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Put Me in the Game Coach! Resident Participation in High-Risk Surgery in the era of Big Data

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Abstract

Background—With the emphasis on quality metrics guiding reimbursement, concerns have emerged regarding resident participation in patient care. This study aimed to evaluate whether resident participation in high-risk elective general surgery procedures is safe.

Materials and Methods—The American College of Surgeons NSQIP database (2005-2012) was used to identify patients undergoing one of five high-risk general surgery procedures. Resident and non-resident groups were created using a 2:1 propensity score match. Postoperative outcomes were calculated using univariate statistics and multivariable logistic regression for the two groups. Predictors of mortality and morbidity were identified using machine learning in the form of decision trees.

Results—25,363 patients met our inclusion criteria. Following matching, each group contained 500 patients and were comparable for matched characteristics. 30-Day mortality was similar between the groups (2.4% v. 2.6% p=0.839). Deep surgical site infection (0% v. 1.6% p=0.005), urinary tract infection (5% v. 2.5% p=0.029), and operative time (275.6 min v. 250 min p=0.0064) were significantly higher with resident participation. Resident participation was not predictive of

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Author Contributions

Adrienne N. Cobb contributed study design, statistical analysis, and manuscript preparation and critical revision.

Emanuel Eguia contributed to study design, manuscript preparation and critical revision of the manuscript.

Haroon Janjua contributed statistical and analytic support.

Paul C. Kuo contributed to analytic strategy, manuscript preparation and critical revision of the manuscript.

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mortality or complications; while age, ASA class, and functional status were leading predictors of both.

Conclusions—Despite growing time constraints and pressure to perform, surgical resident participation remains safe. Residents should be given active roles in the operating room, even in the most challenging cases.

Keywords

surgical education; resident participation; surgery residency; operative experience

INTRODUCTION

Surgical residents want to operate. More importantly, surgical residents need to operate so they can obtain the skills necessary to succeed in independent practice.^{1–3} The model of surgical education has traditionally been “see one, do one, teach one” with residents earning increasing amounts of autonomy as they progress through training and demonstrate increasing levels of competency. However, Bell et al. found that the current operative experience of general surgery residents is insufficient preparation for graduating residents to have basic competency in procedures attending surgeons believe they should be able to perform independently.¹ It is possible that the changing healthcare environment has led to increased pressure on attending surgeons to heighten productivity, efficiency and improve outcomes which have negatively affected residents’ operative experience.

Questions have circulated regarding whether the inclusion of residents in patient care remains safe. Despite being several years removed from Kohn’s *To Err is Human*, many of the same concerns persist.⁴ Patients are now equipped with information from the lay press regarding surgeon outcomes and information regarding the long hours worked by residents.^{5–7} It is not uncommon for patients to ask surgeons if residents will be involved in their case.⁸ While adjustments in duty hours sought to remedy these concerns, staff and trainees worry what the impact of reduced work hours may have on trainees’ ability to practice independently.⁹ A study that surveyed program directors demonstrated that many felt general surgery residents were not prepared to enter the workforce as independent surgeons following their five years of training.^{10–11}

General surgery resident participation has been and continues to be an important topic of conversation and research in resident education, particularly with the more restrictive 80-hour work week^{12–13} and emphasis on quality metrics guiding reimbursement. Previous literature has shown that resident participation does not negatively impact patient mortality for common elective low-risk general surgery procedures.¹⁴ The conclusions regarding morbidity have varied, suggesting that results may vary by procedure type.¹⁵ Studies have examined several procedures across several specialties^{16–20}, but less is known about high-risk general surgery procedures. Thus, this study primarily aimed to evaluate whether resident participation in high-risk elective cases remains safe. We hypothesize that patients who have surgery with resident participation have similar morbidity and mortality than those who do not.

MATERIALS AND METHODS

Data Sources and Patient Selection

The National Surgical Quality Improvement Program (NSQIP) database (2005-2012) was used to identify patients undergoing one of six high-risk procedures: esophagectomy, open abdominal aortic aneurysm repair (AAA), laparoscopic paraesophageal hernia repair (PHR) with Nissen fundoplication, pancreaticoduodenectomy (Whipple), abdominoperineal resection (APR), and hepatectomy. NSQIP is the first validated, national, outcomes-based, risk-adjusted, performance-controlled platform for the measurement and subsequent improvement of medical healthcare delivery.²¹ It is unique in that it allows for the direct evaluation of resident involvement while correcting for potential confounders. Additional information on ACS NSQIP data collection and practices has been described previously and can be accessed on the ACS-NSQIP website (<http://www.acsnsqip.org>). These procedures were deemed high risk by the American College of Cardiology/American Heart Association guidelines for cardiac risk of noncardiac surgery.²²⁻²³ We selected these procedures as a representative sample of more difficult, high-risk procedures that potentially imply decreased resident involvement. Procedures were identified using Current Procedural Terminology (CPT) codes as displayed in Table SI. The institutional review board at our institution deemed this study exempt as the data are de-identified.

Patients over the age of 90 and pregnant patients were excluded. We also excluded patients that had emergent procedures as we focused on elective cases. Because we were interested in the impact of resident participation, those cases that did not contain information regarding resident participation were also dropped. Patient selection criteria are shown in Figure 1.

Statistical Analysis

Outcomes were compared for patients who had procedures with and without resident participation, with selected outcomes evaluated by postgraduate year (PGY). Junior residents were considered as PGY 1-2, senior residents as PGY 3, 4, and 5 and participants were considered fellows if they were PGY 6 or higher. Patient groups were created using a 2:1 propensity score match based on age, sex, race, morbidity probability, ASA class, surgical specialty, comorbidities, and type of procedure. We performed K-nearest neighbor matching with two neighbors utilizing both caliper and radius. The 2:1 matching refers to the use of two propensity scores per patient for matching rather than matching 2 resident participation patients to 1 non-resident patient in the groups which would have resulted in an imbalanced number between groups. Propensity score matching was used to minimize the effect of confounding due to nonrandom assignment of residents to procedures.

Descriptive statistics were used to evaluate the baseline patient characteristics pre and post propensity score matching. Chi-square tests and Student t-test were then used for categorical and continuous variables respectively in the unmatched cohort while McNemar and paired t-test were used for matched groups. Medians with interquartile ranges were reported for both length of stay and operative time throughout the analysis as they were not normally distributed. Comparisons were then made with the Wilcoxon Rank Sum test. The primary outcome of the study was 30-day mortality with the exposure being resident involvement.

Secondary outcomes included a myriad of complications (superficial and deep surgical site infection (SSI), wound disruption, bleeding requiring transfusion, return to operating room (OR), pneumonia, unplanned reintubation, pulmonary embolism (PE), acute renal failure, stroke, myocardial infarction (MI), sepsis, urinary tract infection (UTI), and deep vein thrombosis (DVT), operative time, and length of stay as defined by ACS-NSQIP. Unadjusted postoperative outcomes were calculated using univariate statistics; chi-square and Student t-test for categorical and continuous variables respectively. These same outcomes were also calculated after stratifying by PGY year using chi-square test for proportions and Kruskal Wallis test for means.

Mixed effects multivariable logistic regression models were used to calculate the risk-adjusted odds ratio for 30-day mortality rate as well as the risk-adjusted odds of returning to the OR, increased operative time, and prolonged length of stay. The same was carried out for the postoperative complication variables. Length of stay and operative time were both dichotomized for use in the logistic regression models. Length of stay and operative time were considered prolonged if they exceeded the 75th percentile for that particular procedure. For example, a length of stay greater than 15 days was considered prolonged following esophagectomy while a LOS greater than 3 days was considered prolonged following PHR with Nissen fundoplication. Due to the unequal distribution of both length of stay and operative time, the risk-adjusted odds for the aforementioned variables were calculated by procedure with an appropriately standardized length of stay or operative time. Statistical significance for all analysis was obtained at $\alpha=0.05$. All statistical analyses were performed using STATA 14 software (College Station, TX).

Machine Learning Analysis

Predictors of mortality and overall complications were analyzed using decision tree analysis. Decision tree is a powerful classification algorithm that can be represented by a tree-like structure, where the nodes represent the most important variables to predict the target variable.²⁴ Variables included in the model were patient demographic information, procedure information, comorbidities, as well as level of attending participation (i.e. whether attending operated alone vs. with residents). Once the tree is built, the most important nodes or variables can be identified. Data were split into 80:20 training and validation sets prior to analysis. A separate tree was modeled for each dependent variable: 30-day mortality and morbidity represented by a composite complication variable. Model performance was determined using accuracy and area under the receiver operator curve (AUC). Decision trees were run using the package, 'party' and 'varimp'. All machine learning analysis were completed in R V 3.4.2 (Vienna, Austria).²⁵

RESULTS

There were 25,363 patients that met our inclusion criteria and underwent one of the following procedures: esophagectomy, open AAA repair, pancreatectomy, open hepatectomy, APR, or PHR with Nissen fundoplication. (Figure 1) The most commonly performed procedure was the Whipple representing 40.7% of cases (N = 10,309) and open hepatectomy following close behind with 36.8% (N = 9,329) cases. (Table 1)

Baseline patient characteristics were calculated for the total unmatched cohort but showed some significant differences in patient characteristics such as age, sex, race, and morbidity probability. (Table S2) Therefore, 2:1 propensity score matching was completed, resulting in 500 patients in each group. The matched cohorts were comparable for baseline characteristics as shown in Table 2. The remaining analyses were performed on the matched cohort. The mean age was approximately 62 years old in both groups, with a near equal proportion of males and females in each group. The study population was majority white with a mean ASA class of III. Hypertension was the most common comorbidity for both groups with approximately 50% of each group affected. When examining the residents that were participating in these cases, the majority (68.6%) were in their PGY3-5 years.

Univariate Analysis

The unadjusted rates for several postoperative outcomes are shown in Table 3. Our primary outcome, 30-day mortality, showed no significant difference between patients that had procedures where residents participated as compared to those that did not (2.4% v. 2.6% $p=0.839$). Similar results were noted with return to the OR (5.4% vs. 4.4% $p=0.464$) and total length of stay (6 days IQR (3-9) vs. 6 days IQR (3-9) $p=0.452$). The operative time was significantly longer in cases where residents were involved with a median of 245 minutes IQR (163-351.8) compared to 218 minutes IQR (140-316.8) when attendings operated alone. ($p=.002$). We also evaluated several postoperative complications (Table 3), but the only ones noted to be more frequent in resident participation cases were superficial surgical site infection (7.8% vs. 3.4% $p=.009$) and urinary tract infection (5% vs. 2.5% $p=.029$). Of note, attending only cases had higher rates of deep surgical site infection (0% vs. 1.6% $p=.005$) than resident participation cases. The other postoperative complications were not significantly different between groups.

We also examined unadjusted rates of 30-day mortality, aggregate morbidity, operative time, length of stay, and return to the OR by procedure. Unlike above, patients who underwent a Whipple (3.3% vs. 1.8%, $p<.001$) or an abdominoperineal resection (APR) (1.6% vs. 0%, $p<.001$) with resident participation experienced higher rates of mortality at 30 days postoperatively. However, there were cases such as esophagectomy (0% vs. 4.2% $p<.001$) and hepatectomy (3.5% vs. 4.8%, $p<.001$) where higher rates of 30-day mortality were seen in attending only cases. Aggregate morbidity was significantly higher in AAA repair (58.3% vs. 100% $p=0.035$), Whipple (38.8% vs. 40.4% $p=0.013$), APR (28.1% vs. 37.9%, $p=0.004$), and hepatectomy (25.2% vs. 30.9%, $p<.001$) cases without resident participation. Paraesophageal hernia repair with Nissen fundoplication was the only procedure where resident participation led to a significantly higher rate of aggregate morbidity (11.3% vs. 7.1%, $p<.001$). Interestingly, operative time was similar between groups across the majority of procedures with the exception of APR (295 min IQR (225.5-359) vs. 242.5 min IQR (183-304), $p=0.014$) and Nissen fundoplication (161.5 min IQR (122.8-205.5) vs. 133.5 min IQR (93.8-191.3), $p=0.0002$) where resident participation led to longer operative times. Length of stay was similar between groups and across procedures. However, patients having an esophagectomy (15% vs. 4.2%, $p=0.001$), APR (9.4% vs. 3.5% $p<.001$), or Nissen (2.4% vs. 1.2%, $p<.001$) with resident participation were more likely to return to the OR

postoperatively. Procedure specific postoperative outcome results for the matched cohort are shown in Table 4.

Specific outcomes were also assessed by training year. (Table 5) We saw no significant differences in 30-day mortality (0% v 2.0% v 4.1% $p=0.272$) or return to the OR (5.7% v 4.7% v 7.4% $p=0.505$) for junior residents, senior residents (PGY 3-5), and fellows respectively. However, patients who underwent procedures with senior residents had significantly longer mean LOS with 8.5 days when compared with junior residents (6.6 days) and fellows (6.9 days) ($p<.001$). Operative time also varied by training year, with fellows having the longest median operative time of 260 minutes, followed by senior residents requiring 252.5 minutes and junior resident 193 minutes.

Multivariate Analysis

The risk-adjusted mortality rate was calculated using a mixed effects multivariable logistic regression model. Within the matched cohort, the mortality rate was lower in the resident participation group compared to attending only (0.9% vs. 3.2% $p=.0672$), although not statistically different.

Risk-adjusted odds were then calculated for all the outcomes above and postoperative complications. (Figure 2) Of all the postoperative outcomes tested, UTI was the only one to show a negative impact with resident participation following adjustment. Patients who had procedures where residents were present had 2.3 (95% CI 1.1-4.8) the odds of getting a UTI. The other measures did not show significantly increased or decreased odds of an event secondary to resident participation.

Risk-adjusted odds of prolonged length of stay and operative time were calculated overall and by procedure with standardized lengths of stay and operative time respectively. Overall, cases with resident participation had increased odds of a prolonged operative time (OR 1.5 95% CI 1.1-2.1), but this did not persist when evaluated by procedure. Patients undergoing APR had 4.3 (95% CI 1.5-12.2) odds risk of having a prolonged operative time where residents were involved in the case, but not in the other procedures. (Figure 3A.) Length of stay remained similar between the groups following risk adjustment and stratification by procedure. (Figure 3B.)

Machine Learning

Using decision trees, we found that resident participation was not predictive of mortality nor complications. Factors such as age, ASA class, and functional status were leading predictors of both. We performed a separate decision tree to find predictors of mortality and aggregate morbidity respectively. The goal was to see if resident participation would be indicated as one of the most important variables in our tree. The top 5 predictors of mortality were age greater than 67, if an attending operated alone, poor functional status, presence of dyspnea, and ASA class greater than 3 with an accuracy of 97% and area under the receiver operator curve (AUC) of .61. (Figure 3A) The top 5 predictors of aggregate morbidity were ASA class >3, prior MI, poor functional status, age greater than 80, and when attending is not present in the OR at all with an accuracy of 75% with an AUC of .61. (Figure 3B) Resident

participation was not deemed an important variable in predicting mortality or morbidity by our decision tree algorithms. (Figure S1 & S2)

DISCUSSION

Stakeholders in resident education are tasked with training the next generation of surgeons while prioritizing patient safety, efficiency and cost-effectiveness. This study evaluated the impact of resident participation in high risk elective general surgery cases. We found that mortality was similar for both groups, and postoperative UTI was the only increased morbidity incurred by patients in the resident participation group. Operative times were higher in the resident group as well, but length of stay was not negatively impacted.

Resident participation has been well studied in several surgical areas^{15–18}, and has shown, in many cases, to decrease mortality with an only slight increase in morbidity. However, studies that focused on laparoscopic surgery revealed that resident participation does have a differential impact on outcomes^{26–27}, suggesting that the type of procedure may impact outcomes. For this reason, we focused on high risk elective general surgery procedures. It is common for residents to take a diminished role in these cases due to their technical complexity and the patient's associated comorbidities. Ferraris et al. explored resident participation in high-complexity procedures and found slightly higher operative mortality and postoperative morbidity, but a substantial decrease in failure to rescue in cases where residents were involved.²⁸ Therefore, attending surgeons may be hesitant to allow residents to participate in these cases; fearing poor patient outcomes. We found that patients with resident participation had similar rates of morbidity and mortality compared to those that did not. Mortality rates were low overall in both groups and did not differ significantly. This remained true for other measures such as return to OR and total length of stay. Increases in these measures might suggest an increased risk for technical error or the need for prolonged hospitalization secondary to postoperative complications.

When postoperative complications were evaluated individually, only UTI was significantly increased following risk adjustment in the resident participation. UTI has long been a target of hospital quality improvement given that they account for a large proportion of hospital-acquired infections, increase costs, and can be prevented with consistent sterile insertion.²⁹ We propose that the increased rate of UTI seen in the study among the resident participation group is likely due to insertion by junior residents or medical students whose aseptic technique may be flawed. Not surprisingly, operative time was increased in cases where residents participated which is consistent with the literature^{14–18, 28, 31}. We assert that the additional time spent with trainees in the operating room is integral to the production of confident and competent surgeons and does not lead to poorer outcomes for patients. It may, however, lead to increased costs for the hospital and the patient.^{30–31}

Some studies have shown that the presence of residents improves mortality.^{18,31} It remains unclear whether that is through improving failure to rescue²⁸ or if their presence serves as a proxy for strong hospital infrastructure and academic involvement. While this study focuses on the role resident involvement plays in patient outcomes, the impact of hospital characteristics may also contribute. In a study predicting survival in burn patients, being

treated in a hospital with full-time residents predicted survival along with other characteristics such as advanced imaging capabilities and number of intensive care unit beds.

This study is not without limitations. The data used here are dated, only containing information up to 2012. An analysis of more recent years will be beneficial to see how resident participation has evolved over time and whether the increased case requirements have had an impact. Additionally, we only evaluated a limited number of procedures. Therefore, our data may not be generalizable to other procedures. We also could not control for unmeasured covariates such as operating room staff hospital characteristics. Though we tried to limit selection bias through propensity score matching, it may still be present as ACS-NSQIP membership is overrepresented by tertiary and academic centers that may not be representative of all hospitals conducting these procedures in the United States. Finally, the extent of resident participation in the case is unavailable meaning that a resident who simply retracts is included with a resident who may have done a significant portion of the case. Of note, the variable from which our resident participation groups were created was multilevel, so there are some cases included here that include cases where residents performed the case with the attending available for assistance, but not scrubbed. NSQIP is a very robust surgical dataset for conducting research, but we would assert that the resident participation variable should include some quantification of the participation to make it more useful in studies such as this. This would not only serve researchers, but give programs and residents another benchmark on which to measure resident progression and competency. We also do not have data regarding resident management of patients on the wards, which likely impacts postoperative outcomes as well.

Despite these limitations, the use of ACS-NSQIP data is a strength of our study as it allowed us to identify procedures in which residents were involved as well as control for disease severity in patients using the morbidity probability and Charlson comorbidity index variables. The data are reliable in that they are abstracted by a designated surgical clinical reviewer. We also used various statistical techniques to explore different facets of resident participation including trends over time and machine learning to identify the factors leading to morbidity and mortality. However, outcomes are limited to thirty days and may not capture the full breadth of postoperative complications that occur outside of that timeframe.

CONCLUSIONS

The inclusion of surgical residents in high-risk general surgery cases does not negatively impact outcomes. Apart from UTI rates, resident participation did not significantly increase patient morbidity or mortality. Residents should continue to be given active and engaging roles in the operating room, even in the most challenging cases.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Bell Richard H, , Jr, et al. Operative experience of residents in US general surgery programs: a gap between expectation and experience. *Annals of surgery*. 2009; 249(5):719–724. [PubMed: 19387334]
2. Ericsson KA. An expert-performance perspective of research on medical expertise: the study of clinical performance. *Med Educ*. 2007; 41:1124–1130. 3. [PubMed: 18045365]
3. Borman KR, Vick LR, Biester TW, et al. Changing demographics of residents choosing fellowships: Longterm data from the American Board of Surgery. *J Am Coll Surg*. 2008; 206:782–788. [PubMed: 18471695]
4. Kohn KT, Corrigan JM, Donaldson MS. *To Err Is Human: Building a Safer Health System*. Washington, DC: National Academy Press; 1999.
5. Wei S, Pierce O, Allen M. *Surgeon Scorecard 2015*. 2015
6. Borland S. The surgeons whose patients were up to 30 times likelier to die: NHS to publish death rates of doctors for the first time. *The Daily Mail*. 2013; 28
7. Khullar D. Should Doctors in Training Work Fewer Hours?. *New York Times*. Published February 16, 2016<https://well.blogs.nytimes.com/2016/02/03/should-doctors-in-training-work-fewer-hours/> Accessed January 2018
8. Kempenich JW, Willis RE, Blue RJ, et al. The effect of patient education on the perceptions of resident participation in surgical care. *Journal of Surgical Education*. 2016; 73(6):e117. <http://www.sciencedirect.com/science/article/pii/S1931720416300514> . . doi://doi.org/10.1016/j.jsurg.2016.05.005. <http://www.sciencedirect.com/science/article/pii/S1931720416300514doi://doi.org/10.1016/j.jsurg.2016.05.005>
9. Bilimoria Karl Y, Hoyt David B, Frank Lewis. Making the case for investigating flexibility in duty hour limits for surgical residents. *JAMA surgery*. 2015; 150(6):503–504. [PubMed: 25901476]
10. Neumayer Leigh A, et al. The state of general surgery residency in the United States: program director perspectives, 2001. *Archives of Surgery*. 2002; 137:11–1265. 1262–1265.
11. Soper NJ, DaRosa DA. Presidential address: Engendering operative autonomy in surgical training. *Surgery*. 2014; 156(4):745–751. [PubMed: 25239310]
12. Nasca TJ, Day SH, Amis ES Jr. ACGME Duty Hour Task Force. The new recommendations on duty hours from the ACGME Task Force. *N Engl J Med*. 2010; 363(2):e3. [PubMed: 20573917]
13. Rajaram R, Chung JW, Cohen ME, et al. Association of the 2011 ACGME resident duty hour reform with postoperative patient outcomes in Surgical specialties. *J Am Coll Surg*. 2015; 221(3): 748–757. [PubMed: 26228013]
14. Tseng WH, Jin L, Canter RJ, et al. Surgical resident involvement is safe for common elective general surgery procedures. *Journal of the American College of Surgeons*. 2011; 213(1):19–26. <http://www.sciencedirect.com/science/article/pii/S1072751511001955> . . doi://doi.org/10.1016/j.jamcollsurg.2011.03.014. <http://www.sciencedirect.com/science/article/pii/S1072751511001955doi://doi.org/10.1016/j.jamcollsurg.2011.03.014> [PubMed: 21493108]
15. Raval MV, Wang X, Cohen ME, et al. The influence of resident involvement on surgical outcomes. *J Am Coll Surg*. 2011; 212(5):889–898. [PubMed: 21398151]
16. Patel SP, Gauger PG, Brown DL, Englesbe MJ, Cederna PS. Resident participation does not affect surgical outcomes, despite introduction of new techniques. *J Am Coll Surg*. 2010; 211(4):540–545. [PubMed: 20801695]
17. Seib CD, Greenblatt DY, Campbell MJ, et al. Adrenalectomy outcomes are superior with the participation of residents and fellows. *Journal of the American College of Surgeons*. 2014; 219(1): 53–60. <http://www.sciencedirect.com/science/article/pii/S1072751514001872> . . doi://doi.org/10.1016/j.jamcollsurg.2014.02.020. <http://www.sciencedirect.com/science/article/pii/S1072751514001872doi://doi.org/10.1016/j.jamcollsurg.2014.02.020> [PubMed: 24702888]

18. D'Souza N, Hashimoto DA, Gurusamy K, Aggarwal R. Comparative outcomes of resident vs attending performed surgery: A systematic review and meta-analysis. *Journal of Surgical Education*. 2016; 73(3):391–399. <http://www.sciencedirect.com/science/article/pii/S1931720416000039> . . doi://doi.org/10.1016/j.jsurg.2016.01.002. <http://www.sciencedirect.com/science/article/pii/S1931720416000039doi://doi.org/10.1016/j.jsurg.2016.01.002> [PubMed: 26966079]
19. Aguilar B, Sheikh F, Pockaj B, Wasif N, Gray R. The effect of junior residents on surgical quality: A study of surgical outcomes in breast surgery. *The American Journal of Surgery*. 2011; 202(6): 654–658. [PubMed: 22036204]
20. Iannuzzi JC, Chandra A, Rickles AS, et al. Resident involvement is associated with worse outcomes after major lower extremity amputation. *Journal of Vascular Surgery*. 2013; 58(3): 831.e1. <http://www.sciencedirect.com/science/article/pii/S0741521413008689> . . doi://doi.org/10.1016/j.jvs.2013.04.046. <http://www.sciencedirect.com/science/article/pii/S0741521413008689doi://doi.org/10.1016/j.jvs.2013.04.046>
21. Khuri Shukri F, et al. Successful implementation of the Department of Veterans Affairs' National Surgical Quality Improvement Program in the private sector: the patient safety in surgery study. *Annals of surgery*. 2008; 248(2):329–336. [PubMed: 18650645]
22. Fleisher LA, American College of Cardiology/American Heart Association. Cardiac risk stratification for noncardiac surgery: update from the American College of Cardiology/American Heart Association 2007 guidelines. *Cleve Clin J Med*. 2009 Nov; 76(Suppl 4):S9–15. [PubMed: 19880841]
23. Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. *Circulation*. 1999 Sep 7; 100(10):1043–1049. [PubMed: 10477528]
24. Podgorelec V, Kokol P, Stiglic B, Rozman I. Decision trees: an overview and their use in medicine. *Journal of medical systems*. 2002 Oct 1; 26(5):445–63. [PubMed: 12182209]
25. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; 2017. Vienna, Austria. URL <https://www.R-project.org/>
26. Gorgun E, Benlice C, Corrao E, et al. Outcomes associated with resident involvement in laparoscopic colorectal surgery suggest a need for earlier and more intensive resident training. *Surgery*. 2014; 156(4):825–833. [PubMed: 25239327]
27. Krell RW, Birkmeyer NJ, Reames BN, Carlin AM, Birkmeyer JD, Finks JF. Effects of resident involvement on complication rates after laparoscopic gastric bypass. *Journal of the American College of Surgeons*. 2014; 218(2):253–260. <http://www.sciencedirect.com/science/article/pii/S1072751513011745> . . doi://doi.org/10.1016/j.jamcollsurg.2013.10.014. <http://www.sciencedirect.com/science/article/pii/S1072751513011745doi://doi.org/10.1016/j.jamcollsurg.2013.10.014> [PubMed: 24315885]
28. Ferraris VA, Harris JW, Martin JT, Saha SP, Endean ED. Impact of residents on surgical outcomes in high-complexity procedures. *J Am Coll Surg*. 2016; 222(4):545–555. [PubMed: 26905188]
29. Hooton Thomas M, et al. Diagnosis, prevention, and treatment of catheter-associated urinary tract infection in adults: 2009 International Clinical Practice Guidelines from the Infectious Diseases Society of America. *Clinical infectious diseases*. 2010; 50(5):625–663. [PubMed: 20175247]
30. Wexner T, Rosales-Velderrain A, Wexner SD, Rosenthal RJ. Does implementing a general surgery residency program and resident involvement affect patient outcomes and increase care-associated charges? *The American Journal of Surgery*. 2017; 214(1):147–151. [PubMed: 27889270]
31. Ejaz A, Spolverato G, Kim Y, et al. The impact of resident involvement on surgical outcomes among patients undergoing hepatic and pancreatic resections. *Surgery*. 2015; 158(2):323–330. <http://www.sciencedirect.com/science/article/pii/S0039606015002366> . . doi://doi.org/10.1016/j.surg.2015.01.027. <http://www.sciencedirect.com/science/article/pii/S0039606015002366doi://doi.org/10.1016/j.surg.2015.01.027> [PubMed: 26003913]
32. Damewood Richard B, et al. "Taking Training to the Next Level": The American College of Surgeons Committee on Residency Training Survey. *Journal of surgical education*. 2017; 74(6):e95–e105. [PubMed: 28781132]
33. Cobb Adrienne N, et al. Seeing the forest beyond the trees: Predicting survival in burn patients with machine learning. *The American Journal of Surgery*. 2017

Figure 1.
Patient selection flow chart. AAA: abdominal aortic aneurysm

Figure 2.
Forest plot of risk adjusted outcomes for matched group. OR: operating room

Figure 3. Forest plot of risk-adjusted odds ratios (OR) for (A) total length of stay and (B) operative time by procedure

Figure 4.

Variable Importance for Predicting (A) Mortality and (B) Morbidity with decision trees. The variable importance is a value based on the Gini index or degree of nodal purity within the decision tree. It does not have units but is normalized to have 100 as the maximum for reporting.

Table 1

Frequency of Procedures across entire study population

Procedure	frequency (%)
Esophagectomy	1,244 (4.9)
Rupture AAA Repair	162 (0.64)
Paraesophageal Hernia Repair with	
Nissen Fundoplication	2,316 (9.1)
Hepatectomy (open)	9,329 (36.8)
Pancreaticoduodenectomy	10,309 (40.7)
Abdominoperineal Resection	2,003 (7.9)
Total:	25,363

AAA: abdominal aortic aneurysm

Table 2

Baseline patient characteristics of matched groups

Characteristic	Residents N=500	Non-Residents N=500	p value
Age, mean (SD)	62.5 (14.2)	61.4 (13.8)	0.233
Sex (male), n (%)	224 (44.8)	284 (56.8)	0.61
Race, n (%)			0.324
White	385 (77)	405 (81)	
Black	33 (6.6)	20 (4)	
Hispanic	15 (3)	14 (2.8)	
Asian or Pacific Islander	13 (2.6)	18 (3.6)	
American Indian or Alaska Native	3 (0.6)	2 (0.4)	
Other/Unknown	51 (10.2)	41 (8.2)	
Morbidity Probability, mean (SD)	0.24 (.17)	0.24 (.18)	0.9441
ASA Classification, n (%)			0.397
1. No disturbance	6 (1.2)	12 (2.4)	
2. Mild disturbance	185 (37)	199 (39.8)	
3. Severe disturbance	285 (57)	272 (54.4)	
4. Life threatening	23 (4.6)	16 (3.2)	
Comorbidities, n (%)			
Smoking	93 (18)	90 (18)	0.806
Diabetes	69 (13.8)	69 (13.8)	1
Hypertension	254 (50.8)	244 (48.8)	0.527
COPD	31 (6.2)	30 (6.0)	0.895
Congestive Heart Failure	0	0	1
MI (last 6 months)	0	3 (0.6)	0.083
Renal failure	0	1 (0.20)	0.317
Dialysis	3 (0.6)	2 (0.4)	0.654
Cerebral Vascular Accident	4 (0.8)	4 (0.8)	1
Disseminated cancer	55 (11)	59 (11.8)	0.691
Steroid use	15 (3)	10 (2)	0.361
Weight loss (last 6 months)	42 (8.4)	42 (8.4)	1
Specialty, n (%)			0.543
General Surgery	486 (97.2)	489 (97.8)	
Other	14 (2.8)	11 (2.2)	
PGY of Residents, n (%)			
1–2	35 (7.0)	*	*
3–5	344 (68.8)	*	*
6	121 (24.2)	*	*

ASA: American Society of Anesthesiologists; COPD: Chronic obstructive pulmonary disease; PGY: Postgraduate Year

Table 3

Unadjusted Postoperative Outcomes for Matched groups

Outcome Frequency (%)	Residents N=500	Non-Residents N=500	p value
30 Day Mortality	12 (2.4)	13 (2.6)	0.839
Superficial Surgical Site Infection	28 (7.8)	12 (3.4)	0.009
Deep Surgical Site Infection	0 (0)	8 (1.6)	0.005
Wound Disruption	5 (1)	3 (0.6)	0.478
Bleeding Requiring Transfusion	31 (6.2)	45 (9)	0.234
Pneumonia	19 (3.8)	23 (4.6)	0.528
Pulmonary Embolism	5 (1)	2(0.4)	0.255
Acute Renal Failure	2 (0.40)	5 (1)	0.255
Stroke	3 (0.6)	1 (0.2)	0.316
Myocardial Infarction	3 (0.6)	1 (0.2)	0.316
Sepsis	24 (4.8)	29 (5.8)	0.48
Urinary Tract Infection	25 (5)	12 (2.5)	0.029
Deep Vein Thrombosis	9 (1.8)	9 (1.8)	1
Return to OR	27 (5.4)	22 (4.4)	0.464
Unplanned Reintubation	17(3.4)	17 (3.4)	1
Operative time (min) [median (IQR)]	245 (163-351.8)	218 (140-316.8)	0.002
Total Length of Stay (days) [median (IQR)]	6 (3-9)	6 (3-9)	0.452

OR: operating room

Table 4

Procedure specific postoperative outcomes for Matched Groups

Procedure & Outcomes	Residents N=500	Non-Residents N=500	p value
Esophagectomy			
30 day Mortality n (%)	0 (0)	1 (4.2)	<.0001
Aggregate Morbidity n (%)	8 (40)	14 (58.3)	0.845
Operative Time (min) median (IQR)	388 (330.5-470)	380 (268.3-614.3)	0.934
Length of Stay (days) median (IQR)	11.5 (8.3-14)	12 (8-19)	0.925
Return to OR n (%)	3 (15)	1 (4.2)	0.001
Total	20	24	
Ruptured AAA Repair			
30 day Mortality n (%)	2 (16.7)	3 (37.5)	0.092
Aggregate Morbidity n (%)	7 (58.3)	8 (100)	0.035
Operative Time (min) median (IQR)	263.5 (192-367.8)	201 (155.8-293.5)	0.441
Length of Stay (days) median (IQR)	9.5 (6.3-11)	7 (1.3-13.5)	0.372
Return to OR n (%)	2(16.7)	3 (37.5)	0.092
Total	12	8	
Pancreaticoduodenectomy			
30 day Mortality n (%)	4 (3.3)	2 (1.8)	<.0001
Aggregate Morbidity n (%)	47 (38.8)	46 (40.4)	0.013
Operative Time (min) median (IQR)	350 (287-488.5)	330.5 (263.5-468)	0.359
Length of Stay (days) median (IQR)	9 (7-14.5)	10 (8-15)	0.03
Return to OR n (%)	7 (5.8)	8 (7.0)	<0.001
Total	121	114	
Abdominoperineal Resection			
30 day Mortality n (%)	1 (1.6)	0 (0)	<0.0001
Aggregate Morbidity n (%)	18 (28.1)	22 (37.9)	0.004
Operative Time (min) median (IQR)	295 (225.5-359)	242.5 (183-304)	0.014
Length of Stay (days) median (IQR)	6 (5-9.8)	6 (4-8)	0.128
Return to OR n (%)	6 (9.4)	2 (3.5)	<.0001
Total	64	58	
PHR with Nissen Fundoplication			
30 day Mortality n (%)	1 (0.6)	1 (0.59)	0.993
Aggregate Morbidity n (%)	19 (11.3)	12 (7.1)	<.0001
Operative Time (min) median (IQR)	161.5 (122.8-205.5)	133.5 (93.8-191.3)	0.0002
Length of Stay (days median (IQR)	2 (1-3)	2 (1-3)	0.545
Return to OR n (%)	4 (2.4)	2(1.2)	<.0001
Total	168	170	
Hepatectomy			
30 day Mortality n (%)	4 (3.5)	6 (4.8)	<.0001
Aggregate Morbidity n (%)	29 (25.2)	39 (30.9)	<.0001
Operative Time (min) median (IQR)	251 (164-349)	222.5 (158.8-307.8)	0.275

Procedure & Outcomes	Residents N=500	Non-Residents N=500	p value
Length of Stay (days) median (IQR)	6 (4-8)	6 (4-8)	0.716
Return to OR n (%)	5 (4.3)	6 (4.8)	<.0001
Total	115	126	

AAA: Abdominal Aortic Aneurysm; PHR: Paraesophageal Hernia Repair; OR: operating room;

Table 5

Matched Outcomes by Training Year

Postoperative Outcome	PGY 1-2 (n=35, 7%)	PGY 3-5 (n=344, 68.8%)	PGY >6 (n=121, 24.2%)	p value
30 Day Mortality	0	7 (2.0)	5 (4.1)	0.272
LOS (days) median (IQR)	2 (2-8)	6.5 (3-10)	6 (2-8)	0.002
Return to OR	2 (5.7)	16 (4.7)	9 (7.4)	0.505
Readmission	0	2 (4.7)	1 (5)	0.987
Operative Time (min)				
median (IQR)	193 (121-260)	252.5 (163-359.8)	260 (169.5-367)	0.009

LOS: length of stay; OR: operating room