Risk Factors for 30-Day Hospital Re-Admission with an Infectious Complication after Lower-Extremity Vascular Procedures

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Abstract

Background: Lowering the 30-d re-admission rate after vascular surgery offers the potential to improve healthcare quality. This study evaluated re-admission associated with infections after open and endovascular lower extremity (LE) procedures for peripheral artery disease (PAD).

Methods: Patients admitted for elective LE procedures for PAD were selected from the Cerner Health Facts[®] database. Chi-square analysis evaluated the characteristics of the index admission associated with infection at 30-d re-admission. Multivariable logistic models were created to examine the association of patient and procedural characteristics with infections at re-admission. The microbiology data available at the time of re-admission were evaluated also.

Results: A total of 7,089 patients underwent elective LE procedures, of whom 770 (10.9%) were re-admitted within 30 d. A total of 289 (37.5%) had a diagnosis of infection during the re-admission. These infections included surgical site (14.8%), cellulitis (13.6%), sepsis (8.8%), urinary tract (4.9%), and pneumonia (4.9%). Index stay factors associated with infection at re-admission were fluid and electrolyte disorders, kidney disease, diabetes, previous infection, and chronic anemia. Laboratory results associated with an infection during re-admission were post-operative hemoglobin <8 g/dL, blood urea nitrogen >20 mg/dL, platelet counts >400 × 10³/mcL, glucose >180 mg/dL, and white blood cell count >11.0 × 10³/mcL. Adjusted models demonstrated longer stay, chronic anemia, previous infection, treatment at a teaching hospital, and hemoglobin <8 g/dL to be risk factors for re-admission with infection. Infective organisms isolated during the re-admission stay included *Staphylococcus*, *Enterococcus*, *Escherichia*, *Pseudomonas*, *Proteus*, and *Klebsiella*.

Conclusions: Infectious complications were associated with more than one-third of all re-admissions after LE procedures. Predictors of re-admission within 30 d with an infectious complication were longer stay, greater comorbidity burden, hospitalization in teaching facilities, hemoglobin <8 g/dL, and an infection during the index stay. Microbiology examination at re-admission demonstrated gram-negative bacteria in more than 40% of infections. Further evaluation of high-risk vascular patients prior to discharge and consideration of antibiotic administration for gram-negative organisms at the time of re-admission may improve outcomes.

LOWERING THE 30-D RE-ADMISSION RATE after vascular surgery offers the potential to improve healthcare quality and lower cost. Tsai et al. demonstrated a significant association between re-admission rates and hospital surgical quality [1]. Much of the interest regarding lower re-admission rates is the potential impact on healthcare cost, with annual estimates of greater than \$15 billion in excess spending on re-admissions [2]. Specifically, the Hospital Re-admission Reduction Program section has outlined payment-

adjustment implications based on the newly defined “excess re-admission ratio” [3].

To date, much work has been performed evaluating clinical risk factors and characteristics associated with re-admission among patients undergoing vascular surgery with the goal of identifying high-risk patients. However, there is a gap between identifying risk factors for re-admission, relating them to the cause of re-admission, and, finally, developing changes in practice that would mitigate these risk

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factors, thus improving the quality of care and decreasing re-admissions. Surgical site complications and infections have been described as common diagnoses among surgical re-admissions, yet there is little ability to predict who is at greatest risk [4–6].

This study evaluated 30-d re-admissions and associated infections after lower extremity (LE) procedures to identify characteristics present during the original hospitalization that were associated with re-admission, as well as to define the infection types and microbiology findings at re-admission. This information may help identify patients at risk of re-admission for infection and has the potential to improve quality of care and decrease re-admission rates.

Patients and Methods

Data

Our study population was defined using the Cerner Health Facts® database, which is comprised of medical record data from hospitals that use Cerner's electronic health record and choose to participate. Hospitals decide their degree of data contribution (e.g., encounters, diagnoses, procedures, billing, medications, and laboratory results), and the data undergo a series of validity checks before inclusion. Data are de-identified using methods compliant with the Health Insurance Portability and Accountability Act before being made available for research. The International Classification of Diseases (ICD)-9-CM diagnosis and procedure codes were used to extract data for patients who underwent elective LE procedures for peripheral artery disease (PAD) from September 2008 to March 2014. This study was approved by the University of Missouri Health Sciences Institutional Review Board.

Study population

The population for this study included patients who were re-admitted within 30 d after discharge for a hospital stay during which a diagnosis of PAD was coded (ICD-9-CM diagnosis codes 440.22, 440.24, 440.21, 440.23, 440.20, 440.29, 440.4, or 443.9) and an endovascular (codes 39.50 or 39.90) or open (codes 38.08, 38.18, 38.38, 38.48, 38.88, 39.29, 39.56, 39.57, or 39.58) LE procedure was performed. Patients were excluded if their index stay was designated as emergency or urgent, was 30 or more d in length, had both an endovascular and an open procedure performed, or had another admission within three h of admission or discharge. We also excluded patients who were less than 21 y of age.

Demographics and risk factors

Hospital characteristics (number of beds, teaching facility), procedure type (open vs. endovascular), PAD severity (rest pain, gangrene, claudication, ulceration, or unspecified), and patient characteristics (age, gender, and race) were extracted from the Health Facts database, along with information about acute and chronic diagnoses. The Agency for Healthcare Research and Quality's (AHRQ) Clinical Classifications Software was used to group diagnosis codes into clinically relevant conditions. For example, "hemorrhage or hematoma complicating a procedure" included several diagnosis codes (998.11, 998.12, 998.13) whereas post-hemorrhagic anemia included only one (285.1). The Charlson Comorbidity Index also was determined [7].

Infections

Patients were considered to have had an infection if they had any of the following ICD-9-CM diagnosis codes: Surgical site infection (686.8, 686.9, 996.62, 997.62, 998.51, or 998.59); pneumonia (031.0, 482, 482.2, 482.41, 482.42, 482.83, 482.9, 480.8, 483.8, 485, 481, or 486); sepsis (038.42, 038.40, 038.44, 038.49, 038.10, 038.11, 038.12, 038.19, 038.0, 038.8, 038.9, 449, 790.7, 995.91, or 995.92); LE cellulitis (681.10, 682.6, or 682.7); urinary tract infection (599.0 or 996.64); or other infection (999.31, 003.29, 008.01, 008.43, 008.45, 008.8, 009.0, 021–024, 032.89, 040, 040.00, 041.02, 041.04, 041.09–041.12, 041.19, 041.2–041.4, 041.49, 041.6, 041.7, 041.82, 041.84–041.86, 041.89, 041.9, V09.80, V09.81, V09.90, V09.91, 682, 682.2, 682.5, 682.8, 682.9, 686.01, 032.85, 680.2, 996.65, 996.66, 996.67, or 996.69). Infections were coded separately for the index and re-admission stays.

Statistical analysis

We calculated descriptive statistics for all patient and hospital characteristics. To examine differences between patients re-admitted after open vs. endovascular procedures, we used χ^2 analysis for categorical variables or *t*-tests for continuous variables. Chi-square analysis also was used to determine the characteristics of the index admission associated with having an infection during the re-admission stay; relative risks (RRs) and 95% confidence intervals (CIs) were calculated.

To account for nonrandom assignment of procedure type, a propensity model was developed using logistic regression. This model predicted the probability of receiving an open LE procedure based on patient, encounter, and hospital characteristics. These covariates were entered into a stepwise logistic model to create a propensity score with an entry and exit *p* value set at 0.10.

Associations of patient and hospital characteristics, index admission diagnoses, and post-operative laboratory results with infection during the re-admission stay were modeled using logistic regression. Three models were developed. The first included all patients, whereas the other two examined re-admission after open and endovascular procedures separately. The full model included the propensity score, patient characteristics (age, sex, race, and disease severity), procedure type (open or endovascular), hospital characteristics (number of beds and teaching facility), Charlson Index, length of index stay, index diagnoses, and post-operative laboratory data. The open and endovascular models excluded the propensity score and procedure type. For all models, odds ratios (OR) and 95% CIs were calculated. The *c*-statistic was used to determine model discrimination, and model fit was assessed using the Hosmer-Lemeshow goodness-of-fit χ^2 test. A descriptive examination of the microbiology data available at the time of re-admission also was conducted. The SAS version 9.4 software (SAS Institute, Cary, NC) was used to perform all analyses.

Results

Overall

Of the 7,089 patients who underwent elective LE procedures, 770 (10.9%) were re-admitted within 30 d, with 345 (44.8%) of these having had an open LE procedure and 425 (55.2%) an endovascular procedure (Table 1). The mean age in

TABLE 1. PATIENT, HOSPITAL, AND PROCEDURAL CHARACTERISTICS FOR PATIENTS WITH PERIPHERAL ARTERY DISEASE (PAD) WHO HAD LOWER EXTREMITY (LE) RE-VASCULARIZATION AND WERE RE-ADMITTED WITHIN 30 D, BY PROCEDURE TYPE

	Total (N = 770)		Procedure type		p ^a		
			Endovascular (n = 425)	Open (n = 345)			
Patient characteristics							
Mean age (SD)(y)	67.9	(11.2)	68.4	(11.5)	67.4	(10.9)	0.20
21–59	182	(23.6)	103	(24.2)	79	(22.9)	
60–69	249	(32.3)	123	(28.9)	126	(36.5)	
70–79	215	(27.9)	120	(28.2)	95	(27.5)	
≥80	124	(16.1)	79	(18.6)	45	(13.0)	
Male (%)	463	(60.1)	237	(55.8)	226	(65.5)	0.006
Race/ethnicity (%)						0.52	
African American	196	(25.5)	115	(27.1)	81	(23.5)	
Caucasian	541	(70.3)	292	(68.7)	249	(72.2)	
Other/unknown	33	(4.3)	18	(4.2)	15	(4.4)	
Hospital characteristics (%)							
Bed size							<0.0001
<200	85	(11.0)	53	(12.5)	32	(9.3)	
200–299	161	(20.9)	113	(26.6)	48	(13.9)	
300–499	208	(27.0)	98	(23.1)	110	(31.9)	
500 or more	316	(41.0)	161	(37.9)	155	(44.9)	
Teaching facility	590	(76.6)	293	(68.9)	297	(86.1)	<0.0001
PAD Severity (%)						0.001	
Gangrene	155	(20.1)	85	(20.0)	70	(20.3)	
Rest pain	106	(13.8)	45	(10.6)	61	(17.7)	
Ulceration	108	(14.0)	56	(13.2)	52	(15.1)	
Claudication	181	(23.5)	94	(22.1)	87	(25.2)	
Unknown	220	(28.6)	145	(34.1)	75	(21.7)	
Index mean length of stay (d)(SD)	5.7	(5.6)	5.2	(5.9)	6.2	(5.2)	0.01
Mean Charlson Index, index stay (SD)	2.9	(1.8)	3.0	(1.9)	2.6	(1.6)	<0.001
1	192	(24.9)	96	(22.6)	96	(27.8)	
2	206	(26.8)	107	(25.2)	99	(28.7)	
3+	372	(48.3)	222	(52.2)	150	(43.5)	
Infection during re-admission stay (%)							
Any	289	(37.5)	132	(31.1)	157	(45.5)	<0.0001
LE cellulitis	105	(13.6)	53	(12.5)	52	(15.1)	0.29
Surgical site infection	114	(14.8)	27	(6.4)	87	(25.2)	<0.0001
Urinary tract infection	38	(4.9)	22	(5.2)	16	(4.6)	0.73
Pneumonia	38	(4.9)	22	(5.2)	16	(4.6)	0.73
Sepsis	68	(8.8)	27	(6.4)	41	(11.9)	0.007
Other infection	125	(16.2)	54	(12.7)	71	(20.6)	0.003

^aChi-square (*t*-test for continuous) comparison of having endovascular vs. open procedure.
SD = standard deviation.

the total series was 67.9 y. A majority of the study population was Caucasian (70%), and 25% were African-American. More than half of the population was male (60%), and males were more likely to have had open procedures ($p < 0.006$).

On average, patients who had endovascular LE procedures experienced significantly shorter hospital stays (5.2 vs. 6.2 d; $p = 0.01$) and had higher Charlson Index scores (3.0 vs. 2.6; $p < 0.001$). The overall infection rate at re-admission was 37.5%. Surgical site infections were the most common (14.8%), followed by LE cellulitis (13.6%). Patients who had open LE procedure were more likely to have an infection during the re-admission stay than were patients who had endovascular procedures (45.5% vs. 31.1%, respectively; $p < 0.0001$).

Index diagnoses and conditions (Table 2) most strongly associated with infection during the re-admission stay were infection during the index stay (RR 1.71; 95% CI 1.42–2.06),

chronic anemia (RR 1.71; 95% CI 1.43–2.04), hemorrhage or hematoma complicating a procedure (RR 1.64; 95% CI 1.21–2.23), post-hemorrhagic anemia (RR 1.62; 95% CI 1.29–2.05), and end-stage renal disease (RR 1.52; 95% CI 1.23–1.89). Post-operative laboratory results associated with an infection during the re-admission stay were hemoglobin concentration < 8 g/dL (RR 1.98; 95% CI 1.63–2.40), platelet count $> 400 \times 10^3$ /mcL (RR 1.53; 95% CI 1.18–1.99), blood urea nitrogen concentration (BUN) > 20 mg/dL (RR 1.43; 95% CI 1.19–1.72), and serum glucose concentration > 180 mg/dL (RR 1.43; 95% CI 1.16–1.78).

Models

The propensity model had a non-significant goodness-of-fit statistic, indicating adequate calibration ($\chi^2 = 9.91$;

TABLE 2. UNADJUSTED ASSOCIATION OF SELECTED DIAGNOSES AND POST-OPERATIVE LABORATORY TESTS DURING THE INDEX HOSPITAL ENCOUNTER WITH INFECTION DURING RE-ADMISSION STAY (FREQUENCY [COLUMN %])

Diagnosis or Laboratory Value	Re-admission (30 d)			RR (95% CI)	p ^a
	Total (N=770)	No Infection (n=481)	Infection (n=289)		
Diagnoses during the index admission					
Fluid and electrolyte disorders	104 (13.5)	54 (11.2)	50 (17.3)	1.34 (1.07–1.68)	0.01
Anemia	157 (20.4)	69 (14.4)	88 (30.5)	1.71 (1.43–2.04)	<0.0001
Chronic kidney disease	195 (25.3)	107 (22.3)	88 (30.5)	1.29 (1.07–1.56)	0.01
Diabetes	364 (47.3)	208 (43.2)	156 (54.0)	1.31 (1.09–1.57)	0.003
Lower extremity ulcer	179 (23.3)	92 (19.1)	87 (30.1)	1.42 (1.18–1.72)	<0.001
Thyroid disorders	48 (6.2)	22 (4.6)	26 (9.0)	1.49 (1.13–1.96)	0.01
End-stage renal disease	91 (11.8)	42 (8.7)	49 (17.0)	1.52 (1.23–1.89)	<0.001
Infections during Index admission					
Any	123 (16.0)	52 (10.8)	71 (24.6)	1.71 (1.42–2.06)	<0.0001
Cellulitis, abscess of leg or foot	64 (8.3)	27 (5.6)	37 (12.8)	1.62 (1.28–2.04)	<0.001
Surgical site	12 (1.6)	7 (1.5)	5 (1.7)	1.11 (0.57–2.19)	0.76
Urinary tract	21 (2.7)	9 (1.9)	12 (4.2)	1.55 (1.05–2.26)	0.06
Pneumonia	19 (2.5)	9 (1.9)	10 (3.5)	1.42 (0.92–2.19)	0.16
Sepsis	9 (1.2)	3 (0.6)	6 (2.1)	1.79 (1.12–2.87)	0.06
Other	41 (5.3)	15 (3.1)	26 (9.0)	1.76 (1.37–2.26)	<0.001
Other complications					
Hemorrhage/hematoma	30 (3.9)	12 (2.5)	18 (6.2)	1.64 (1.21–2.23)	<0.01
Acute post-hemorrhagic anemia	62 (8.1)	26 (5.4)	36 (12.5)	1.62 (1.29–2.05)	<0.001
Post-operative laboratory results ^b					
Hemoglobin (<8 g/dL)	52 (7.9)	14 (3.5)	38 (14.5)	1.98 (1.63–2.40)	<0.0001
Glucose					
Low (<80 mg/dL)	15 (2.3)	9 (2.3)	6 (2.3)	1.00 (0.54–1.88)	0.98
Optimal (80–180 mg/dL)	548 (83.3)	343 (86.6)	205 (78.2)	0.72 (0.59–0.89)	0.005
High (>180 mg/dL)	95 (14.4)	44 (11.1)	51 (19.5)	1.43 (1.16–1.78)	0.002
BUN					
Low (males <8; females <6 mg/dL)	17 (2.6)	12 (3.0)	5 (1.9)	0.73 (0.35–1.54)	0.37
Normal (males 8–20; females 6–20 mg/dL)	431 (65.5)	279 (70.5)	152 (58.0)	0.73 (0.60–0.88)	0.001
High (>20 mg/dL)	210 (31.9)	105 (26.5)	105 (40.1)	1.43 (1.19–1.72)	0.0003
Potassium					
Low (<3.7 mEq/L)	31 (4.7)	25 (6.3)	6 (2.3)	0.47 (0.23–0.98)	0.017
Normal (3.7–5.2 mEq/L)	591 (89.8)	354 (89.4)	237 (90.5)	1.07 (0.78–1.49)	0.65
High (3.7–5.2 mEq/L)	36 (5.5)	17 (4.3)	19 (7.3)	1.35 (0.98–1.87)	0.10
Sodium					
Low (<135 mEq/L)	73 (11.1)	40 (10.1)	33 (12.6)	1.15 (0.88–1.52)	0.31
Normal (135–145 mEq/L)	580 (88.2)	355 (89.7)	225 (85.9)	0.82 (0.63–1.06)	0.14
High (>145 mEq/L)	5 (0.8)	1 (0.3)	4 (1.5)	2.02 (1.29–3.17)	0.06
Platelet count					
Low (<150 10 ³ /μL)	73 (11.1)	47 (11.9)	26 (9.9)	0.88 (0.64–1.22)	0.43
Normal (150–400 10 ³ /μL)	539 (81.9)	330 (83.3)	209 (79.8)	0.87 (0.69–1.09)	0.24
High (>400 10 ³ /μL)	46 (7.0)	19 (4.8)	27 (10.3)	1.53 (1.18–1.99)	0.006
White blood cell count					
Low (< 4.5 10 ³ /μL)	6 (0.9)	5 (1.3)	1 (0.4)	0.42 (0.07–2.50)	0.24
Normal (4.5–11.0 10 ³ /μL)	474 (72.0)	299 (75.5)	175 (66.8)	0.78 (0.64–0.95)	0.01
High (> 11.0 10 ³ /μL)	178 (27.1)	92 (23.2)	86 (32.8)	1.32 (1.09–1.60)	0.006

^aChi-square (*t*-test for continuous) comparison of having an infection during re-admission stay vs. no infection.

^bThe 112 encounters with no post-operative laboratory data are excluded from the laboratory analyses.

CI=confidence interval; RR=relative risk.

p=0.27), and a c-statistic of 0.71. The model-predicted probability of having an open procedure was used as a covariate in the overall model. After controlling for patient demographics and Charlson Index, several factors were associated with infection during the re-admission stay (Table 3): Post-operative hemoglobin <8 g/dL (OR 2.92; 95% CI 1.48–5.78), chronic anemia (OR 2.09; 95% CI 1.35–3.23),

prior infection (OR 1.77; 95% CI 1.08–2.91), being in a teaching facility (OR 1.78; 95% CI 1.06–3.00), and greater length of stay (OR 1.05; 95% CI 1.01–1.08). Having an endovascular procedure was protective for re-admission with infection (OR 0.48; 95% CI 0.33–0.70). The model discrimination c-statistic was 0.71 and calibration was adequate ($\chi^2=3.54$; p=0.89).

TABLE 3. MULTIVARIABLE LOGISTIC REGRESSION MODELS FOR RISK FACTORS FOR INFECTION DURING RE-ADMISSION STAY, OVERALL AND BY PROCEDURE TYPE^a

	<i>Infection during re-admission Stay* (n=262)</i>		<i>Re-admission infection by LE procedure</i>			
			<i>Endovascular (n=123)</i>		<i>Open (n=139)</i>	
	<i>OR (95% CI)</i>	<i>p</i>	<i>OR (95% CI)</i>	<i>p</i>	<i>OR (95% CI)</i>	<i>p</i>
Propensity score	0.41 (0.12–1.43)	0.16				
Age (y)	0.99 (0.98–1.01)	0.4338	0.99 (0.97–1.01)	0.34	1.00 (0.98–1.02)	0.99
Female	0.99 (0.69–1.40)	0.9624	0.99 (0.61–1.62)	0.96	1.13 (0.67–1.88)	0.65
Race (reference = African American)						
Caucasian	1.39 (0.91–2.10)	0.1249	1.62 (0.91–2.92)	0.10	1.02 (0.56–1.85)	0.96
Other	1.03 (0.41–2.59)	0.9507	1.29 (0.35–4.69)	0.70	0.70 (0.18–2.65)	0.59
Charlson Index (reference = 1)						
2					2.22 (1.11–4.45)	0.02
3+					1.06 (0.51–2.20)	0.88
Endovascular procedure	0.48 (0.33–0.70)	0.0001				
Length of stay (d)	1.05 (1.01–1.08)	0.01	1.09 (1.04–1.13)	0.0002		
Teaching facility	1.78 (1.06–3.00)	0.02				
Anemia as an index diagnosis	2.09 (1.35–3.23)	0.0009	2.89 (1.65–5.07)	0.0002		
Infection during index stay	1.77 (1.08–2.91)	0.02			2.65 (1.24–5.70)	0.01
Hemoglobin <8 g/dL	2.92 (1.48–5.78)	0.002			4.98 (2.01–12.3)	0.0005

^aBecause post-operative laboratory values were included in the model, 112 observations with no laboratory data were excluded, leaving 658 observations for modeling.

CI=confidence interval; OR=odds ratio.

For infection during the re-admission stay following an endovascular procedure, only chronic anemia (OR 2.89; 95% CI 1.65–5.07) and length of stay (OR 1.09; 95% CI 1.04–1.13) were statistically significant after adjusting for other covariables. For infection during the re-admission stay following an open procedure, post-operative hemoglobin <8 g/dL (OR 4.98; 95% CI 2.01–12.30) and infection during the index stay (OR 2.65; 95% CI 1.24–5.70) remained statistically significant. Both models had modest discrimination and adequate calibration (endovascular: c-statistic = 0.73; $\chi^2 = 6.9$; $p = 0.54$; open: c-statistic = 0.70; $\chi^2 = 6.43$; $p = 0.59$).

Micro-organisms present during re-admission stay

Of the 289 patients in whom an infection diagnoses was coded during the re-admission stay, 60% (n=175) had no microbiology data available to examine; 28% (n=81) had a single organism present, and the remaining 11% (n=33) had multiple organisms. Microbiology findings at the time of re-admission for patients with an infection coded included several common isolates: *Staphylococcus*, *Enterococcus*, *Escherichia*, *Pseudomonas*, *Proteus*, and *Klebsiella* (Fig. 1).

Discussion

This analysis of patients who underwent elective LE procedures demonstrated an overall re-admission rate of 10.9%, with 37.5% of these having an infection during the re-admission stay. Site complications, particularly surgical site infections, were the most common infections coded during the re-admission stay. Significant factors during the original index procedure stay that were associated with a higher risk of infection at re-admission included the number of beds in the hospital, the presence in a teaching facility, male gender,

a higher number of co-morbidities, chronic anemia as a hospital diagnosis, an infection during the index stay, a post-operative hemoglobin concentration <8 g/dL, and a hematoma complicating a procedure. Low serum potassium was associated with a lower likelihood re-admission infection. After adjusting for age, race, co-morbidity burden, and the propensity to receive an open procedure, we found that a longer stay, procedures performed at teaching facilities, a diagnosis of chronic anemia, hemoglobin <8 g/dL, and an infection during the index stay were the most strongly associated with being re-admitted with an infection. Endovascular procedures were associated with a decreased chance of re-admission with an infection. At re-admission, *Staphylococcus* was the most common organism isolated; other common isolates were gram-negative bacteria, including *Pseudomonas* and *Klebsiella*.

Vascular surgery patients are at significant risk for re-admission, with rates as high as 30% [8,9]. Lower-extremity bypass procedures are associated with a high rate of unplanned re-admissions [4,10]. We found that among patients re-admitted with an infection, surgical site infection and LE cellulitis were the most common. This is similar to previous reports that have identified surgical site complications, including infections, as the most common reason for re-admission [11,12]. Engelbert et al. evaluated more than 2,000 patients from a single institution and found that surgical site complications were the most common re-admitting diagnosis, with site infection accounting for 20% of the re-admissions [10]. McPhee et al. noted a higher rate of re-operation, a lower rate of limb salvage at one y, and a higher mortality rate among patients re-admitted after LE bypass [5]. A mean cost of \$10,000 is associated with each re-admission for patients with prior LE bypass [13].

After adjusting for patient characteristics and co-morbidities, we found that chronic anemia and low hemoglobin concentration

FIG. 1. Micro-organisms found during re-admission stay in patients with an infection.

during the index hospitalization were associated with a higher risk of re-admission with infection. Patients with hemoglobin <8 g/dL were almost five times more likely to be re-admitted with an infection within 30 d after an open LE procedure. Suggested reasons for this association are that collagen deposition and tensile strength in surgical sites are limited by perfusion and tissue oxygen tension [14]. Other investigators have shown a direct correlation between blood transfusion for LE bypass and more wound infections [15–17]. In one analysis examining cardiac surgery and the relation between transfusion and the risk of major infection, researchers found that each unit of blood transfused was associated with a 29% increase in the crude risk of major infection [18]. Furthermore, in a study looking at hemoglobin concentration after total joint arthroplasty, a low hemoglobin concentration was a significant risk factor for surgical site infection [19].

We previously found that a longer stay was associated with 30-d re-admission after vascular intervention [8]. The current study demonstrates that a longer stay also is associated with infection at the time of re-admission [20]. Damrauer et al. analyzed this association, noting length of stay to be associated with post-operative complications during the index admission [21]. However, these complications did not impact the risk of 30-d re-admission. In this analysis, many of the factors associated with a greater likelihood re-admission with an infection may be patient factors leading to prolonged admission, such as a greater co-morbidity burden as well as infections at the initial procedure. Co-morbidities associated with re-admission and infection in bivariable analysis included a diagnosis of diabetes at the time of the index procedure. Previous investigations have supported this conclusion indirectly by demonstrating a direct association between insulin-dependent diabetes and a higher risk of 30-d re-admission [4,12,22]. Although the association between diabetes and re-admission is not surprising, it may well represent an association between poor glucose control and an overall

higher risk of infection. Supporting this hypothesis is the finding by Greenblatt et al. that there is no statistically significant increase in the risk of surgical site infection after open extremity revascularization among patients with diabetes [23]. Our analysis has demonstrated that a high glucose concentration and diabetes during the index hospitalization were associated with infections at re-admission, suggesting that this co-morbidity is not well managed during the admission and procedure stay and may be an area appropriate for targeted improvement.

Other co-morbidities found in bivariable analysis associated with infection during the re-admission stay included chronic kidney disease. Specifically, dialysis increases the risk of re-admission among vascular surgery patients [16]. Using laboratory data, we also found that patients with BUN >20 mg/dL were at a higher risk of infection at the time of re-admission. This finding correlates with data proposed by Vandecasteele et al. demonstrating that uremia depresses the immune system, potentially exposing patients on hemodialysis to a higher risk of colonization by pathogens such as *S. aureus* [24].

We found that patients in teaching facilities were 1.8 times more likely to be re-admitted with infectious complications than were those treated in non-teaching facilities. This is likely related to the higher co-morbidity burden, low socioeconomic status, and complexity of patients treated at teaching facilities, which is not controlled for adequately by the Charlson Index. Gohil et al. evaluated infection-related re-admission and found that academic hospitals had higher all-cause and infection-related re-admission rates, possibly because of caring for patients with more co-morbidities having longer stays, discharging more patients to skilled nursing facilities, and having more patients living in federal poverty areas [25].

Finally, our evaluation of the microbiology of these infections found that the most common isolates were *Staphylococcus*, *Enterococcus*, *Escherichia*, *Pseudomonas*, and *Klebsiella*. *Staphylococcus* was also the most common organism isolated in prior studies [26]. Noteworthy from our current investigation is the higher than expected frequency of

gram-negative bacteria, including *Pseudomonas* and *Klebsiella*, seen at re-admission. It has been demonstrated in previous studies evaluating surgical site infections that causative pathogens depend on the type of surgery, and the most commonly isolated organisms are gram positive, including *S. aureus*, coagulase-negative staphylococci, and *Enterococcus* spp. [26]. Contrary to previous publications regarding surgical site infections being caused by gram-positive organisms, this study demonstrated that greater than 40% of these infections at the time of re-admission after LE procedures were caused by gram-negative bacteria; and this finding should be considered at the time of re-admission to enable appropriate antibiotic selection. Our analysis is limited by the use of ICD-9 codes to identify procedures and diagnoses, and coding can differ among institutions. All of the procedures utilized for this analysis were performed in hospitals; no procedures performed in out-patient facilities are included in the data set. In addition, we are unable to determine re-admissions to hospitals in different health systems. As Health Facts is a proprietary database comprised of electronic records from hospitals and hospital systems that use Cerner's electronic health record, our ethnicity data may not be reflective completely of the U.S. population; urban, smaller, and rural hospitals may be underrepresented.

In conclusion, infections are a major reason of re-admission within 30 d after LE procedures, accounting for more than one-third of all re-admissions. Factors associated with re-admission included a greater co-morbidity burden, longer stay, procedures performed at teaching facilities, low hemoglobin concentration, and having an infection during the index stay. Microbiology analysis of these infections at re-admission demonstrated gram-negative bacteria in more than 40% of cases. Future studies will be needed to develop prevention strategies to reduce re-admission based on these risk factors in the vascular surgery population.

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Author Disclosure Statement

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