Resident-Sensitive Processes of Care: Impact of Surgical Residents on Inpatient Testing

Clifford C Sheckter, MD, Jeffrey Jopling, MD, Qian Ding, MS, Amber W Trickey, PhD, MS, CPH, Todd Wagner, PhD, Arden M Morris, MD, MPH, FACS, Mary T Hawn, MD, MPH, FACS

BACKGROUND: Health care value is a national priority, and there are substantial efforts to reduce overuse of low-value testing. Residency training programs and teaching hospitals have been implicated in excessive testing. We evaluated the impact of surgery residents on the frequency of inpatient testing and investigated potential inter-resident variation.

STUDY DESIGN: Inpatient laboratory and imaging orders placed on general surgery services were extracted from an academic institution from 2014 to 2016 and linked to National Surgical Quality Improvement Program data. Using negative binomial mixed effects regression with unstructured covariance, we evaluated the frequency of testing orders compared with median use, accounting for case, patient, and attending-level variables.

RESULTS: There were 111,055 laboratory orders and 7,360 imaging orders linked with 2,357 patients. Multivariable analysis demonstrated multiple significant predictors of increased testing including: postoperative complications, medical comorbidities, length of stay, relative value units, attending surgeon, and resident surgeon (95% CIs > 1, $p < 0.05$). Compared with the median resident physician, 47 residents (37.9%) placed significantly more laboratory orders, and 2 residents (1.6%) placed significantly more imaging orders (95% CI >1, $p < 0.05$). Resident identification explained 3.5% of the total variation in laboratory ordering and 4.9% in imaging orders.

CONCLUSIONS: Individual surgical residents had a significant association with the frequency of inpatient testing after adjusting for attending, case, and patient-level variables. There was greater resident variation in laboratory testing compared with imaging, yet surgical residents had small contributions to the total variation in both laboratory and imaging testing. Our models provide a means of identifying high users and could be used to educate residents on their ordering patterns. (J Am Coll Surg 2019;228:798−806. © 2019 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

Health care value is a national priority, and there are substantial efforts to reduce overuse of low-value testing.[1] Excessive testing is associated with iatrogenic anemia, excessive costs, and unnecessary evaluation of incidental findings.[2-4] Specifically, teaching hospitals have been implicated in excessive testing, even when adjusting for differences in patient complexity often attributed to academic centers.[5] Some suggest that the learning environment lends itself to more testing because studies are ordered for demonstrative reasons (ie academic purposes), while others believe resident physicians are overtesting due to inexperience and uncertainty.

Resident surgeons are guided by attendings in patient care decisions, but many testing orders are placed autonomously. Therefore, resident surgeons may have a direct

Disclosure Information: Nothing to disclose.

Support: This study was supported by the National Center for Research Resources and the National Center for Advancing Translational Sciences, National Institutes of Health, through grant UL1 TR001085.

Disclaimer: The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIH.

Presented at the American College of Surgeons 104th Annual Clinical Congress, Scientific Forum, Boston, MA, October 2018.

Received September 2, 2018; Revised December 16, 2018; Accepted December 16, 2018.

From the Department of Surgery (Sheckter, Jopling, Morris, Hawn) and the Stanford—Surgery Policy Improvement Research and Education Center (Sheckter, Jopling, Ding, Trickey, Wagner, Morris, Hawn), Department of Surgery, Stanford University, Stanford, CA.

Correspondence address: Mary T. Hawn, MD, MPH, FACS, Department of Surgery, Stanford University, 300 Pasteur Dr MC 5115, Alway Building, Room M121, Stanford, CA 94305. email: mhawn@stanford.edu

https://doi.org/10.1016/j.jamcollsurg.2018.12.037
ISSN 1072-7515/19

Abbreviations and Acronyms

EMR	= electronic medical record
ICC	= intraclass coefficient
IRR	= incidence rate ratios
NBMER	= negative binomial mixed effects regression
PGY	= postgraduate year
QITI	= Quality In-Training Initiative
RVU	= relative value unit

impact on the quality and cost of patient care. The Choosing Wisely campaign[1] has stimulated a national conversation on thoughtful testing, and many interventions have been implemented to curb testing at the resident level.[6,7] However, these interventions attempt to reduce testing with blunt instruments, and none of them consider additional important factors that might actually drive testing, such as patient comorbidities, surgical complexity, complications, attending surgeon preferences, and payers (insurance status).

Resident training should encompass education on appropriate use of testing that considers the complexity of patient care and ensures that residents are not penalized for ordering testing when warranted. With a focus on providing high-quality care, resident physicians should be keen to discern complications, and respond appropriately with proper diagnostic testing and treatment. Risk-adjusted use feedback has the opportunity to educate residents on their practice patterns compared with their peers, and potentially provide a means of safely reducing wasteful testing. This study aimed to investigate possible predictors of laboratory testing and radiographic imaging in general surgery inpatients at an academic institution, and estimate the potential impact of individual residents on the overall variation in laboratory ordering. We hypothesized that patient and surgical complexity, along with postoperative complications, are associated with increased testing. We additionally hypothesized that individual residents will contribute substantially to the total variation in inpatient testing.

METHODS

Data sources

The local 2014 to 2016 American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database[8] was combined with single institutional clinical electronic medical record (EMR) data: the Stanford Medicine Research Data Repository.[9] The NSQIP database contains more than 150 variables including preoperative characteristics/comorbidities, intraoperative data including procedure information and operative time, and postoperative data including 30-day outcomes related to morbidity, mortality, and length of stay. The merger of these 2 databases generated multiple resident-patient pairings, whereby any given pair had at least 1 laboratory or imaging order within the 30-day postoperative period.

Study population

We abstracted preoperative risk factors and postoperative complications from patients included in our institution's NSQIP database. From the EMR data warehouse, we pulled information for laboratory and imaging orders placed during the index surgical admission from January 2014 to January 2017. We extracted data through January 2017 to include orders for late 2016 admissions that extended into 2017. Only orders placed by general surgery-related residents were included: general surgery categorical residents, general surgery preliminary residents, and surgical specialty residents in their first 2 years of general surgery training (ie urology, plastic surgery, cardiothoracic surgery, and vascular surgery). Residents who spent only limited portions of their intern year in general surgery-related rotations were excluded (eg orthopaedic surgery). Residents were also excluded if they left the program in the middle of their training. Specialty residents were excluded when placing orders outside of their general surgery rotations (ie beyond postgraduate year 2).

Laboratory and imaging orders data were processed separately with similar data management and analysis methods. Orders from 0 to 30 days after the surgical procedure with an order date before hospital discharge were included. A total of 124 unique residents placed laboratory orders that met inclusion criteria, and 122 residents placed imaging orders that met inclusion criteria. We calculated the sum of lab and imaging orders separately for each unique resident-patient pair, and merged with NSQIP to incorporate patient demographics and clinical information.

Statistical analysis

The primary outcomes of interest were adjusted total counts of laboratory and imaging orders. We hypothesized that individual residents were associated with the number of orders after adjustment for relevant patient factors and attending surgeons. In order to test this hypothesis, we evaluated patient- and resident-level characteristics associated with the number of orders. Furthermore, we sought to quantify the proportion of order total variance explained by resident factors. Secondary analysis included subgroups of patients without any complications occurring after surgery, attempting to further isolate the impact of residents on inpatient testing. Our study questions were: 1) Do providers influence the number of orders, after adjusting for patient demographics, patient preoperative severity of illness, postoperative occurrences, and attending surgeons? and 2) What proportion of the variance in order totals is due to resident factors, after accounting for selected covariates? In order to address the study questions with the patient-provider cross-clustered count data and account for observed over-dispersion in the distribution of number of orders, we used negative binomial mixed effects regression (NBMER) models for both lab and imaging order outcomes.

Model specification

To examine our first question, we calculated patient-level random intercept NBMER models with unstructured covariance to assess the impact of resident, patient, case, and attending-level fixed covariates including: resident identification, postgraduate year (PGY), attending surgeon, preoperative NSQIP characteristics, and NSQIP postoperative occurrences (complications) (eTable 1). Individual attending surgeon IDs were included in the models as separate fixed effects for attendings with >2% of the total orders, and attending IDs with ≤2% of orders were combined as an "other" referent category. The overall p value of the resident ID variable indicated whether residents contributed significantly to the models. Additionally, we determined point estimates and confidence intervals for each resident's orders by applying a conservative definition of the reference resident. The selected reference for each order type was the resident with the closest aggregated mean number of orders to the median among all residents.

To address our second study question, we assessed the proportion of the variance in total laboratory orders due to resident factors by calculating NBMER models with random intercepts and random slopes per resident. All other factors (eg patient, procedure, attending surgeon) were included as fixed covariates in the regression models as described above. Compound symmetric covariance structures were specified. In order to quantify the proportion of lab and imaging order variance explained by the grouping structure (ie residents), intraclass correlation coefficients (ICC) were calculated as described by Nakagawa and colleagues[10] using the delta method for estimation of observation-level variance.

Sensitivity analysis

Both models were re-evaluated after excluding patients with any postoperative complication in attempt to evaluate whether model fitness and ICCs changed. Statistical analyses were conducted using SAS v. 9.4. Statistical significance was assessed at the level of $p < 0.05$. The study was granted exemption by the Stanford Institutional Review Board.

RESULTS

A total of 111,055 resident inpatient laboratory orders were linked with 2,357 patients in NSQIP, yielding 5,933 resident-patient pairs. For imaging, 7,360 orders were paired with 2,357 patients, yielding 2,153 resident-patient pairs (Fig. 1). The most frequent laboratory orders were metabolic studies (eg chemistries and electrolytes) at 47.0% followed by blood count studies (eg red blood cells, white blood cells, platelets, etc) at 24.4%. Coagulation (9.6%), infectious disease (3.2%), and troponin (0.8%) studies made up the remainder, while 14.9% of laboratory orders did not fall into any category (eg rheumatologic panels). The majority of imaging studies were chest x-rays (61.8%) followed by abdominal and pelvis x-rays (24.4%). Deep venous thrombosis studies (eg lower extremity venous duplex, chest CT angiography) comprised 4.1% of studies followed by abdominal CT scans at 3.0%. Other studies (eg extremity CT, head MRI) made up 6.8%.

Laboratory predictors

Resident identification was a significant predictor of laboratory ordering ($p < 0.001$) (Table 1). Evaluating incidence rate ratios, 47 of 124 residents (37.9%) placed significantly more laboratory orders (95% CI >1) than the median resident after adjusting for patient, attending, and procedural characteristics (Fig. 2). Only 1 resident (0.8%) placed significantly fewer orders ($p < 0.05$, 95% CI < 1). Resident PGY was also an independent predictor of laboratory ordering (Fig. 3). Using chief residents as the reference case, junior residents ordered significantly fewer labs, with interns actually placing the fewest orders ($p < 0.001$). Attending surgeon identification was also predictive of laboratory ordering ($p < 0.001$). Case complexity, as measured by relative value unit (RVU), was associated with increased laboratory orders ($p < 0.001$), along with patient length of stay ($p < 0.001$) (eFig. 1).

Regarding preoperative patient characteristics, age and sex were both associated with frequency of laboratory ordering. Older patients received more orders ($p = 0.002$) along with men ($p = 0.006$). When looking at baseline comorbidities and medical history, the following were associated with increased laboratory ordering: disseminated cancer ($p = 0.001$), and transfusion history ($p = 0.016$). For postoperative occurrences (complications), multiple variables predicted increased laboratory

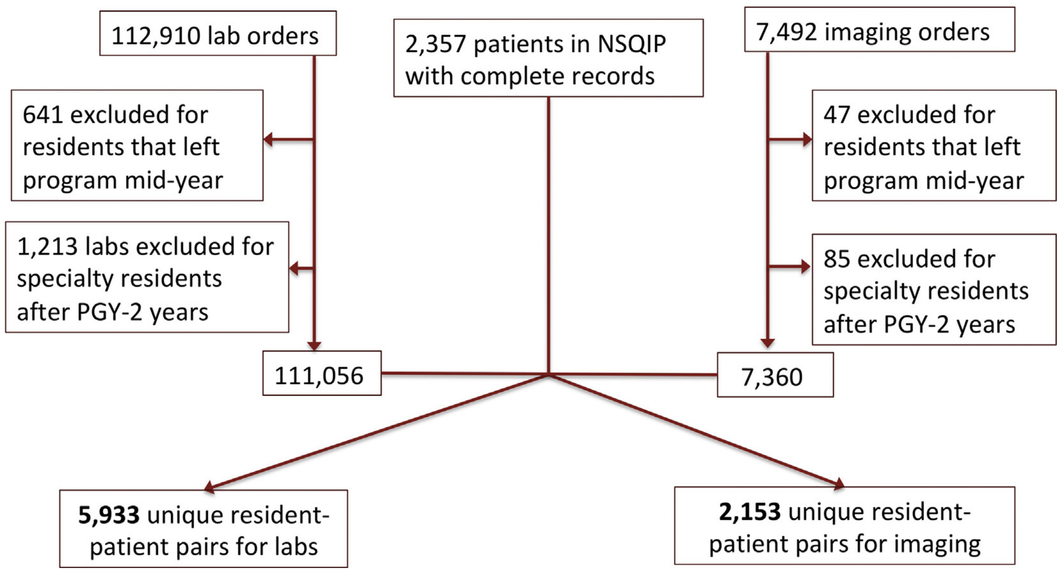


Figure 1. Selection criteria for surgery residents and NSQIP patients included in analysis. PGY, postgraduate year.

ordering including organ space surgical site infections ($p < 0.001$), ventilation > 48 hours ($p = 0.002$), urinary tract infection ($p = 0.008$), and postoperative transfusion ($p < 0.001$).

Imaging predictors

Resident identification was a significant predictor of imaging orders ($p < 0.001$) (Table 1). When evaluating incidence rate ratios among residents, only 2 residents (1.6%) placed significantly more imaging orders than the median resident adjusting for patient, attending, and procedural characteristics (95% CI >1) (Fig. 4). Similarly, 3 residents (2.5%) placed significantly fewer orders than the median resident ($p < 0.05$, 95% CI < 1). Resident PGY was associated with frequency of imaging orders. Setting chief residents as the reference, second-year residents (PGY-2) ordered significantly more imaging ($p = 0.007$) (Fig. 5). Attending surgeon identification was also predictive of imaging ordering ($p < 0.001$). Case complexity, as measured by RVU, did not reach a statistically significant level of association with increased imaging orders ($p = 0.071$); however, patient length of stay was associated with frequency of imaging orders ($p < 0.001$) (eFig. 2).

Regarding preoperative patient characteristics, age and sex were not associated with frequency of imaging ordering. When looking at baseline comorbidities and medical history, previous blood transfusion ($p = 0.004$) was the only predictor of increased imaging orders. For postoperative occurrences (complications), 3 variables predicted imaging ordering including unplanned intubation ($p < 0.001$), urinary tract infection ($p = 0.044$), and septic shock ($p = 0.002$).

Intraclass correlation coefficients and R^2

In order to quantify the total model variation attributed to resident physicians, intraclass correlation coefficients (ICC) were calculated. The resident physician variable explained 3.5% (ICC 0.035) of the total variation in laboratory ordering and 4.9% (ICC 0.049) of the total variation in imaging ordering (Table 2). When excluding all patients who had complications, the ICC decreased to near zero (<0.01) for laboratories, and increased to 10.5% (ICC 0.105) for imaging. In looking at overall model fit, the laboratory model yielded an R^2 of 0.572, which increased to 0.848 when excluding patients with measured postoperative occurrences. The imaging model yielded an R^2 of 0.857, which increased slightly to 0.896 when excluding postoperative complications.

DISCUSSION

Resident identification was independently associated with the frequency of inpatient testing. After adjusting for patient, attending, and procedural characteristics, 37.9% of residents were significantly high users for laboratory orders. This percentage of residents with increased use was much smaller for imaging, for which less than 2% were flagged. Residents contributed to a relatively small proportion of the overall variation in laboratory orders—3.5%. Likewise, residents represented a small proportion of the total variation in the imaging orders, although it was larger, at 4.9%. Multiple other variables

Table 1. Results from the Multivariable Negative Binomial Mixed Effects Regression Models of Resident Laboratory and Imaging Orders

	Laboratory order		Imaging order	
Significant predictor	**Adjusted IRR (95% CI)**	**p Value**	**Adjusted IRR (95% CI)**	**p Value**
Resident ID	See Fig. 2	<0.01	See Fig. 3	<0.01
PGY		<0.01		<0.01
1	0.41 (0.32,0.53)	<0.01	1.17 (0.85, 1.61)	0.33
2	0.64 (0.50, 0.81)	<0.01	1.53 (1.12, 2.09)	<0.01
3	0.66 (0.58, 0.76)	<0.01	1.06 (0.84, 1.33)	0.65
4	0.54 (0.46, 0.63)	<0.01	0.87 (0.66, 1.15)	0.33
5	Reference		Reference	
Surgeon ID*	Data not shown	<0.01	Data not shown	<0.01
Age, y	1.003 (1.001, 1.006)	<0.01		
Sex				
Female	0.92 (0.87, 0.98)	<0.01		
Male	Reference			
Hospital length of stay, d	1.018 (1.015, 1.022)	<0.01	1.009 (1.006, 1.011)	<0.01
Disseminated cancer				
Yes	1.12 (1.05, 1.20)	<0.01		
No	Reference			
Transfusion		0.02		<0.01
Yes	1.32 (1.05, 1.66)		0.64 (0.47, 0.87)	
No	Reference		Reference	
Systemic sepsis (within 48 h before operation)		0.01		0.05
SIRS	0.67 (0.49, 0.90)	<0.01	0.59 (0.36, 0.98)	0.04
Sepsis	0.70 (0.54, 0.89)	<0.01	0.77 (0.53, 1.11)	0.16
Septic shock	0.99 (0.64, 1.55)	0.98	1.16 (0.68, 1.97)	0.59
None	Reference		Reference	
Work relative value unit	1.010 (1.007, 1.012)	<0.01	1.003 (0.9998, 1.006)	0.07
Occurrence of postoperative complication				
Deep incisional SSI				
No	Reference			
Yes	0.60 (0.42, 0.85)	<0.01		
Organ/space SSI				
No	Reference			
Yes	1.26 (1.15, 1.38)	<0.01		
Unplanned intubation				
No			Reference	<0.01
Yes			1.39 (1.17, 1.66)	
On ventilator > 48 h				
No	Reference	<0.01		
Yes	1.37 (1.12, 1.67)			
Acute renal failure				
No	Reference	0.02		
Yes	0.66 (0.47, 0.93)			
Urinary tract infection				
No	Reference	<0.01	Reference	0.04
Yes	1.26 (1.06, 1.47)		1.25 (1.006, 1.56)	

(Continued)

Table 1. Continued

Significant predictor	Laboratory order		Imaging order	
	Adjusted IRR (95% CI)	p Value	Adjusted IRR (95% CI)	p Value
Transfusion intraop/postop (72h of surgery start time)				
No	Reference	<0.01		
Yes	1.20 (1.11, 1.31)			
Septic shock				
No			Reference	<0.01
Yes			1.36 (1.12, 1.66)	

Only statistically significant predictors are provided in the table. Other predictors included: preoperative variables: sex, Hispanic ethnicity, diabetes mellitus, dyspnea (within 30 d), functional status, COPD, ascites (within 30 d), congestive heart failure, hip, renal, dialysis or hemofiltration (within 2 wk), steroid use for chronic condition, >10% loss of body weight (within 6 mo), bleeding disorder requiring hospitalization, systemic sepsis (within 48 h); post occurrence variables: pulmonary embolism, progressive renal insufficiency, cerebrovascular accident, cardiac arrest requiring CPR, myocardial infarction, vein thrombosis requiring therapy.

*Individual surgeons with <2% data were put together into an "other" category.

IRR, incidence rate ratio; PGY, postgraduate year; SIRS, systemic inflammatory response syndrome; SSI, surgical site infection.

also predicted laboratory and imaging orders including attending surgeon, resident PGY, length of stay, preoperative patient comorbidities, and complications. Relative value units were implicated only in laboratory ordering, and were not associated with imaging.

Compared with imaging orders, the greater inter-resident variation for laboratory testing likely stems from the greater volume of laboratory testing. There are few routine postoperative imaging orders after alimentary-related operations, aside from daily chest x-rays in intubated patients (which was the most common imaging order in our study). In this investigation, there were 7,360 imaging orders compared with more than 111,000 laboratories, reflecting the relative rarity of imaging orders. Because these orders are less frequent, there is less opportunity to have differential use, and the precision of regression coefficients is comparatively reduced. Meanwhile, the ICC for imaging orders was greater than for laboratories, suggesting that the overall variation in imaging orders may be more attributable to residents. We theorize that the routine nature of laboratory ordering—including nursing-led blood draws—leads to reflexive testing. Imaging, however, is not routine and is likely more influenced by surgeon decision making. These data suggest residents were largely in agreement for imaging given the limited variation. When excluding patients with complications, the ICC for laboratory orders approached near zero, suggesting that residents practice more uniformly with routine postoperative patients. Resident practice patterns likely diverge when addressing complications, as shown by greater ICC when including patients with postoperative occurrences.

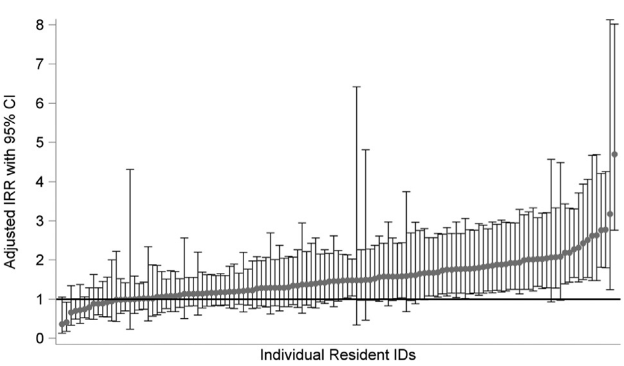


Figure 2. Caterpillar plot of incidence rate ratios (IRR) in laboratory ordering. Represents 124 surgical residents. One resident (0.8%) placed significantly fewer lab orders than the median resident (95% CI of IRR < 1) after adjustment for patient, attending, and procedural characteristics. Forty-seven residents (37.9%) placed significantly more lab orders than the median resident (95% CI of IRR > 1) after adjustment for patient, attending, and procedural characteristics.

The pattern of PGY ordering was paradoxical—chief-level residents ordered more labs than interns (ie PGY-1). This finding is likely explained by practice patterns at our institution, and has also been witnessed in other studies.[7] Laboratory and imaging orders are commonly placed at the conclusion of surgery via the EMR. Interns are less commonly in the operating room for complex cases that routinely have postoperative laboratory studies, and therefore, they do not place these orders. For the remainder of the hospital stay, interns predominantly place orders. The volume of orders placed immediately postoperatively—many that are recurring—exceeded the laboratory orders placed by interns in subsequent postoperative days. Our institution currently allows for recurring orders for up to 3 days, which did not change over the study period. This feature may explain the greater testing by PGY-5s, whose initial postoperative orders were activated for days, when otherwise PGY-1 residents would

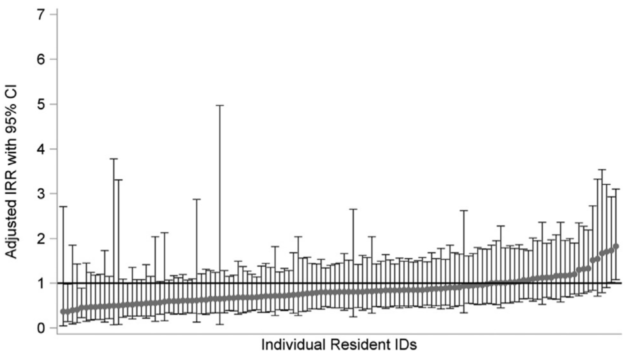


Figure 3. Median and interquartile range of laboratory orders count per resident per patient by postgraduate year.

be placing these orders. For imaging, the ordering pattern was different. PGY-2 residents were significantly more likely to order radiographs compared with any peer. Our results also demonstrated that chest x-rays were the most commonly ordered study. PGY-2 residents staff the surgical ICU and are responsible for placing all orders. Given that intubated patients frequently receive chest x-rays, logically, the PGY-2 resident would be associated with the highest ordering frequency.

Attending surgeon was another important variable associated with laboratory ordering. Although we did not expose the granularity of this finding, it is important to note that certain attendings were associated with increased ordering, independent of patient and case level variables. In initial iterations of our model, we evaluated surgical specialty as a predictor variable, but there was significant collinearity with attending surgeon—which was logical given that attendings practice within subspecialties. Therefore, this was not included in our analysis. Naturally, length of stay predicted ordering frequency; patients who stayed longer had more opportunity to accrue studies. The RVU would also appear as a logical predictor of increased testing given greater case complexity, and likely longer operative times with inherent risk for complications. Yet, the RVU variable was only statistically significantly associated with laboratory ordering. This once again likely reflects the limited use of imaging for any operation regardless of complexity.

Select complications were associated with the frequency of laboratory and imaging studies. Surgical site infections and intubations were positively associated in both models, yet postoperative cardiac events were not. This is not to say that laboratories or imaging studies are not ordered with cardiac events—they are likely ordered every time. Instead, it represents the poor specificity of ordering physicians in diagnosing these events (ie troponins are always ordered for chest pain, yet most chest pain is not a cardiac event). The focus of this study was not investigating the predictive value of any study in determining postoperative events; however, one could potentially investigate this type of question with these data.

Although many investigations have evaluated interventions to reduce the unnecessary burden of excessive testing,[7,11-13] few studies have evaluated variables associated with frequency of testing, and none have specifically investigated the surgical population. Our analysis is the first to establish resident- and patient-level variables associated with increased testing. The variation within residents suggests there may be personality differences

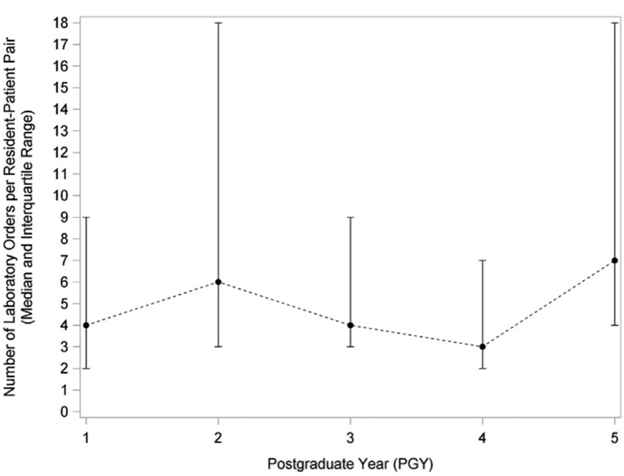


Figure 4. Caterpillar plot of incidence rate ratios (IRR) in imaging ordering. Represents 122 surgical residents. Three residents (2.5%) placed significantly fewer imaging orders than the median resident (95% of IRR < 1) after adjustment for patient, attending, and procedural characteristics. Two residents (1.6%) placed significantly more imaging orders than the median resident (95% CI of IRR > 1) after adjustment for patient, attending, and procedural characteristics.

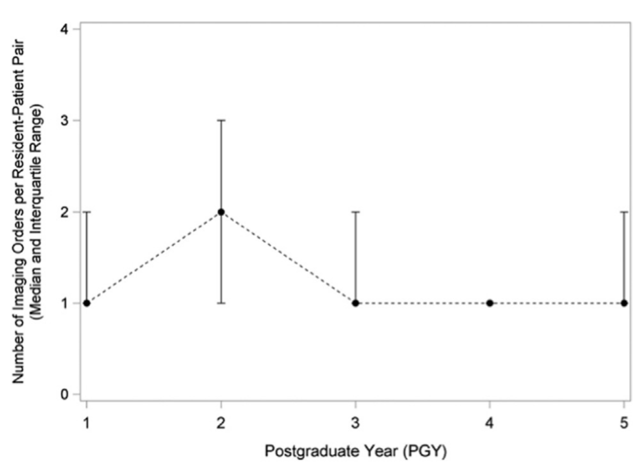


Figure 5. Median and interquartile range of imaging orders count per resident per patient by postgraduate year.

Table 2. Negative Binomial Mixed Effects Regression Models R^2 and Intraclass Correlation Coefficients

Variable	Resident-patient pair, n	Model R^2	Model ICC
Lab order			
Full data	5,933	0.572	0.035
Subset without complication	3,182	0.848	0.001
Imaging order			
Full data	2,153	0.857	0.049
Subset without complication	1,131	0.896	0.105

ICC, intraclass correlation coefficient.

between residents that lead to practice pattern differences. This has been described in other parts of the surgical literature, where variation in surgeon decision-making has been attributed to personality differences.[14,15] In a health care climate that increasingly analyzes physician behavior through data,[16] well-informed models, such as the one we propose, offer a more precise and accurate means of assaying physician practice patterns and determining meaningful change.

The American College of Surgeons Quality In-Training Initiative (QITI)[17] attempts to improve resident education through linking residents with the 30-day postoperative NSQIP data. The QITI holds the promise of investigating variation in outcomes associated with resident surgeons. Although QITI does not link to an institution's EMR, our study shows the feasibility of advancing the QITI mission by adding another level of data granularity. This could become a vital tool incorporated into surgical education as a means of performance improvement. This type of modeling could also be applied to other patient care scenarios, such as medication ordering, or wherever the EMR is used.

Limitations

This study is limited by its retrospective nature and the accuracy of data collection through NSQIP. Regarding causality, we cannot assess the relationship between testing and complications. Possibly, though unlikely, laboratory and imaging orders could have led to complications, as opposed to complications leading to laboratory and imaging orders (more likely).

Our analysis also was unable to determine the direct relationship between senior and junior residents. Common practice paradigms in resident training involve chief level residents suggesting orders for more junior residents to execute. Therefore, higher use on the part of a junior resident could be dependent on the demands and practice patterns of the corresponding chief. We do not believe this element of practice pattern is relevant given that the junior level residents switch rotations every 4 weeks and spend time with all chief level residents. Our model does adjust for attending preferences, which likely represent a more meaningful variable in the frequency of testing.

Surgical residents change rotations throughout the year, which potentially introduces confounding, given that services have particular cultures that may lend to variation in ordering practices. However, any differences between services should be equalized when looking at aggregate ordering patterns because the exposure to different services is uniform (ie all residents complete the same rotations).

Regarding the reference case for our models, there was no ground truth or absolute reference for the number of imaging or laboratory orders for a given operation or postoperative course. As with any regression analysis, one must choose a reference case. Therefore, we chose the median performing resident because it should approximate the standard of care for a given institution. The distribution of ordering per resident was fairly clustered around the median, supporting the notion that this group orders the "norm" for our institution.

Additional limitations include studying a period of only 3 years, which is shorter than the duration of training for a surgeon. There could be inherent bias between classes of residents that is not captured by postgraduate year, especially when considering that each class of residents is relatively small (eg 5 graduating residents per year). This investigation was also limited to a single institution, which makes these findings contextual. Though the directionality of significance for variables such as PGY may be the signature of one facility, the methodology used is generalizable to any institution. Finally, ICC estimates should be cautiously interpreted, as the specification of ICC for NBMER models used in this study was recently developed, and the statistical community has not yet reached consensus on a widely accepted methodology.[10,18,19]

CONCLUSIONS

The frequency of inpatient testing was influenced by many factors including surgical residents, attending surgeons, case complexity, patient comorbidities, and postoperative complications. There was greater variation in laboratory testing compared with imaging, yet surgical residents as a whole contributed to a small amount of the total variation in both laboratory and imaging testing. Our model provides a precise means of identifying high users using EMR and NSQIP data. Quality improvement interventions could leverage this methodology to measure meaningful changes in the frequency of testing, and educate resident surgeons on their practice patterns.

Author Contributions

Study conception and design: Sheckter, Jopling, Ding, Trickey, Wagner, Morris, Hawn

Acquisition of data: Trickey, Ding, Sheckter, Hawn

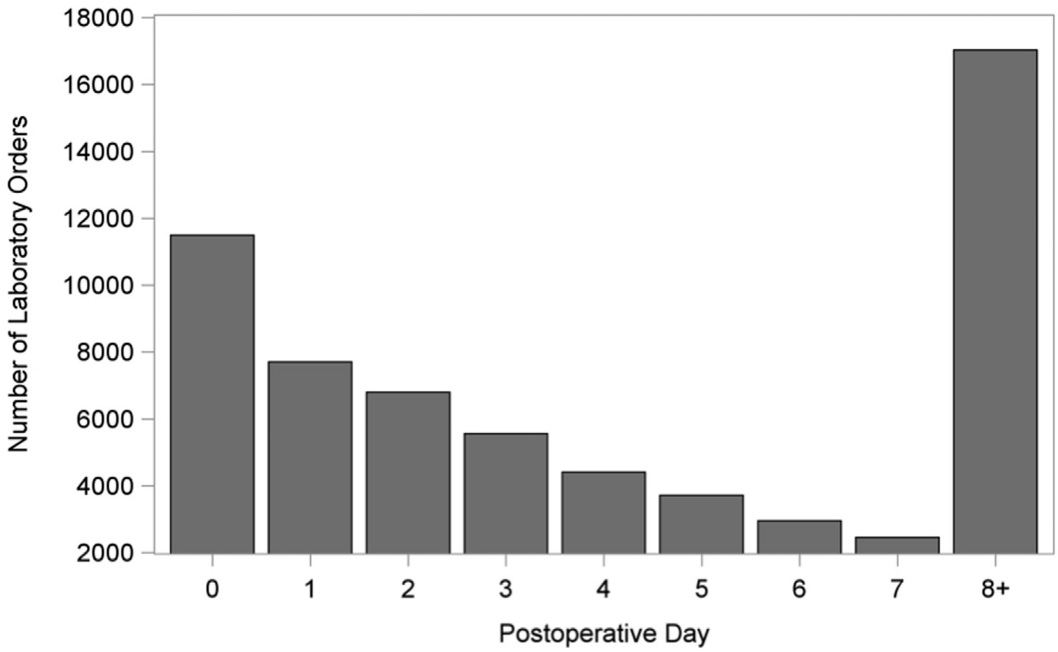
Analysis and interpretation of data: Sheckter, Ding, Trickey, Wagner, Morris, Hawn

Drafting of manuscript: Sheckter, Jopling, Ding, Trickey, Wagner, Morris, Hawn

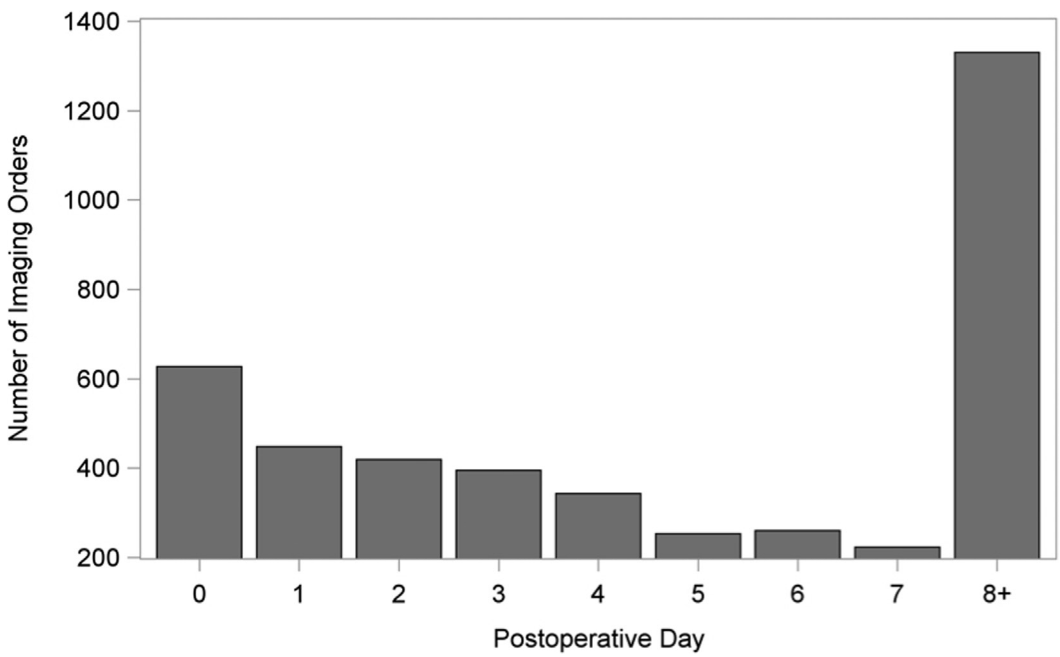
Critical revision: Sheckter, Jopling, Ding, Trickey, Wagner, Morris, Hawn

REFERENCES

1. Choosing Wisely. Promoting conversations between providers and patients. Available at: http://www.choosingwisely.org/. Accessed February 5, 2018.
2. Salisbury AC, Reid KJ, Alexander KP, et al. Diagnostic blood loss from phlebotomy and hospital-acquired anemia during acute myocardial infarction. Arch Intern Med 2011;171:1646−1653.
3. Eaton KP, Levy K, Soong C, et al. Evidence-based guidelines to eliminate repetitive laboratory testing. JAMA Intern Med 2017;177:1833−1839.
4. Blood Testing. Choosing Wisely. Available at: http://www.choosingwisely.org/clinician-lists/sabm-blood-testing/. Accessed August 7, 2018.
5. Valencia V, Arora VM, Ranji SR, et al. A comparison of laboratory testing in teaching vs nonteaching hospitals for 2 common medical conditions. JAMA Intern Med 2018;178:39−47.
6. Stuebing EA, Miner TJ. Surgical vampires and rising health care expenditure: reducing the cost of daily phlebotomy. Arch Surg 2011;146:524−527.
7. Miyakis S, Karamanof G, Liontos M, Mountokalakis TD. Factors contributing to inappropriate ordering of tests in an academic medical department and the effect of an educational feedback strategy. Postgrad Med J 2006;82:823−829.
8. Ingraham AM, Richards KE, Hall BL, Ko CY. Quality improvement in surgery: the American College of Surgeons National Surgical Quality Improvement Program approach. Adv Surg 2010;44:251−267.
9. Lowe HJ, Ferris TA, Hernandez PM, Weber SC. STRIDE−An integrated standards-based translational research informatics platform. AMIA Annu Symp Proc AMIA Symp 2009:391−395.
10. Nakagawa S, Johnson PCD, Schielzeth H. The coefficient of determination R2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. J R Soc Interface 2017;14.
11. Corson AH, Fan VS, White T, et al. A multifaceted hospitalist quality improvement intervention: Decreased frequency of common labs. J Hosp Med 2015;10:390−395.
12. McDonald EG, Saleh RR, Lee TC. Mindfulness-based laboratory reduction: reducing utilization through trainee-led daily "time outs." Am J Med 2017;130:e241−e244.
13. Lee VS, Kawamoto K, Hess R, et al. Implementation of a value-driven outcomes program to identify high variability in clinical costs and outcomes and association with reduced cost and improved quality. JAMA 2016;316:1061−1072.
14. Teunis T, Janssen SJ, Guitton TG, et al. Surgeon personality is associated with recommendation for operative treatment. Hand N Y N 2015;10:779−784.
15. Kadzielski J, McCormick F, Herndon JH, et al. Surgeons' attitudes are associated with reoperation and readmission rates. Clin Orthop 2015;473:1544−1551.
16. Paranjpe P. How to use data analytics to engage physicians. Health Manag Technol 2016;37:12.
17. Sellers MM, Fordham M, Miller CW, et al. The Quality In-Training Initiative: giving residents data to learn clinical effectiveness. J Surg Educ 2018;75:397−402.
18. Carrasco JL. A generalized concordance correlation coefficient based on the variance components generalized linear mixed models for overdispersed count data. Biometrics 2010;66:897−904.
19. Aly SS, Zhao J, Li B, Jiang J. Reliability of environmental sampling culture results using the negative binomial intraclass correlation coefficient. SpringerPlus 2014;3:40.



eFigure 1. Histogram of all laboratory orders by postoperative day.



eFigure 2. Histogram of all imaging orders by postoperative day.

eTable 1. National Surgical Quality Improvement Project Data Elements

Preoperative characteristic	Postoperative occurrence
Age	Acute renal failure requiring dialysis
Sex	Deep incisional surgical site infection
Hispanic ethnicity	Intraoperative or postoperative cardiac arrest requiring cardiopulmonary resuscitation
Evidence of significant preoperative weight loss	Intraoperative or postoperative myocardial infarction
Preoperative functional status	Intraoperative or postoperative unplanned intubation
Evidence of preexisting sepsis	On ventilator >48 hours
Preoperative transfusion requirement	Organ/space surgical site infection
Preoperative comorbidities of renal disease	Pneumonia
Dialysis requirement	Progressive renal insufficiency
Dyspnea	Pulmonary embolism
Presence of ascites	Sepsis
Steroid use	Septic shock
Smoking status	Stroke/cerebral vascular accident;
Presence of chronic obstructive pulmonary disease	Superficial surgical site infection
Presence of cancer	Transfusion intra/postoperatively
	Urinary tract infection
	Vein thrombosis requiring therapy
	Wound disruption