Operative Autonomy among Senior Surgical Trainees during Infrainguinal Bypass Operations Is Not Associated with Worse Long-term Patient Outcomes

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Background: In an era of rapidly evolving surgical training, intraoperative teaching remains paramount to the education of surgical trainees. The impact of surgical trainees' level of expertise on outcomes after infrainguinal bypass surgery, a technically demanding operation, remains unknown. The purpose of this study was to explore the effects of surgical residents' experience on outcomes after infrainguinal bypass surgery.

Methods: Using the American College of Surgeons National Surgical Quality Improvement Program database, we identified patients who underwent infrainguinal bypass from 2005 to 2012. Patients were stratified according to the training level of the most senior operating trainee. Univariate and multivariate analyses, as well as propensity score matched analysis, were performed to compare patient cohorts on operative time, length of hospital stay (LOS), bleeding, early graft failure, unplanned readmission, and 30-day mortality.

Results: A total of 19,579 patients were identified, of which 35.6% were female and 64.4% were male; mean age was 67.6 years. A PGY1 (postgraduate year) was the highest level trainee operating on 2.5%, a PGY2−4 for 26.2%, and a PGY5+ (postgraduate year 5 or greater) for 37.1%. Attending surgeons operated without trainees on 34.2%. PGY5+s were more likely to operate on patients who were younger, non-White, male, and on dialysis. In multivariable analysis, involvement of any surgical trainee was associated with procedures that took a greater length of time, had a greater odds of blood transfusion, and necessitated a longer hospital LOS relative to procedures performed by an attending surgeon alone. Only bypasses wherein PGY5+s were involved were associated with greater odds of early graft failure, unplanned readmission, and 30-day mortality when compared with procedures done without trainee involvement. After excluding lower extremity bypasses in which an attending surgeon operated without a trainee, propensity score matching analysis showed that patients operated on by PGY5+s had longer operative time (4.11 vs. 3.96 hr, $P < 0.0001$) and greater rates of postoperative bleeding (9.77% vs. 8.15%, $P = 0.004$) relative to patients operated on by attendings assisted by PGY1−4s, but no statistically significant difference in LOS, early graft failure, unplanned readmission, and perioperative mortality.

Conclusions: Operative involvement of senior trainees was associated with worse outcomes during infrainguinal bypass, potentially reflecting a lesser extent of attending surgeon involvement, but no difference in patient outcomes after bypass procedure.

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INTRODUCTION

The classic Halstedian model of training surgeons advocates a gradual increase in trainees' responsibilities with each advancing year of surgical residency.[1,2] In the setting of this established paradigm, the Institute of Medicine (IOM) published their well-known treatise, *To Err is Human*, regarding the state of patient safety in the United States.[3] In the wake of this report, and substantiated by highly publicized accounts of medical errors, broad measures have been implemented to optimize the healthcare environment and patient outcomes.[4,5] With respect to medical education and training, this included such measures as more stringent work hour restrictions, greater trainee oversight by board certified physicians, and instructions on performing patient hand-offs from one trainee to another.[5–7] These reforms, as well as a plethora of others, have been instituted in an effort to ensure that patient outcomes are not compromised in the hands of invested, yet inexperienced, trainees.

Certainly the future of patient safety relies on the training of safe healthcare providers, yet such training inherently increases the potential for harm, as resident autonomy is a necessary component of training. As shown in a variety of specialties, graduated responsibility and autonomy during training is tied closely to confidence in a trainee's competence, both among trainees as well as among their supervising attending physicians.[8–11] The gravity of this is nowhere more evident than in the operating room, where surgical residents must transition from first assistant to surgeon chief to attending surgeon.

Surgical education has undergone a cultural shift following the 1999 IOM report. The classic ''See one, do one, teach one'' philosophy of surgical training has since been scrutinized due to patient safety concerns. From preinternship ''bootcamps'' to laparoscopic, endoscopic, and endovascular simulation, initiatives have been made to ensure and enhance technical proficiency among surgical residents.[12] Many programs pilot simulated crisis situations in the operating room, trauma bay, and on the ward to ensure that residents perform well at times of high pressure and stress.[13] Still, these proficiencies must ultimately translate into real world practice where residents are provided opportunities to practice independent decision making and to demonstrate procedural competency. This is particularly true in the field of vascular surgery, where a poorly placed stitch or inadequate knot creates the potential for blood loss, vascular occlusion, compromised tissue vitality, or even death. While simulation training has fittingly supplemented residents' preparation for endovascular procedures, exposure to and practice with open vascular surgical procedures are diminishing. As a consequence, trainee involvement during these procedures is increasingly imbued with risk.

Infrainguinal bypass procedures are a collection of technically challenging operations performed often in highly comorbid patients with significantly diseased blood vessels. Many such patients have already undergone and failed prior endovascular intervention, suggesting that they carry the worst form of atherosclerotic burden and the greatest susceptibility to technical complications. Moreover, this burden of disease puts them at significant risk for developing systemic morbidity and overall mortality postoperatively. From a technical standpoint, lower extremity arterial bypass surgery entails exposure of blood vessels, vascular anastomoses, and tunneling of conduit. These techniques demand the utmost technical finesse, with mastery achieved only by repeated exposure and performance. Amid a fragile patient population, the learning curve associated with lower extremity bypass surgery is certainly steep and often fraught with setbacks.

We hypothesized that lower extremity arterial bypass procedures provide a compelling test case to determine the impact of surgical resident operative involvement on outcomes because there are diminishing opportunities to perform open vascular surgery. This study sought to compare outcomes following infrainguinal bypass among patients operated on by chief residents and fellows with outcomes of patients operated on by more junior residents using data from the National Surgical Quality Improvement Program (NSQIP).

METHODS

Data

This study is a retrospective cohort study using data collected from the American College of Surgeons NSQIP Participant Use File from 2005 to 2012. This is a clinical dataset built from individual patient records collected from patients across the United States. At each participating site, a trained clinical reviewer abstracts hundreds of variables. Variables include demographics and preoperative risk factors, intraoperative data, and postoperative outcomes. Patients undergoing infrainguinal bypass for peripheral vascular disease were identified using Current Procedural Terminology codes: 35556 (femoral—popliteal bypass with vein), 35566 (femoral—distal bypass with vein), 35571 (popliteal—distal bypass with vein), 35583 (femoral—popliteal bypass with in situ vein), 35585 (femoral—distal bypass with in situ vein), 35587 (popliteal—distal bypass with in situ vein), 35656 (femoral—popliteal bypass with prosthesis), 35666 (femoral—distal bypass with prosthesis), and 35671 (popliteal—distal bypass with prosthesis). Using the variable for the ''level of most senior operating resident surgeon'' involved in the bypass procedure, patients were stratified according to the most experienced operating resident: PGY1 (postgraduate year), PGY2—4, and PGY5+s (PGY 5 and greater). This stratification was undertaken to simulate the traditional experience-based hierarchy within surgical training programs, that of interns, junior residents, and chief residents and fellows. This scheme also accounted for ambiguity in labeling residents who might be primarily occupied with a research fellowship in the midst of their clinical years, an experience that most commonly occurs after the second or third years of postgraduate training, but would otherwise be labeled as a PGY2-, 3-, or 4-level resident. A fourth cohort of patients operated on by attending surgeons without operative involvement of resident surgeons was included for comparison. Patients were excluded if their information was missing within the database.

Covariates and Outcomes

Patient-level covariates studied included race, age, sex, body mass index, admission type (emergent, nonemergent), use of smoking tobacco, abuse of alcohol, use of steroids, and comorbidities (diabetes mellitus, chronic obstructive pulmonary disease, pneumonia, ascites or esophageal varices, congestive heart failure, history of myocardial infarction [MI], angina, history of cardiac procedure, history of percutaneous coronary intervention, acute renal failure, need for dialysis, history of cerebrovascular accident [stroke], history of transient ischemic attack, neuromuscular deficit, cancer, bleeding disorder, and surgical procedure in preceding 30 days). Procedure-level covariates included specialty of attending surgeon (vascular surgery, nonvascular surgery), material of bypass graft (vein, prosthetic), and level of bypass (femoral—popliteal with vein, femoral—popliteal without vein, femoral—tibioperoneal with vein, femoral—tibioperoneal without vein, popliteal—tibial with vein, and popliteal—tibial without vein). Postoperative covariates included development of complications (infection, sepsis, wound dehiscence, pulmonary embolus, renal failure, stroke, MI, and requirement of blood transfusion at any time during their hospital course).

Primary outcomes included operative time, length of hospital stay (LOS), clinically significant intraoperative blood loss (i.e., required transfusion), early graft failure, unplanned readmission, and 30-day postoperative mortality.

Statistical Analysis

Patient characteristics, operative details, and patient outcomes were stratified by the level of most senior operating trainee surgeon (intern, junior resident, chief resident/fellow, attending alone) and were compared using *t*-tests and chi-squared tests for continuous and categorical variables, respectively. Linear regression was used to model the effects of baseline characteristics on operative time, intraoperative blood loss, and LOS. We report coefficients with associated 95% confidence intervals and *P* values. Logistic regression was used to model the effects of baseline characteristics on early graft failure, unplanned readmission within 30 days, and 30-day postoperative mortality. We report odds ratios (ORs) with associated 95% confidence intervals and *P* values. Goodness-of-fit of the logistic regression models was measured as the area under the receiver operating characteristic (ROC) curve.

In order to determine whether the rates of operative time, LOS, blood loss, graft failure, unplanned readmission, and 30-day mortality could be explained by the experience level of the operating resident surgeon (chief resident/fellow versus junior resident/intern), patients treated by senior-level trainees and junior-level trainees were propensity score matched on demographic, procedure-related, and admission-related characteristics. Propensity score matching was performed 1:1 without replacement using a nearest-neighbor approach and a 0.02 standard deviation caliper restriction. Confidence intervals were computed using 500 bootstrap replicates. All statistical analyses were performed using STATA software (version 12, College Station, TX) and the psmatch2 routines.[14] Statistical significance for all analyses was defined as a *P* value <0.05. The study was conducted in accordance with the Helsinki Declaration and study protocol approval was provided by the Penn State Milton S. Hershey Medical Center Institutional Review Board (IRB STUDY00003999).

Table I. Demographic, disease-related, and procedure-related characteristics of patients undergoing infrainguinal bypass, stratified by the level of operating surgeon

Variable	Intern (n = 488)	Junior resident (n = 5,132)	Chief resident/fellow (n = 7,256)	Attending alone (n = 6,703)	P value
Age (years)	67.5	67.6	66.7	68.6	0.0001
18–49	7.79%	6.80%	6.77%	4.54%	0.476
50–64	32.58%	33.16%	35.54%	30.91%	0.119
65–74	28.89%	28.72%	29.63%	31.60%	0.775
75–84	20.70%	23.17%	21.87%	25.32%	0.388
85+	10.04%	8.14%	6.19%	7.64%	0.786
Sex					0.036
Male	64.75%	64.26%	65.53%	63.17%	
Female	35.25%	35.74%	34.47%	36.83%	
Race					<0.0001
White	69.88%	70.81%	69.28%	73.74%	
Black	17.01%	18.71%	18.67%	12.34%	
Hispanic	2.87%	3.35%	3.07%	3.80%	
Other	10.25%	7.13%	8.97%	10.11%	
BMI	27.37	27.41	27.63	27.45	0.197
Normal weight	34.43%	33.75%	32.59%	34.54%	
Overweight	35.45%	34.22%	34.22%	18.22%	
Obese	15.78%	19.25%	19.07%	10.59%	
Morbidly obese	10.66%	9.10%	10.60%	1.30%	
>10% weight loss over 6 months	1.23%	1.50%	1.47%	5.13%	0.745
Admission type					0.922
Emergency	5.74%	5.30%	5.15%	5.13%	
Other	94.26%	94.70%	94.85%	94.87%	
Social history					
Cigarettes in last year	41.80%	40.06%	41.79%	42.35%	0.084
Moderate etOH use	6.56%	5.71%	5.77%	5.74%	0.896
Diabetes mellitus	42.01%	44.91%	43.88%	42.92%	0.148
Insulin dependent	23.36%	25.45%	25.47%	23.24%	0.008
Noninsulin dependent	7.38%	6.86%	6.34%	6.94%	0.445
Pulmonary comorbidities					
History of severe COPD	11.27%	12.24%	12.05%	14.29%	<0.0001
Current pneumonia	0.00%	0.21%	0.30%	0.28%	0.517
Hepatic comorbidities					
Ascites	0.00%	0.19%	0.26%	0.24%	0.627
Esophageal varices	0.00%	0.12%	0.07%	0.06%	0.621
Cardiac comorbidities					
Congestive heart failure	2.25%	3.00%	2.56%	2.43%	0.242
History of MI	2.87%	1.58%	1.93%	2.15%	0.063
Hypertension	85.86%	84.76%	84.12%	84.11%	0.559
Angina	1.23%	1.99%	1.89%	2.27%	0.235
History of cardiac procedure	22.34%	23.73%	25.28%	23.54%	0.053
History of PCI	15.78%	18.94%	19.49%	19.84%	0.130
Renal comorbidities					
Acute renal failure	1.23%	1.50%	1.61%	1.04%	0.028
Chronic dialysis	6.35%	7.40%	7.61%	6.25%	0.010
Neurologic comorbidities					
CVA with neuro deficit	7.99%	7.11%	7.08%	7.41%	0.777
CVA without neuro deficit	7.99%	7.19%	6.68%	7.03%	0.548
History of TIA	7.58%	6.55%	7.46%	7.03%	0.262
Neuromuscular deficit	2.87%	3.35%	3.17%	3.22%	0.912
Cancer	0.41%	0.55%	0.51%	0.34%	0.355
Bleeding disorder	22.34%	25.53%	24.05%	23.57%	0.061
≥1u pRBC preoperatively	1.02%	0.88%	0.94%	0.73%	0.574

(*Continued*)

Table I. Continued

Variable	Intern ($n = 488$)	Junior resident ($n = 5,132$)	Chief resident/fellow ($n = 7,256$)	Attending alone ($n = 6,703$)	P value
Steroid use for chronic condition	4.71%	3.66%	4.31%	3.42%	0.028
Surgery in the past 30 days	4.71%	7.19%	7.19%	5.10%	<0.0001
Specialty of surgeon					
Vascular	97.13%	97.47%	97.20%	90.48%	<0.0001
Nonvascular	2.87%	2.53%	2.80%	9.52%	<0.0001
Type of graft					
Vein	70.49%	67.32%	69.79%	63.99%	<0.0001
Prosthetic	29.51%	32.68%	30.21%	36.01%	<0.0001
Bypass					
Femoral—popliteal, vein	38.32%	33.61%	31.41%	35.58%	<0.0001
Femoral—popliteal, nonvein	23.36%	24.81%	21.35%	28.96%	<0.0001
Femoral—TP, vein	26.43%	25.33%	28.61%	22.08%	<0.0001
Femoral—TP, nonvein	5.53%	7.03%	8.17%	6.33%	<0.0001
Popliteal—tibial, vein	5.74%	8.38%	9.77%	6.33%	<0.0001
Popliteal—tibial, nonvein	0.61%	0.84%	0.69%	0.73%	0.793

BMI, body mass index; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; etOH, alcohol; PCI, percutaneous coronary intervention; pRBC, packed red blood cells; TP, tibioperoneal.

RESULTS

Patient Characteristics

Patients who underwent infrainguinal bypass for peripheral vascular disease between 2005 and 2012 were included in the study. Patients with missing data or having discordant information about resident participation were excluded from the analyses. A total of 19,579 patients were identified. Among them, 488 underwent bypass with an intern as the most senior operating resident (PGY1), 5,132 with a junior resident (PGY2—4), and 7,256 with a chief resident/fellow (PGY5+). Attending surgeons performed 6,703 operations without involvement of any surgical trainee.

Descriptive statistics are shown in Table I. Cohorts differed significantly in terms of age, race, sex, various comorbidities, specialty of attending surgeon, type of bypass graft, and level of bypass. Patients for whom a chief resident/fellow was the operating resident surgeon were more often younger ($P = 0.0001$), male ($P = 0.036$), non-White ($P < 0.0001$), on dialysis ($P = 0.010$), and had undergone a surgical procedure in the preceding 30 days. Their procedures were more commonly distal bypasses, including femoral—tibioperoneal and popliteal—tibial bypasses ($P < 0.0001$), as shown in Figure 1. In contrast, procedures performed with the assistance of more junior residents were generally more proximal bypasses done on older, female, White patients who were less frequent on dialysis. In particular, procedures performed with an intern as the operating resident surgeon were more often done on patients with the least proportion of pulmonary or renal disease, although these patients had the greatest proportion of preoperative steroid use. Interns operated more often with nonvascular trained attending surgeons, assisting more commonly with femoral—popliteal bypass procedures, which were more commonly done using vein graft.

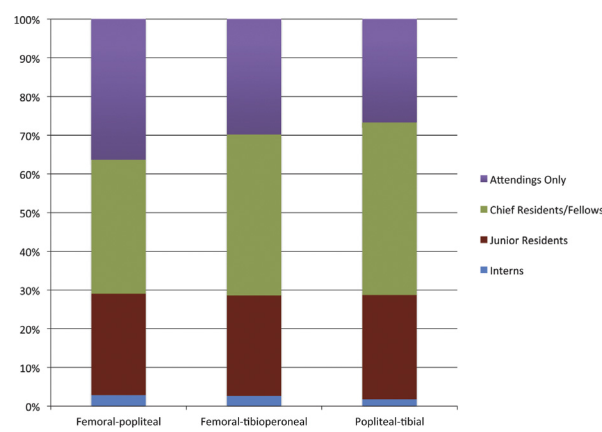

Fig. 1. Proportions of lower extremity arterial bypass procedures with vein graft performed involving residents.

Perioperative Characteristics

Multivariate analyses of intraoperative and postoperative outcomes are presented in Tables II and III, respectively. Relative to a patient who underwent a bypass procedure by an attending surgeon alone, involvement of any trainee was associated with

Table II. Multivariable analyses of intraoperative outcomes among patients undergoing infrainguinal bypass

	Operating room time		Intraoperative blood loss	
Variable	Coefficient	*P* value	Odds ratio	*P* value
Highest level of trainee				
Attending alone	Reference		Reference	
Intern	0.77	<0.0001	1.47	0.023
Junior resident	0.83	<0.0001	1.31	<0.0001
Chief resident/fellow	1.09	<0.0001	1.70	<0.0001
Race				
White	Reference		Reference	
Black	0.11	0.001	1.56	<0.0001
Hispanic	0.07	0.286	1.29	0.059
Other	0.02	0.632	1.35	<0.0001
Age (years)				
18−49	−0.06	0.280	0.59	<0.0001
50−64	−0.02	0.430	0.78	0.000
65−74	Reference		Reference	
75−84	−0.01	0.844	1.13	0.092
85+	−0.16	0.001	1.26	0.023
Sex				
Male	Reference		Reference	
Female	−0.06	<0.0001	1.32	<0.0001
BMI				
Normal weight	−0.11	0.001	1.08	0.289
Overweight	−0.06	0.054	0.93	0.318
Obese	Reference		Reference	
Morbidly obese	0.16	<0.0001	0.89	0.276
Acuity				
Emergency	0.33	<0.0001	1.50	<0.0001
Other	Reference		Reference	
Comorbidities				
Smoker	−0.11	<0.0001	0.83	0.003
Drinker	0.12	0.020	0.90	0.446
DM	0.08	<0.0001	1.33	<0.0001
COPD	−0.11	0.002	1.11	0.187
Pneumonia	−0.06	0.773	0.64	0.407
CHF	0.09	0.243	1.49	0.003
History of MI	−0.09	0.289	1.18	0.315
Hypertension	0.00	0.924	1.29	0.003
ARF	0.10	0.334	1.15	0.476
CVA with deficit	−0.09	0.073	1.12	0.317
Hemiplegia/paraplegia	0.06	0.486	1.01	0.972
Cancer	0.13	0.461	1.36	0.356
Bleeding disorder	0.17	<0.0001	1.71	<0.0001
Steroid use	−0.12	0.051	1.28	0.045
Surgical specialist				
Vascular trained	Reference		Reference	
Nonvascular trained	0.19	0.001	1.15	0.266
Type of graft				
Vein	Reference		Reference	
Prosthetic	−0.85	<0.0001	1.07	0.236
			AROC = 0.6577	

ARF, acute renal failure; AROC, area under the receiver operating characteristic curve; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DM, diabetes mellitus.

Table III. Multivariable analyses of postoperative outcomes among patients undergoing infrainguinal bypass

Variable	Length of stay		Early graft failure		Unplanned readmission		Thirty-day mortality	
	Coefficient	*P* value	Odds ratio	*P* value	Odds ratio	*P* value	Odds ratio	*P* value
Highest level of trainee								
Attending alone	Reference		Reference		Reference		Reference	
Intern	0.94	0.022	0.86	0.526	1.81	0.077	1.60	0.125
Junior resident	1.15	<0.0001	1.12	0.196	1.21	0.256	1.04	0.766
Chief resident/fellow	1.76	<0.0001	1.32	<0.0001	1.43	0.016	1.30	0.039
Race								
White	Reference		Reference		Reference		Reference	
Black	2.18	<0.0001	1.39	<0.0001	1.70	<0.0001	1.43	0.011
Hispanic	2.57	<0.0001	1.41	0.043	0.97	0.929	1.04	0.881
Other	1.82	<0.0001	0.92	0.496	1.03	0.897	1.06	0.747
Age (years)								
18−49	−0.23	0.354	1.70	<0.0001	0.90	0.701	0.20	0.003
50−64	−0.33	0.023	1.13	0.171	1.02	0.881	0.71	0.037
65−74	Reference		Reference		Reference		Reference	
75−84	0.96	<0.0001	1.02	0.805	0.93	0.679	2.05	<0.0001
85+	2.61	<0.0001	1.25	0.109	0.93	0.784	3.09	<0.0001
Sex								
Male	Reference		Reference		Reference		Reference	
Female	0.41	0.001	1.15	0.048	0.91	0.428	1.23	0.056
BMI								
Normal weight	0.27	0.083	0.99	0.928	0.96	0.825	1.14	0.354
Overweight	−0.07	0.648	0.88	0.156	0.94	0.718	0.86	0.309
Obese	Reference		Reference		Reference		Reference	
Morbidly obese	0.28	0.204	0.83	0.152	1.04	0.853	0.74	0.217
Acuity								
Emergency	3.32	<0.0001	2.02	<0.0001	0.77	<0.0001	2.81	<0.0001
Other	Reference		Reference		Reference		Reference	
Comorbidities								
Smoker	−0.34	0.007	1.08	0.309	0.90	0.448	0.93	0.579
Drinker	−0.04	0.855	0.89	0.434	1.01	0.978	0.95	0.865
DM	1.61	<0.0001	0.87	0.042	1.14	0.306	1.43	0.001
COPD	0.57	0.002	1.03	0.732	1.31	0.103	2.13	<0.0001
Pneumonia	6.69	0.001	1.25	0.675	Omitted		1.50	0.432
CHF	5.18	0.000	1.34	0.119	0.72	0.368	2.29	<0.0001
History of MI	4.44	<0.0001	0.88	0.601	1.28	0.487	2.12	0.001
Hypertension	−0.04	0.787	0.87	0.129	1.24	0.277	1.26	0.198
ARF	3.13	<0.0001	0.90	0.709	1.30	0.535	2.61	<0.0001
CVA with deficit	0.86	0.002	0.98	0.904	1.01	0.957	1.01	0.97
Hemiplegia/paraplegia	1.12	0.009	1.10	0.664	1.22	0.571	1.27	0.43
Cancer	1.79	0.080	1.13	0.771	1.67	0.480	5.21	<0.0001
Bleeding disorder	0.95	<0.0001	1.18	0.025	1.15	0.273	1.48	<0.0001
Steroid use	1.19	<0.0001	1.18	0.285	0.79	0.467	1.89	0.001
Surgical specialist								
Vascular trained	Reference		Reference		Reference		Reference	
Nonvascular trained	−0.24	0.348	0.93	0.665	1.41	0.160	1.11	0.671
Type of graft								
Vein	Reference		Reference		Reference		Reference	
Prosthetic	−1.09	<0.0001	1.03	0.719	1.13	0.312	1.18	0.117
Wound complication								
SSI	0.44	0.052	1.54	<0.0001	3.52	<0.0001	0.33	<0.0001
Deep wound infection	0.53	0.167	2.94	<0.0001	4.31	<0.0001	0.93	0.835
Organ space infection	1.47	0.108	4.02	<0.0001	5.69	<0.0001	1.66	0.347

(*Continued*)

Table III. Continued

	Length of stay		Early graft failure		Unplanned readmission		Thirty-day mortality	
Variable	Coefficient	*P* value	Odds ratio	*P* value	Odds ratio	*P* value	Odds ratio	*P* value
Wound dehiscence	0.03	0.943	1.12	0.613	1.99	0.018	0.45	0.134
Other complication								
Pulmonary embolism	2.87	0.151	2.23	0.195	4.62	0.048	1.66	0.634
DVT	1.49	0.061	1.82	0.038	3.40	0.001	2.31	0.027
ARF	6.45	<0.0001	1.17	0.676	0.34	0.289	9.14	<0.0001
CVA	4.18	<0.0001	1.88	0.051	1.86	0.251	5.13	<0.0001
MI	2.86	<0.0001	1.55	0.042	1.63	0.102	7.08	<0.0001
Bleeding	2.18	<0.0001	1.00	0.977	5.79	<0.0001	1.07	0.651
			AROC = 0.6344		AROC = 0.7400		AROC = 0.8036	

ARF, acute renal failure; AROC, area under the receiver operating characteristic curve; BMI, body mass index; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DM, diabetes mellitus; DVT, deep venous thrombosis; SSI, surgical site infection.

increased operative time even after controlling for other demographic and procedure-related covariates associated with greater technical difficulty and operative time (intern 0.77 hr, junior resident 0.83 hr, chief resident/fellow 1.09 hr, all $P < 0.0001$). Logistic regression for bleeding intraoperatively and up to 72 hr showed that relative to the reference patient operated on by an attending surgeon only, bypasses done with the involvement of a trainee surgeon were associated with greater likelihood of clinically significant blood loss (intern: OR 1.47, $P = 0.023$; junior resident: OR 1.31, $P < 0.0001$; chief resident/fellow: OR 1.70, $P < 0.0001$) (Table II). Linear regression for LOS showed that involvement of a resident of any level was associated with greater LOS (intern: 0.94 days, $P = 0.022$; junior resident: 1.15 days, $P < 0.0001$; chief resident/fellow: 1.76 days, $P < 0.0001$) (Table III). Logistic regression for early graft failure showed that relative to a reference patient, patients who underwent bypass with the involvement of a chief resident/fellow had a 32% greater odds of early graft failure (OR 1.32, $P < 0.0001$) although involvement of a more junior resident was not associated with a greater odds of early graft failure (Table III). Logistic regression for unplanned readmission showed that relative to a reference patient, only procedures done with the involvement of a chief resident/fellow as the highest level operating resident surgeon were associated with a greater odds of readmission (OR 1.43, $P = 0.016$) (Table III). Finally, in logistic regression of 30-day mortality, again only chief resident/fellow was associated with a significantly greater odds of death among bypass patients (OR 1.30, $P = 0.039$), whereas interns and junior residents' involvement was not significantly associated with 30-day mortality (Table III).

Because patients who were treated by chief residents/fellows had a number of significantly different distributions of characteristics compared with patients treated by more junior residents, propensity score matching was undertaken to match patients. In the matched cohorts, patients for whom a chief resident/fellow was the most senior operating trainee surgeon took a statistically significant greater amount of operative time (4.11 vs. 3.96 hr, $P < 0.0001$) and had a greater frequency of clinically significant bleeding (9.77% vs. 8.15%, $P = 0.004$) relative to patients in whom a more junior resident was the highest level operating resident surgeon (Table IV). Differences in LOS, early graft failure, unplanned readmission, and 30-day mortality were not statistically significant between matched cohorts (Fig. 2).

DISCUSSION

In contemporary vascular surgery, endovascular techniques are eclipsing open procedures.[15] Yet, surgical trainees must still be taught how to perform open bypass procedures and must have a measure of operative autonomy during their training.[16] Infrainguinal bypass is a technically challenging open surgical procedure performed in a typically unhealthy population associated with significantly elevated risk of complications. This study sought to compare outcomes following infrainguinal bypass among patients operated on by chief residents and fellows with outcomes of patients operated on by more junior residents. We found that in accordance with being allowed more operative autonomy than their more junior colleagues, chief residents and fellows were involved in cases that took longer operative time and had greater intraoperative blood loss. Yet

Table IV. Propensity score matched outcomes among patients undergoing infrainguinal bypass, stratified by the level of most senior operating trainee surgeon

				95% confidence		
Variable	≥PGY5	<PGY5	ATT	Lower	Upper	*P* value
Operative time (hr)	4.11	3.96	0.15	0.081	0.207	<0.0001
Bleeding	9.77%	8.15%	1.63%	0.005	0.027	0.004
LOS	9.20	8.90	0.30	−0.131	0.690	0.181
Graft failure	5.46%	5.00%	0.47%	−0.004	0.013	0.287
Unplanned readmission	2.31%	2.17%	0.14%	−0.003	0.008	0.345
Thirty-day mortality	2.47%	2.15%	0.32%	−0.002	0.009	0.246

ATT, average treatment effect on the treated (i.e., treated ≥PGY5).

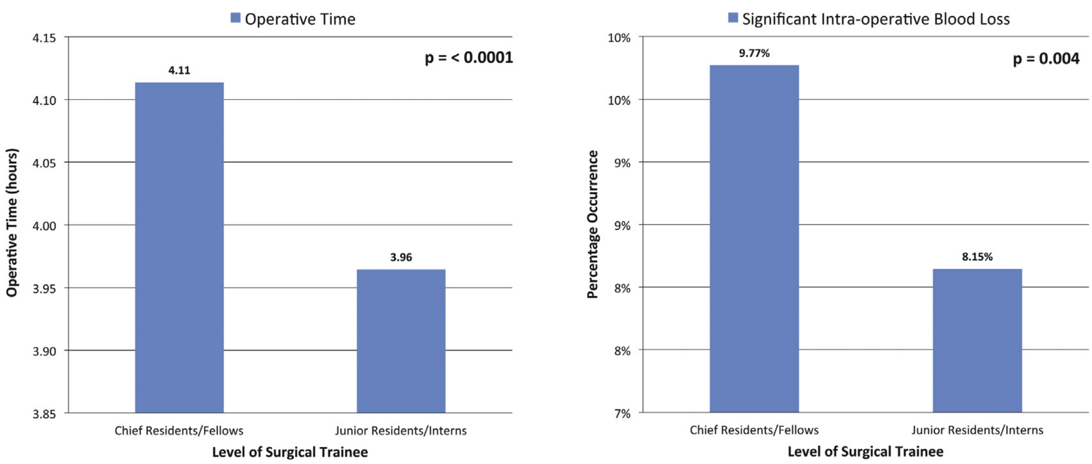

Fig. 2. Statistically significant propensity score matched outcomes, comparing patients operated on by chief residents/fellows and patients operated on by junior residents/interns.

despite these intraoperative differences, senior trainees did not differ from junior residents with regard to total hospital LOS, morbidity such as graft failure or other complications responsible for unplanned readmissions, or 30-day mortality.

The resident work hour restrictions, enhanced attending oversight, and diminished resident autonomy that ensued after sweeping Accreditation Council for Graduate Medical Education policy changes in 2003 continue to raise concerns that residents' competency is being hindered. The impact on residents' competence is especially evident in surgical fields where errors and poor quality can have mortal consequences.[5,8,9,11] While a number of studies have questioned whether resident involvement contributes to negative outcomes, we found that in infrainguinal bypass procedures, allowing senior residents to operate has some, albeit not enduring, consequences for patient safety.[17–28] Our finding of longer operative times and greater blood loss may simply reveal that attending surgeons are intervening less than they might when junior residents are operating. Scarborough et al.[27] and Hernandez-Irizarry et al.[28] found a similar result that more senior operating residents had longer operative times for common general surgery procedures. Reeves et al.[22] found a similar phenomenon after comparing outcomes among residents performing carotid endarterectomy. In contrast, no difference in operative times during below knee amputation or above knee amputation was found between junior and senior residents. This difference between findings of Iannuzzi et al. and Reeves et al., as well as of this study is likely attributable to how senior operating resident surgeons were defined in each study. More specifically, Iannuzzi found no difference when comparing residents at or below the PGY5 level, whereas the latter 2 studies identified differences when including trainees likely to be at the typically more autonomous fellowship (i.e., PGY6+) level.[18,22] When seniority is high enough among trainees that the probability of operative interference by attending surgeons is minimized, surgical cases are shown to take longer.

Much like operative time, intraoperative blood loss was found to be greater when chief residents and fellows were operating than when more junior residents were operating during infrainguinal bypass procedures. In the field of vascular surgery, intraoperative blood loss is a marker of operative proficiency. Assuming that junior residents act more as first assistants to attending surgeons and that attendings act more as first assistants to chief residents and fellows, it is not surprising that patients operated on by chief residents and fellows would manifest greater intraoperative blood loss secondary to relatively greater operative involvement of the trainee surgeon. Among other vascular surgical procedures, DiDato et al.[23] also found that the need for transfusion was greater when senior residents were involved in open abdominal aortic aneurysm repair (AAA), although not when they were involved in endovascular repairs. In their study of the effect senior trainees' involvement has on perioperative outcomes, matching cases of senior resident involvement with cases of attending involvement only, blood loss was shown to be greater with senior resident involvement, yet enduring that negative effects were not observed in terms of long-term morbidity and mortality.[23]

Although intraoperative outcomes have a significant influence on postoperative outcomes, contemporary markers of the efficiency, quality, and safety of patient care are largely measured in the postoperative period. As this pertains to infrainguinal bypass surgery, early graft failure, LOS, unplanned readmission within 30 days, and 30-day mortality are commonly used as a proxy for the quality of healthcare delivery.[29] This study confirms findings of previous studies that reveal no difference in patient outcomes when residents participate in surgical management. As previously noted among AAA operations with and without senior resident involvement, among major lower extremity amputations comparing junior and senior resident involvement, and among a variety of general surgical procedures, autonomous involvement of senior residents in complex procedures does not lead to worse outcomes.[17−19,22,23] It is unknown, however, whether this finding is attributable to equal intraoperative care or to enhanced postoperative management, as Castleberry et al.[21] found that even when postoperative morbidity is greater with resident involvement, perioperative mortality and failure-to-rescue rates benefit. Divergent findings regarding postoperative morbidity, however, between the vascular patients in this study and the oncologic patients studied by Castleberry et al. are likely related to greater immunosuppression among the latter population. This risk factor could not be risk-adjusted by the previous study's authors but would suggest less tolerance for intraoperative adversity at the hands of trainees and greater subsequent postoperative morbidity.[21] Still, these studies show that mortality and long-term outcomes are actually improved when senior trainees are given the opportunity to operate autonomously.

Specific to the study of outcomes following infrainguinal bypass procedures, early graft failure is a serious concern for vascular surgeons. In the present analysis, this outcome would certainly reveal the quality of intraoperative management, as graft failure in the first 30 postoperative days is generally attributed to the adequacy of technique.[30] Our finding of no differences between junior and senior trainees in early graft failure must be interpreted in light of Scarborough et al.'s study in which bypasses performed by a resident of any level (i.e., PGY1+) and bypasses performed by an attending surgeon only were matched.[24] In their study, propensity score matching showed that early graft failure rates were worse when trainees were involved in the operation. In contrast to Scarborough et al., our findings suggest that when trainees have adequate surgical experience (i.e., chief residents and fellows) and are provided guidance by attending-level first assistants, patients do just as well as when attending surgeons do most of the operating with junior residents first assisting. This is a particularly reassuring finding when the traditional Halstedian model of surgical education is being increasingly threatened by scrutiny related to patient safety.[1,11,17,19]

Because consideration must be given for training programs wherein a PGY4 is the most senior general surgery trainee on the vascular surgery service, restratification of our junior and senior trainee cohorts into patients operated on by trainees at the PGY1−3 levels versus patients operated on by trainees at the PGY4+ levels yields some differences of unclear significance. After this restratification, propensity score matching showed associations with an approximately 1 day longer LOS, a 1.5% greater odds of early graft failure, and a 1.4% greater odds of 30-day mortality among patients operated on with senior trainee involvement. There were no differences after matching in operative time, odds of intraoperative blood loss, and odds of unplanned readmission. These findings, which differ from our original stratification, prompt a few observations. First, the restratified cohorts are unlikely to represent a dichotomy based on trainee operative autonomy, as operative time and intraoperative blood loss were not statistically significantly different between cohorts. Second, it is more likely that this restratification correlates with severity of patient illness and perhaps postoperative management, through variables not provided in the database, and therefore not controlled for in analysis. Finally, in spite of the low likelihood that the clinical conduct of trainees at the PGY4 level are accountable for longer LOS and greater odds of early graft failure and 30-day mortality, these findings certainly provoke consideration to explore how differences between residents at the PGY4 and PGY5 levels affect patient care, a consideration to be pursued in future study.

As with all studies of a retrospective nature performed on large clinical databases, our findings must be considered in the context of its limitations. First, we were unable to determine reasons for readmission or mortality because we retrospectively analyzed a database with a limited set of covariates. Therefore, we were unable to reliably determine that these outcomes were directly attributable to resident involvement in the procedure. Moreover, variables that were not available in the dataset may be potential confounders and could not be controlled. For example, we were unable to determine the level of autonomy provided to residents during infrainguinal bypass procedures. Given the tradition of graduated responsibility in medical and surgical education, we used a more conservative stratification scheme in our propensity score matching, in which patients treated by trainees in PGY5+ were matched against patients treated by trainees in PGY4−. It is most likely that the PGY5+ cohort would represent chief residents and fellows of vascular surgery who would, as a group, be provided the most autonomy of all surgical trainees. Third, infrainguinal bypass procedures were identified using diagnosis and procedure codes. There is the potential for coding errors, although it is unlikely that such errors would be systematic. Finally, in spite of adjustment within our multivariable and propensity score matching models, significant selection bias may persist and may account in part for the statistically significant associations between training level and intraoperative outcomes.

In conclusion, senior surgical trainee involvement in infrainguinal bypass procedures, where there is greater likelihood of autonomy provided by attending surgeons, may lengthen operative time and worsen intraoperative blood loss but does not appear to lead to enduring postoperative harm. This is a reaffirmation that in spite of increasing regulation and oversight, surgical residents and fellows are completing their training as safe surgeons with neither great risk to patient safety nor heavy burden of patient harm in their wake. Further work remains to evaluate the impact of resident involvement on outcomes after open and endovascular procedures since the advent of the integrated vascular surgical residency paradigm to determine how this shift in surgical education impacts the safety of the vascular patient.

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