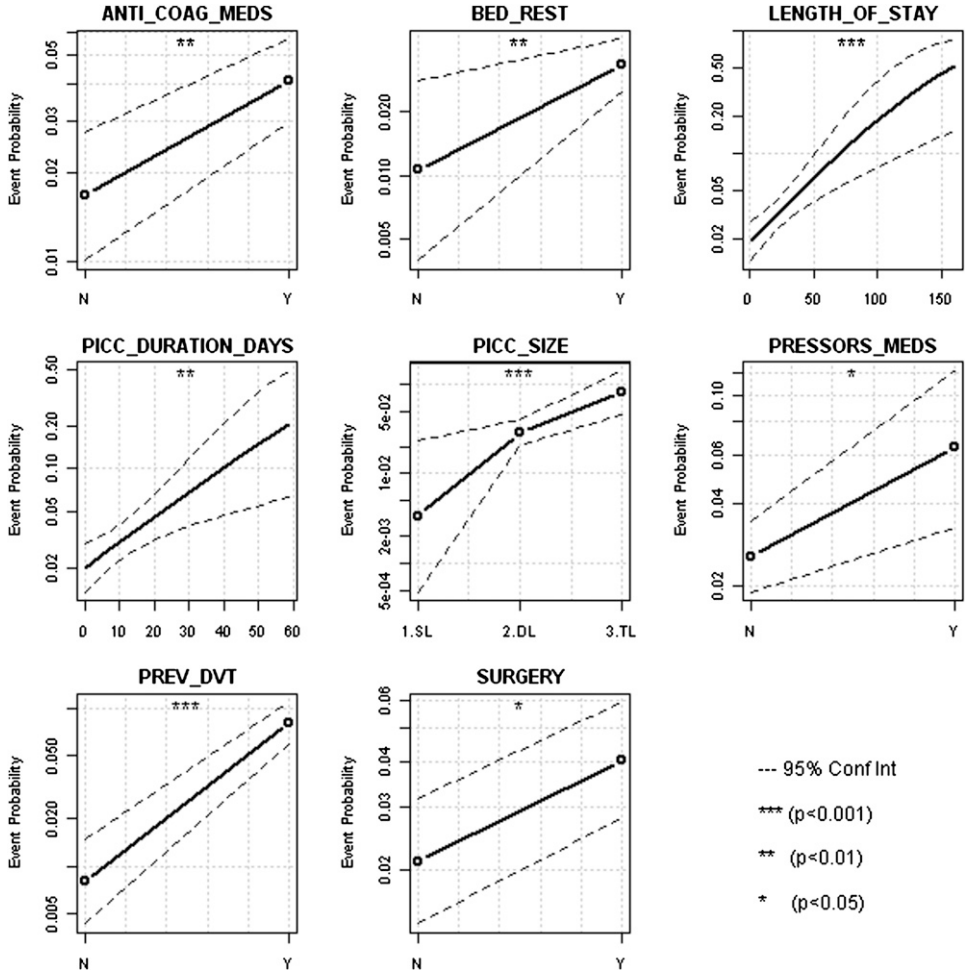

FIGURE 2. Univariate effect plots for risk factors attaining an unadjusted $P < .05$. See Figure 1 legend for expansion of abbreviation.

DISCUSSION

Ambiguity regarding risk factors for DVT attributable to PICC use exists. Our finding that PICC size is a risk factor for DVT is consistent with the findings of Grove and Pevec.[14] However, there are a number of differences between our two studies. In the Grove and Pevec study, varying gauges for single- and double-lumen catheters were inserted. They also included PICCs inserted by both radiologists and nurses who used different brands of catheters and methods of insertion and observed different rates of DVT. Contrary to our observation, Grove and Pevec reported that rates of DVT depended on the indication for the PICC (antibiotics, 1.6%; total parenteral nutrition, 5%; chemotherapy, 8%). Only cancer patients would receive chemotherapy, and cancer has been identified as a risk factor in other studies.[16] Because patient diagnosis was not examined in the study by Grove and Pevec, it is difficult to ascertain whether catheter size, chemotherapy, or cancer diagnosis was the true risk factor for PICC-associated DVT. Further, because patients were not randomized and important differences were observed in patients with different PICC sizes, their study could not attribute causality to the relationship between PICC size and risk of DVT. Although our study also was not randomized, we believe that the vigorous quantification of multiple risk factors in our univariate analysis suggests that larger catheter size is associated with increased DVT risk rather than a surrogate for other patient characteristics.

Although Abdullah et al[16] and Allen et al[17] reported no association between catheter size and DVT risk, both were small studies (n = 26 and n = 119, respectively). Loewenthal et al[24] reported that 4F catheters had a higher complication rate than 3F catheters, but they did not specifically report DVT rates, and only four of 209 inserted PICCs were documented as removed because of thrombosis. We also believe that the large sample size of our study makes our observation of association between DVT rate and catheter size compelling and consistent with a previous central line study.[18]

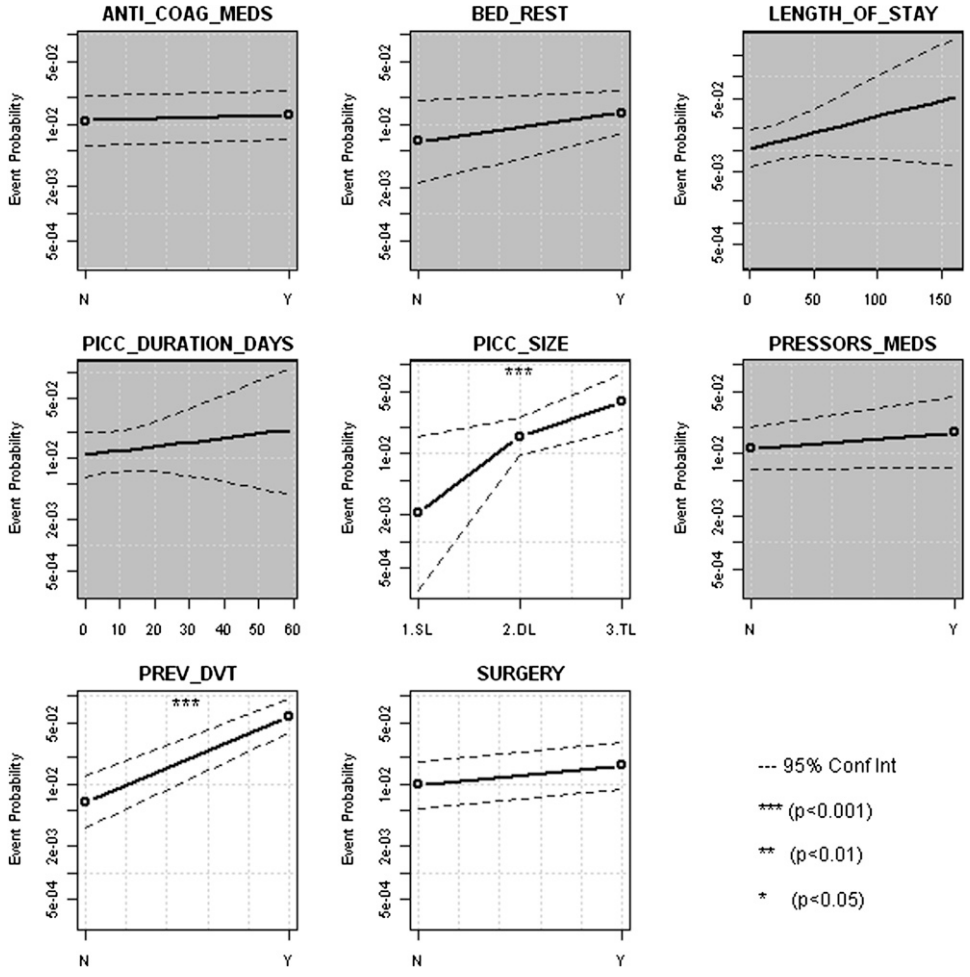

FIGURE 3. Effect plots controlling for PICC size, prior DVT, and surgery for all risk factors found to be associated with DVT risk in the univariate analysis (Fig 2). Grayed-out risk factors did not significantly contribute to the discriminatory power of the model. See Figure 1 legend for expansion of abbreviation.

We explored 20 other possible risk factors univariately (see "Study Design") to understand the potential magnitude and direction of the relationships and identified a highly predictive model that could be deployed in a clinical setting. For example, despite the antithrombotic effects of anticoagulation medications, patients receiving anticoagulants were observed to have a higher risk of DVT in the univariate analysis. However, there was a strong relationship between prior DVT and use of an anticoagulation medication. Once prior DVT was in the model, anticoagulation medication no longer added to the predictive power of the model, and it was no longer statistically significant at the $P = .05$ level. This finding is consistent with another recent study that reported that PICC-associated DVT was significantly more common in patients with previous DVT.[25] Routine use of anticoagulants for prophylaxis among patients with PICCs was associated with a lower DVT rate in one study[26] but not in another.[11] The eighth edition of the American College of Chest Physicians evidence-based clinical practice guidelines recommends against the routine use of anticoagulation for the prevention of PICC-associated DVT.[27] In addition, surgery duration >1 h continued to provide marginal predictive utility in our model, although it was not statistically significant at the $P = .05$ level.

Our study identified both patient-specific and catheter-specific risk factors for PICC-associated DVT. Therefore, we believe that the decision to place a PICC and the number of lumens chosen should be a thoughtful decision based on the specific clinical needs of the patient. Catheter size should be based on compelling clinical indications not on convenience or department stock. Despite our observation of a reduced risk of DVT with smaller, single-lumen catheters, there are disadvantages to using smaller sized catheters and catheters with fewer lumens. Smaller catheters are more fragile and more prone to kink and occlude.[14] Our results suggest that the risk of DVT attributable to larger sized catheters should be considered when deciding how many lumens will be needed. The results of this study suggest that triple-lumen 6F catheters should not be routinely used in the absence of an indication for three lumens.

The present study was possible through the use of an extensive EMR that contained the data to examine possible confounding of a number of putative risk factors and a reliable and consistent method to identify PICC-associated DVT. The 2,014 PICCs were inserted by a relatively small number of certified nurses using the same insertion technique and vein selection protocol. Moreover, the fact that only three different PICC sizes based on the number of lumens were used during this study simplified the interpretation of the results.

Limitations

This study only included the PICCs inserted at the bedside by certified nurses. Although most PICCs at this hospital are inserted by the PICC team, and a growing number of PICCs are being inserted by PICC teams throughout the country, the findings from this study may not be applicable to PICCs inserted by other personnel using other methods or in different patient groups. Interventional radiologists use different methods and often place PICCs in a distinct patient population, which may affect risk for DVT.

Tip location has been reported to be a DVT risk factor. Catheter tip placement in the distal superior vena cava (ie, more peripherally) was associated with a higher risk for DVT than tip placement at or just above the right atrium,[28] but that study only compared the tip placement between the superior vena cava and the axillosubclavian-innomiate vein. Following initial PICC placement in our study, the exact tip location within the superior vena cava (proximal, middle, or distal) was only subsequently documented for patients with PICC-associated DVT, which precludes comparison with the group of patients unaffected by DVT. Therefore, we may have failed to observe an association between tip location and DVT.

Although the PICC team used ultrasonography at the bedside to be sure that the vein size was sufficient for the requested catheter, the actual size of the accessed veins was not documented during this study. Thus, we were restricted to just comparing the different insertion veins rather than a direct comparison of the measured lumen size of the veins. Additionally, 77% of the PICCs inserted in this study were placed in the basilic vein, which is the largest of the three veins used by the PICC team. We are not aware of any literature that specifically reports the amount of space in a vein that should remain after a catheter has been inserted. Moreover, the vein size is dynamic and may change after PICC insertion. The standard from the Infusion Nurse Society[29] is that the smallest catheter that will accommodate the prescribed therapy should be used in the largest vein. The mechanism by which increasing catheter size is associated with higher DVT risk could be related to stasis induced by the catheter, vessel injury, or other mechanisms. We are unaware of any objective quantification of vessel trauma related to PICC size. Future studies may shed more light on this question.

We report symptomatic DVT in this study. Higher rates of DVT have been reported among patients having surveillance ultrasound performed prior to PICC removal.[17] Therefore, the true incidence of PICC-associated DVT is underreported in this study, although asymptomatic DVT may not have the same clinical implications as symptomatic DVT. In addition, the observed rate of pulmonary embolism following a diagnosis of PICC-associated DVT in our population was low, making precise estimates of risk difficult. Finally, our outcomes were assessed until 5 days after PICC removal or hospital discharge. It is possible that we did not ascertain additional cases of DVT that occurred following PICC removal or in patients who left the hospital with a PICC in place.

In conclusion, prior DVT and surgery lasting >1 h were found to help to identify patients at increased risk for PICC-associated DVT. More importantly, increasing PICC size was found to be significantly associated with risk of DVT. Rates of PICC-associated DVT may be reduced by improved selection of patients and catheter size.

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Ms Sharp: contributed to the conception and design, data acquisition, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
Ms Linford: contributed to the conception and design, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
Mr Lloyd: contributed to the conception and design, data acquisition, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
Dr Tripp: contributed to data acquisition, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
Dr Jones: contributed to data acquisition, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
Dr Woller: contributed to analysis and interpretation of data and revised it critically for important intellectual content and approved the final version.
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Dr Elliott: contributed to analysis and interpretation of data and revised it critically for important intellectual content and approved the final version.
Dr Weaver: contributed to the conception and design, analysis and interpretation of data, and revised it critically for important intellectual content and approved the final version.
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References

1. Funk D, Gray J, Plourde PJ. Two-year trends of peripherally inserted central catheter-line complications at a tertiary-care hospital: role of nursing expertise. *Infect Control Hosp Epidemiol*. 2001;22(6):377-379.
2. Ng PK, Ault MJ, Maldonado LS. Peripherally inserted central catheters in the intensive care unit. *J Intensive Care Med*. 1996;11(1):49-54.
3. Lam S, Scannell R, Roessler D, Smith MA. Peripherally inserted central catheters in an acute-care hospital. *Arch Intern Med*. 1994;154(16):1833-1837.
4. Neuman ML, Murphy BD, Rosen MP. Bedside placement of peripherally inserted central catheters: a cost-effectiveness analysis. *Radiology*. 1998;206(2):423-428.
5. Safdar N, Maki DG. Risk of catheter-related bloodstream infection with peripherally inserted central venous catheters used in hospitalized patients. *Chest*. 2005;128(2):489-495.
6. Chaitowitz I, Heng R, Bell K. Managing peripherally inserted central catheter-related venous thrombosis: how I do it. *Australas Radiol*. 2006;50(2):132-135.
7. Kahn SR, Ginsberg JS. The post-thrombotic syndrome: current knowledge, controversies, and directions for future research. *Blood Rev*. 2002;16(3):155-165.
8. Moser KM, Fedullo PF, LitteJohn JK, Crawford R. Frequent asymptomatic pulmonary embolism in patients with deep venous thrombosis. *JAMA*. 1994;271(3):223-225.
9. Prandoni P, Polistena P, Bernardi E, et al. Upper-extremity deep vein thrombosis. Risk factors, diagnosis, and complications. *Arch Intern Med*. 1997;157(1):57-62.
10. Elman EE, Kahn SR. The post-thrombotic syndrome after upper extremity deep venous thrombosis in adults: a systematic review. *Thromb Res*. 2006;117(6):609-614.
11. Kerr TM, Lutter KS, Moeller DM, et al. Upper extremity venous thrombosis diagnosed by duplex scanning. *Am J Surg*. 1990;160(2):202-206.
12. King MM, Rasnake MS, Rodriguez RG, Riley NJ, Stamm JA. Peripherally inserted central venous catheter-associated thrombosis: retrospective analysis of clinical risk factors in adult patients. *South Med J*. 2006;99(10):1073-1077.
13. Chemaly RF, de Parres JB, Rehm SJ, et al. Venous thrombosis associated with peripherally inserted central catheters: a retrospective analysis of the Cleveland Clinic experience. *Clin Infect Dis*. 2002;34(9):1179-1183.
14. Grove JR, Pevec WC. Venous thrombosis related to peripherally inserted central catheters. *J Vasc Interv Radiol*. 2000;11(7):837-840.
15. Ong B, Gibbs H, Catchpole I, Hetherington R, Harper J. Peripherally inserted central catheters and upper extremity deep vein thrombosis. *Australas Radiol*. 2006;50(5):451-454.
16. Abdullah BJ, Mohammad N, Sangkar JV, et al. Incidence of upper limb venous thrombosis associated with peripherally inserted central catheters (PICC). *Br J Radiol*. 2005;78(931):596-600.
17. Allen AW, Megargell JL, Brown DB, et al. Venous thrombosis associated with the placement of peripherally inserted central catheters. *J Vasc Interv Radiol*. 2000;11(10):1209-1214.
18. Smith JP. Thrombotic complications in intravenous access. *J Intraven Nurs*. 1998;21(2):96-100.
19. Pryor TA, Gardner RM, Clayton PD, Warner HR. The HELP system. *J Med Syst*. 1983;7(2):87-102.
20. Clayton PD, Narus SP, Huff SM, et al. Building a comprehensive clinical information system from components. The approach at Intermountain Health Care. *Methods Inf Med*. 2003;42(1):1-7.
21. Evans RS, Linford LH, Sharp JH, White G, Lloyd JF, Weaver LK. Computer identification of symptomatic deep venous thrombosis associated with peripherally inserted central catheters. *AMIA Annu Symp Proc*. 2007:236-240.
22. Kearon C, Kahn SR, Agnelli G, Goldhaber S, Raskob GE, Comerota AJ; American College of Chest Physicians. Antithrombotic therapy for venous thromboembolic disease: American College of Chest Physicians evidence-based clinical practice guidelines (8th edition). *Chest*. 2008;133(6 suppl):454S-545S.
23. Efron B, Tibshirani R. Improvements on cross-validation: the .632 + bootstrap method. *J Am Stat Assoc*. 1997;92(438):548-560.
24. Loewenthal MR, Dobson PM, Starkey RE, Dagg SA, Petersen A, Boyle MJ. The peripherally inserted central catheter (PICC): a prospective study of its natural history after cubital fossa insertion. *Anaesth Intensive Care*. 2002;30(1):21-24.
25. Lobo BL, Vaidean G, Broyles J, Reaves AB, Shorr RI. Risk of venous thromboembolism in hospitalized patients with peripherally inserted central catheters. *J Hosp Med*. 2009;4(7):417-422.
26. Paauw JD, Borders H, Ingalls N, et al. The incidence of PICC line-associated thrombosis with and without the use of prophylactic anticoagulants. *JPEN J Parenter Enteral Nutr*. 2008;32(4):443-447.
27. Geerts WH, Bergqvist D, Pineo GF, et al; American College of Chest Physicians. Prevention of venous thromboembolism: American College of Chest Physicians evidence-based clinical practice guidelines (8th edition). *Chest*. 2008;133(6 suppl):381S-453S.
28. Cadman A, Lawrance JA, Fitzsimmons L, Spencer-Shaw A, Swindell R. To clot or not to clot? That is the question in central venous catheters. *Clin Radiol*. 2004;59(4):349-355.
29. Infusion Nurses Society. Infusion nursing standards of practice. *J Infus Nurs*. 2006;29(1 suppl):S1-S92.