Hospital Operative Volume and Quality Indication for General Surgery Operations Performed Emergently in Geriatric Patients

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BACKGROUND: Within the growing geriatric population, there is an increasing need for emergency operations. Optimizing outcomes can require a structured system of surgical care based on key quality indicators. To investigate this, the current study sought to answer 2 questions. First, to what degree does hospital emergency operative volume impact mortality for geriatric patients undergoing emergency general surgery (EGS) operations? Second, at what procedure-specific hospital volume will geriatric patients undergoing an emergency operation achieve at or better than average mortality risk?

STUDY DESIGN: Retrospective cohort study of geriatric patients (aged 65 years and older) who underwent 1 of 10 EGS operations identified from the California State Inpatient Database (2010 to 2011). β-Logistic generalized linear regression was used, with the hospital as the unit of analysis, to investigate the relationship between hospital operative volume and in-hospital riskv-adjusted mortality. Hospital operative volume thresholds to optimize probability of survival were defined.

RESULTS: There were 41,860 operations evaluated at 299 hospitals. For each operation, mortality decreased as hospital emergency operative volume increased (p < 0.001 for each operation); for every standardized increase in volume (meaning +1 natural logarithm of volume), the reduction in mortality ranged from 14% for colectomy to 61% for appendectomy. Hospital volume thresholds, which optimize to 95% probability of survival, varied by procedure, with a mean of 14 operations over 2 years. More than 50% of hospitals did not meet the threshold benchmarks, representing 22% of patients.

CONCLUSIONS: Survival rates for geriatric patients were improved substantially when emergency operations were performed at hospitals with higher operative volumes. Consistent with all active Quality Programs of the American College of Surgeons, hospital operative volume appears to be an important metric of surgical quality for older patients undergoing emergency operations. (J Am Coll Surg 2019;228:910−923. © 2019 by the American College of Surgeons. Published by Elsevier Inc. All rights reserved.)

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Abbreviations and Acronyms

ACS   = American College of Surgeons
AHA   = American Hospital Association
CQGS  = Coalition for Quality in Geriatric Surgery
EGS   = emergency general surgery
SID   = State Inpatient Database
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As the US geriatric population increases,[1] there is significant interest in ensuring safe and high-quality surgical care for older persons. The American College of Surgeons (ACS), in concert with the John A Hartford Foundation, has formed the Coalition for Quality in Geriatric Surgery (CQGS), with more than 50 stakeholder organizations working to create verifiable hospital-based standards to improve outcomes for older surgical patients.[2] The ACS NSQIP and the American Geriatric Society have jointly published best practice guidelines on the "Optimal Perioperative Management of the Geriatric Patient."[3] The National Quality Forum, one of the nation's leading patient safety organizations, has endorsed specific quality measures for geriatric surgical patients.[4] The ACS NSQIP Geriatric Surgery Pilot has developed and tested a quality improvement data set with metrics targeted to an older population, including cognition, decision making, mobility, and function.[5,6]

Currently, much of the focus is on optimizing outcomes for older patients undergoing elective operations.[7,8] However, as the US population ages, the number of older patients who will require emergency surgical interventions will increase.[9-11] Current data show that, depending on the general surgery operation, anywhere from 10% to 44% of operations in older persons are emergent.[12,13] This presents additional challenges because emergency operations in older patients are associated with higher morbidity and mortality,[14-16] as well as increased costs[17,18] relative to elective operations. Accordingly, there is a significant opportunity, with broad clinical implications, to improve the care of older persons with acute surgical diseases.[19-21]

The ACS Quality Programs[22] provide a valuable, tested framework on which to base improvements in emergency surgery procedures for geriatric patients. For many surgical disciplines, quality improvement is synonymous with an accreditation process that verifies surgical centers using specific criteria to ensure standards of care and optimize outcomes. Across multiple surgical subspecialties, including bariatrics,[23] trauma,[24] and pediatric surgery,[25] discipline-specific hospital volume is a fundamental criterion of accreditation, and serves as a

quality indicator that institutions must meet to become a verified center.

To test the concept that hospital emergency operative volume is a key quality indicator and determinant of mortality in older patients undergoing surgical emergencies, the current study sought to answer 2 questions. First, to what degree does hospital emergency operative volume influence mortality for geriatric patients undergoing common emergency general surgery (EGS) operations? Second, at what procedure-specific hospital volume will geriatric patients undergoing an emergency operation achieve at or better than average mortality risk? The hypothesis was that higher hospital volume would be associated with lower postoperative in-hospital mortality. An additional hypothesis was that hospital emergency operative volume reaches a threshold above which nearly all hospitals performing the emergency operation in older patients would realize the average mortality risk or lower.

METHODS
Data sets and variables
This is a population-based, retrospective cohort study of all geriatric patients (65 years and older) who underwent 1 of 10 EGS operations in the state of California during a 24-month period from January 1, 2010 to December 31, 2011. The 10 operations analyzed were appendectomy, cholecystectomy, colectomy, inguinal and femoral hernia repair (analyzed together), lysis of adhesions (no bowel resections were performed in the lysis of adhesions group, by definition), excision of necrotizing soft-tissue infection, repair of perforated peptic ulcer disease (either gastric or duodenal ulcers), small bowel resection, umbilical hernia repair, and ventral hernia repair. Both laparoscopic and open operations were included; trauma operations were excluded.

Two data sets were used. The first was the State Inpatient Database (SID) for California (data from 2010 and 2011). The state of California was chosen because it is the most populous state in the US (population of 37 million in 2011), with a diverse population and varied geography with both urban and rural areas. The SID is part of a family of data sets developed by the Healthcare Cost and Utilization Project, and sponsored by the Agency for Healthcare Research and Quality.[26] Data abstracted included patient demographics, chronic health conditions, hospital-based metrics, and in-hospital mortality. The second data set was the American Hospital Association (AHA) Annual Survey of Hospitals Database for 2010 and 2011.[27] The same

Table 1. Characteristics of 41,860 Geriatric Patients Undergoing Emergency General Surgery Operations in California in 2011 and 2012, Recorded in the State Inpatient Database

Variable	Survived	Died	p Value*
Patient, n	39,550	2,310	—
Female sex, n (%)	21,780 (55.1)	1,279 (55.4)	0.91
Race and ethnicity,[†] n (%)			<0.001
White	24,401 (64.0)	1,521 (67.8)	
Black	1,697 (4.4)	135 (6.0)	
Non-black, non-white	4,296 (11.3)	204 (9.1)	
Hispanic	7,753 (20.3)	385 (17.1)	
Age, y, mean (SD)	76.3 (7.5)	79.9 (7.7)	<0.001
Comorbidity, van Walraven score, mean (SD)	5.5 (7.1)	13.9 (8.1)	<0.001
Payor source,[†] n (%)			<0.001
Medicare	33,754 (85.3)	2,083 (90.2)	
Medicaid	1,977 (5.0)	112 (4.8)	
Private insurance	3,385 (8.6)	104 (4.5)	
Self-pay or other	433 (1.1)	11 (0.5)	

Table shows overall patient characteristics; for patient characteristics by operation type, see Appendix E Tables E1 to E10.
*p Values are from 2-sided *t*-test for continuous variables and chi-square for categorical variables.
[†]Because of missing individual data for race and ethnicity and payor source, the total number of patients for those variables are lower than the patient totals for the survived and died columns.

California acute care hospitals in the SID and the AHA were paired, enabling risk adjustment at the hospital level.

For the current analyses, only patients undergoing urgent/emergency operations with specific EGS diagnoses were included. Patients were identified using ICD-9 procedural codes (Appendix A); only patients who were listed in the SID data set as having undergone 1 of the 10 operations as a primary core operation were included (as opposed to a secondary operation/procedure). ICD-9 diagnosis codes (Appendix B) identified patients with a specific diagnosis of an EGS condition. Given the ability to longitudinally track patients within SID, patients were not included more than once.

The chosen acute surgical conditions are among most prevalent emergent surgical diseases requiring operative intervention in the US and have a non-trivial risk of postoperative morbidity and mortality.[14,28,29] An operation was defined as being performed urgently/emergently if it was associated with an admission not scheduled, as defined by the SID unscheduled admission variable.

The transfer status of patients was accounted for in the inclusion/exclusion criteria; "transfer status" refers to the actual movement of a patient to or from one acute care hospital to another in California. If a patient urgently/emergently underwent an operation at one acute care hospital and was later transferred out to a second hospital, mortality was attributed to the transferring hospital that initially provided care; this is in keeping with the public reporting of mortality rates.[30]

Hospital volume was defined as the total number of patients having urgent/emergent operations at each acute care hospital during the 2-year period. Pediatric hospitals and rehabilitation hospitals were excluded from the analysis, as were governmental hospitals, such as Veterans Affairs hospitals. Any hospital that performed fewer than 3 of the specific operations of interest during the 2 years was excluded from the analyses. Hospitals doing an average of 1 emergent operation per year were not representative of the hospital types of interest, nor did they contribute reliable information about a mortality rate. Operative mortality was defined as a death that occurred during the patient's index hospitalization.

Statistical analyses and outcomes measures

The first research question evaluated the degree to which hospital operative volume influences hospital mortality rate for each of the 10 specified procedures. An ecological analysis was performed based on the hospital characteristics as predictors of the hospital's mortality rates, not the individual patient's characteristics as predictors of the patient's mortality; in other words, the hospital was the unit of analysis. An ecological analysis is a reasonable and valid approach for a study of the relationship between a hospital-level contextual risk factor (in this case volume) and a hospital-level contextual end point (incidence rate of mortality).[31]

β-Logistic generalized linear regression[32] was used to examine the relationship between hospital emergency operative volume and postoperative inpatient mortality,

Table 2. β-Regression Estimates for the Impact of Hospital Operative Volume on Hospital Mortality Rate, by Operation

	Multivariable risk-adjusted model		
Operation	Estimate*	95% CI	p Value
Appendectomy	0.39	0.36−0.42	<0.001
Cholecystectomy	0.51	0.48−0.56	<0.001
Colectomy	0.86	0.78−0.96	<0.001
Inguinal and femoral hernia repair	0.45	0.40−0.50	<0.001
Lysis of adhesions	0.61	0.54−0.68	<0.001
Necrotizing soft-tissue infection excision	0.53	0.40−0.69	<0.001
Repair of perforated peptic ulcer disease	0.64	0.50−0.82	<0.001
Small bowel resection	0.74	0.65−0.84	<0.001
Umbilical hernia repair	0.40	0.32−0.50	<0.001
Ventral hernia repair	0.46	0.41−0.53	<0.001

*These are β-regression coefficient estimates for hospital volume (ie procedure count). They quantitatively demonstrate the decrease in hospital mortality proportion for each operation type when the natural log of hospital volume is increased by +1. For example, a +1-unit change in natural log volume (meaning an integer increase from 1 to 2 or 2 to 3 or 3 to 4) for colectomy will decrease morality by 14% (as defined in the table). This 14% predicted decrease in mortality proportion occurs at each increase in integer interval, meaning that if a hospital increases colectomy natural log volume by 2 to 3, they can expect a 14% decrease in mortality, and if they increase natural log operative volume by 3 to 4, they can expect another 14% decrease in mortality proportion. Note that by comparison, a +1-unit change in natural log volume from 1 to 2 or 2 to 3 or 3 to 4 for small bowel resection will decrease morality by 26% over each interval. However, natural log volumes are difficult to conceptualize, so it is helpful to transform these natural log volume integers (such as 1, 2, 3, and 4) back into actual hospital operative volumes. The natural log volume integer can be back-converted to an actual operative volume like this: for the natural log volume integer 2: $2 = \ln(x) \rightarrow x = e^2 = 7.4$ operations; for the volume integer 3: $3 = \ln(x) \rightarrow x = e^3 = 20.1$ operations; for the natural log volume integer 4: $4 = \ln(x) \rightarrow x = e^4 = 54.6$ operations. Therefore, in terms of actual operative volume, a +1-unit change in natural log volume integer from 2 to 3 (7.4 operations vs 20.1 operations = +12.7 operations) is not equivalent to the change from 3 to 4 (20.1 operations vs 54.6 operations = +34.5 operations) − this highlights the exponential function of the natural log. Please see Figure 1 to appreciate this visually, as there are graphs for mortality proportion (on the y-axis) plotted against both actual operative volume, as well as natural log volume integer (on the x-axis).

with adjustment for both a hospital's patient case-mix and other relevant hospital-type characteristics. The primary outcomes measure was the proportion (a value from 0 to 1) of patients with in-hospital mortality during the 2-year period (defined as the number of patients who died during that admission after undergoing an emergency operation, divided by all patients undergoing that same type of emergency operation at that hospital during the 2 years). Mortality proportion data typically exhibit an S-shaped, or sigmoidal, curve with asymptotes at the limits of 0 and 1 when plotted against a predictor. In contrast to the β-logistic generalized linear regression with logit link function used in the current study, ordinary regression does not capture this relationship. The β distribution supports a range from 0 to 1, and the logit link ensures that the predicted mean stays within bounds (0, 1). The model regressed the mortality proportion at each hospital on the natural logarithm of the hospital volume plus hospital-level characteristics as covariates to adjust for variation in case-mix across hospitals. The general equations for the β-regression models, by operation, are available from the corresponding author on request.

The natural logarithm transformation of volume was used in the model for the operative volume predictor. The results are based on a +1 standardized increase in the natural logarithm transformation of volume. To interpret this from an operative volume standpoint, one must transform the natural log integer into a hospital operative volume—see footnote in Appendix C for full explanations of this. There are 2 major reasons why this natural logarithm transformation was chosen for the models. The first is because the logit is the canonical link function for the β-regression, and therefore both the predictor of interest (hospital urgent/emergent operative volume) and the end point of interest (proportion of mortality) would be on the natural log scale. The second is that, from a practical interpretation standpoint, hospital volume is believed to have a multiplicative effect rather than an additive effect. For example, an additive effect would suggest that a difference of 20 operations between hospitals with volumes of 5 operations vs 25 operations would be equivalent to the difference of 20 operations between hospitals with volumes of 100 operations vs 120 operations; the multiplicative effect would interpret this differently, saying the difference between hospitals with volumes of 5 operations vs 25 operations would be 5 times as large, and the difference between hospitals with volumes of 100 operations vs 120 operations would be 1.2 times as large.

Patient case-mix characteristics were included as hospital-level means or percentages to serve as covariates in the models that adjust for case-mix differences between hospitals. These included mean age, mean Elixhauser-van Walraven Comorbidity Index, and percentages of sex, race, and payor status. The Elixhauser-van Walraven is a widely used, validated, weighted measure of a patient's

chronic disease burden.[33] Coexisting conditions were identified in the SID data set using ICD-9 diagnosis codes, which were then used to calculate an Elixhauser-van Walraven comorbidity index. Unadjusted as well as multivariable risk-adjusted models were tested to predict in-hospital mortality; odds ratios represented the effects of hospital volume on survival proportion.

A pseudo-R^2 statistic[34,35] was calculated for each β-regression model as a generalized linear model analog to the linear regression R^2 statistic, denoting the proportion of the variance of the dependent variable explained by the model predictor of interest with covariates. Importantly, the values for the β-regression model pseudo-R^2 statistic are very different than the values for the linear regression R^2 statistic: a wider range of pseudo-R^2 values represent good model fit compared with the standard R^2.

Patient-level characteristics were compared between those who died and those who survived. Chi-square tests were used to compare differences in proportions for categorical variables; these data were summarized by frequencies with percentages. Group means were compared using 2-sample t-tests for normally distributed continuous variables; data were summarized by mean (SD) values. Hospital-level characteristics (medical school affiliation; trauma center status; high technology capability) were evaluated and presented as frequencies with percentages. A hospital had a "medical school affiliation" if it was defined in the AHA data set as a teaching hospital as reported to the American Medical Association, which accredits medical schools.[36] A hospital was considered a trauma center if it was either a Level I or Level II trauma center as defined and verified by the ACS Committee on Trauma[24] (note the AHA data set designation of trauma center, which was missing many variables and is based on state-level standards, was not used). A hospital was defined as having "high technology capability" if it performed adult open heart procedures and/or major liver or heart organ transplantation; this variable is therefore a proxy for a hospital's ability to manage and treat intensely sick patients in the perioperative period, as these operations often demand ICU admission and blood banking abilities, among others.[27,37]

The second research question was at what hospital operative volume would patients undergoing an emergency operation realize the average or lower mortality risk for that operation. The volume threshold was analyzed using the results of the β-regression models. The threshold (also referred to as the "threshold benchmark" or "benchmark") was defined as the hospital operative volume above which ≥95% of the hospitals were performing at or better than the average risk-adjusted mortality rate. For example, if a patient were to have a

non-elective cholecystectomy at a hospital with a cholecystectomy operative volume greater than the volume threshold, there would be a 95% chance that that patient's mortality risk (as defined by hospital mortality proportion) would be lower than the average risk-adjusted mortality for all hospitals performing cholecystectomies. Average mortality risk was defined and calculated by operation as the mean in-hospital risk-adjusted mortality at all acute care hospitals included in the analysis performing that specific EGS operation.

A p value <0.05 was defined as statistically significant. All statistical analyses were conducting using SAS, version 9.4 (SAS Institute). This study was approved by the Human Investigation Committee of the Yale University Human Research Protection Program for biomedical research.

RESULTS

Of the 425 acute care hospitals in California, the number meeting the inclusion criterion of performing emergent operations ranged from 62 performing umbilical hernia repairs to 298 performing cholecystectomies; 299 different acute care hospitals were included. Additional breakdown of hospital-level characteristics by operation are found in Appendix D. The 3 highest-volume operations were cholecystectomy (n = 17,427), colectomy (n = 6,727), and appendectomy (n = 4,857). The 3 lowest-volume operations were umbilical hernia repair (n = 268), excision of necrotizing soft-tissue infection (n = 666), and repair of perforated peptic ulcer disease (n = 871).

At 299 different acute care hospitals in California, 41,860 patients underwent EGS operations (Table 1). Overall unadjusted mortality rate was 5.5%, though it varied significantly by operation (Appendix E): 0.6% for appendectomy, 1.5% for cholecystectomy, 14.2% for colectomy, 2.3% for inguinal and femoral hernia repair, 6.2% for lysis of adhesions, 11.4% for necrotizing soft-tissue infection excision, 17.7% for repair of perforated peptic ulcer disease, 12.6% for small bowel resection, 1.1% for umbilical hernia repair, and 2.4% for ventral hernia repair. Relative to the non-decedents, the decedents were more likely to be white, have a payor source of Medicare, were older and had higher van Walraven comorbidity scores (Table 1). Open vs laparoscopic operations did not significantly impact mortality outcomes. Additional breakdown of patient-level characteristics, by operation, is found in Appendix E.

Multivariable β-regression models found that risk-adjusted mortality significantly decreased as volume increased for all 10 EGS operations, although the relative magnitude of this inverse relationship varied substantially
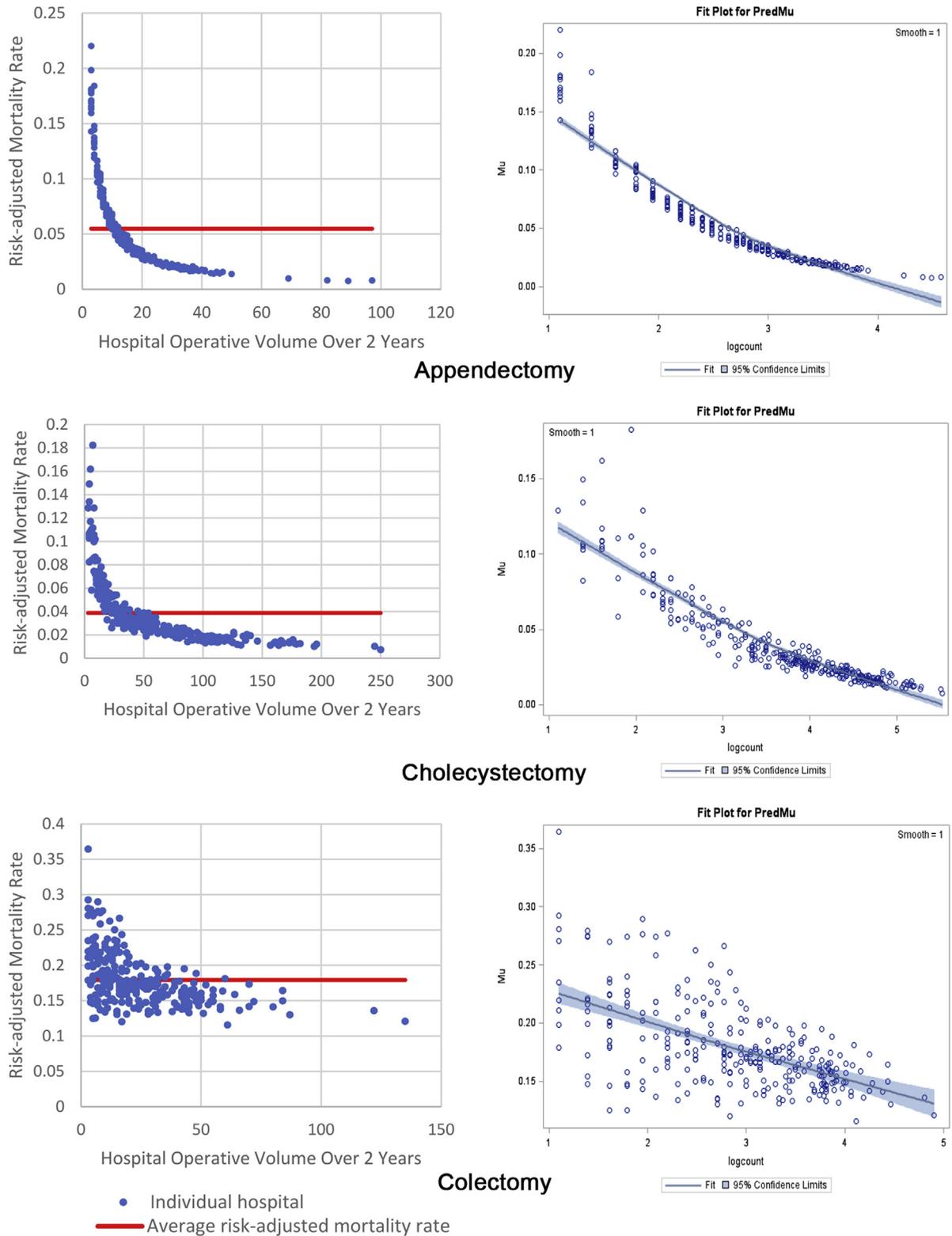
Figure 1. Two β-fit plots for each of the 10 emergency general surgery operations. The left plot shows the inverse volume to mortality relationship: the x-axis is hospital operative volume over 2 years; the y-axis is risk-adjusted hospital mortality rate; the thick flat line represents the average risk-adjusted mortality; every blue dot represents an individual hospital. The right plot is the relationship modeled in the β-regression analyses (plots on right are titled "Fit Plot for PredMu" meaning predicted mortality): the x-axis is natural log-transformed hospital operative volume; the y-axis is risk-adjusted hospital mortality rate (in the figure labeled "Mu"); every dot represents an individual hospital.
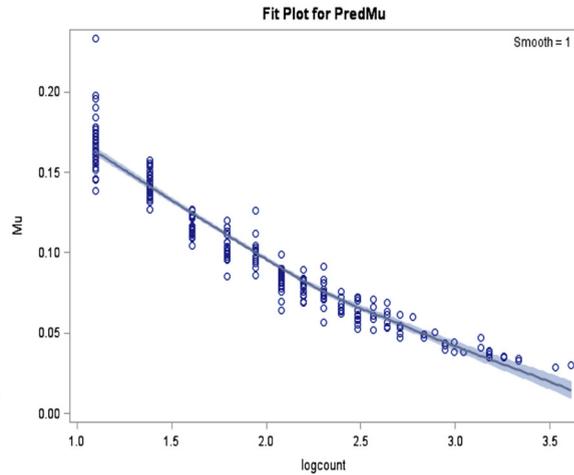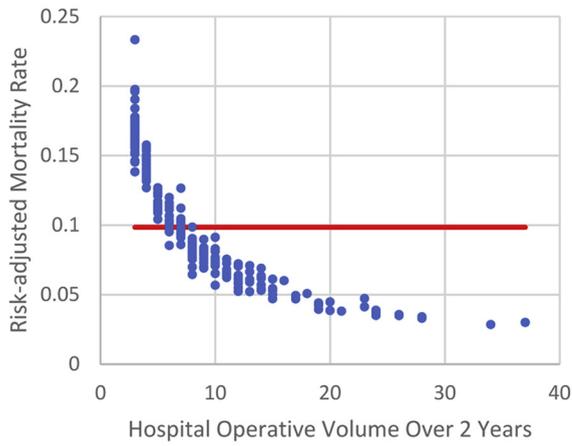
Inguinal Hernia Repair
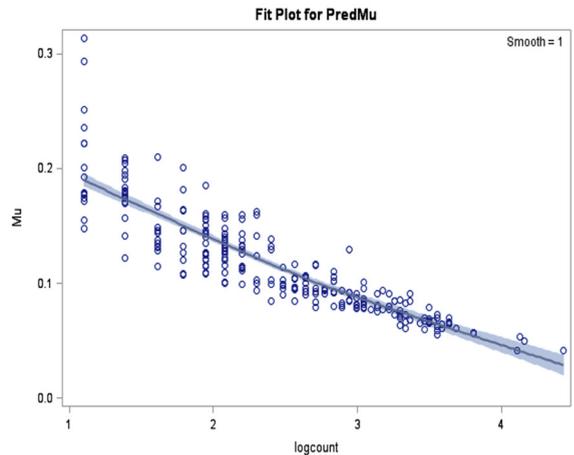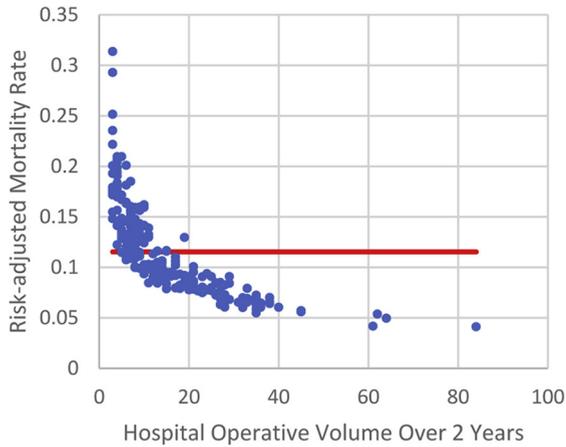
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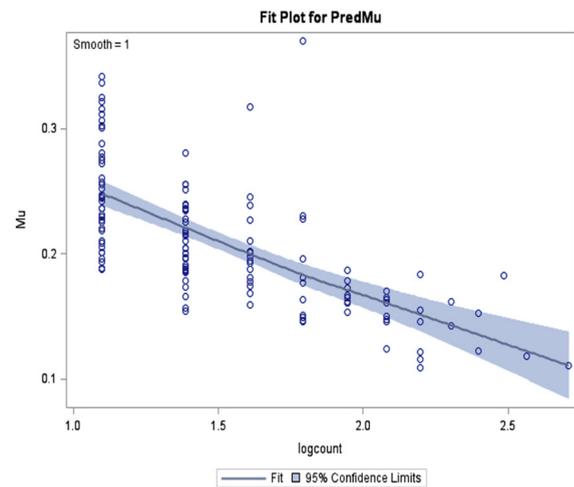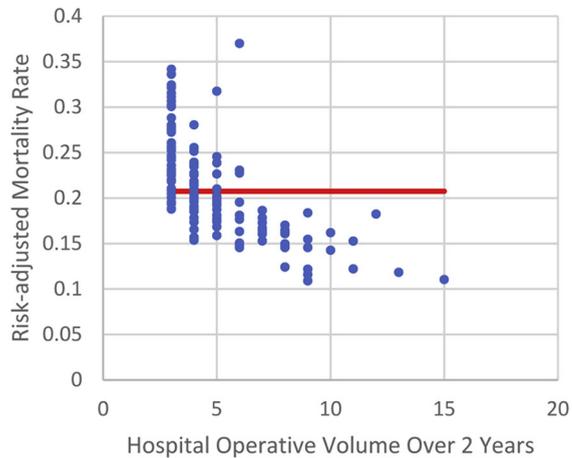
Necrotizing Soft Tissue Infection Resection

• Individual hospital
—— Average risk-adjusted mortality rate

Figure 1. Continued.

Repair of Perforated Viscus

Small Bowel Resection

Umbilical Hernia Repair

Figure 1. Continued.

Ventral Hernia Repair

Figure 1. Continued.

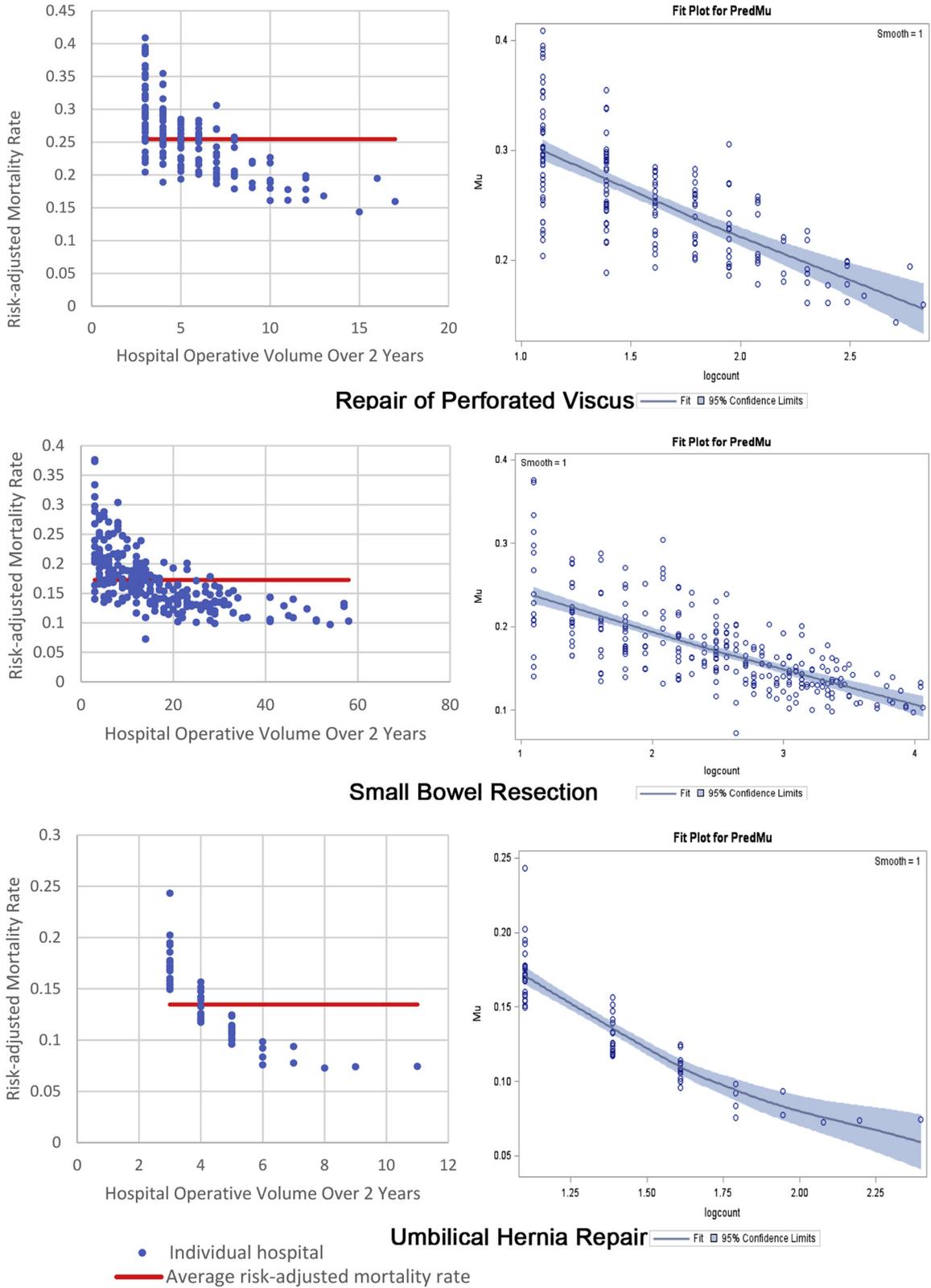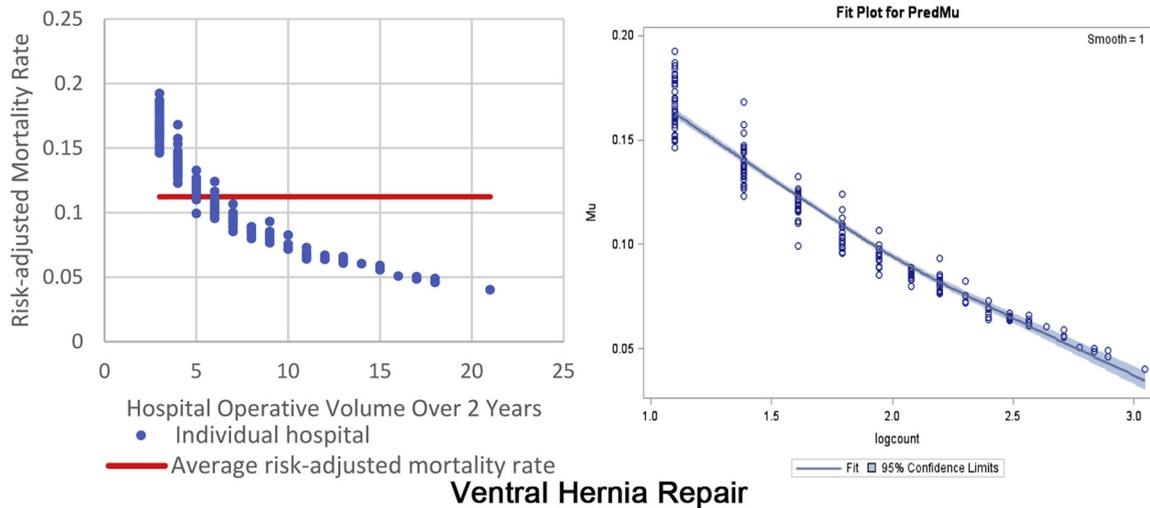by procedure (Table 2). Relative to other covariates in the β-regression models, hospital operative volume was the most important characteristic, with significant impact on mortality for every operation studied (Appendix C). Even with operations that have a lower risk of mortality (<2%), there remained a survival benefit to having the operation done at a higher-volume hospital.

The inverse volume to mortality relationship is shown graphically in the β-fit plots for all 10 operations (Fig. 1). For each operation, the high-volume hospitals tend to cluster together, indicating less variability and higher precision, and at the lower-volume hospitals, there is wide variation in mortality. In terms of model fit, each operation's β-regression pseudo R^2 indicated that each model fit the data well; pseudo R^2 values ranged from 0.16 for repair of perforated viscus to 0.74 for appendectomy. Full results of β-regression by operation, including hospital-level and patient-level covariates that were significantly associated with death, are found in Appendix C.

The hospital operative volume thresholds at which there was a 95% chance that that institution performed at or better than the average risk-adjusted mortality rate varied by operation (Table 3), from 38 cases over 2 years for colectomy to 5 cases over 2 years for umbilical hernia repair. On average, >50% of the hospitals did not meet the volume thresholds, representing 22% of patients. The number of hospitals failing to meet these threshold mortality standards varied by operation type, from 30% of all hospitals for cholecystectomy to 81% of institutions for repair of perforated peptic ulcer disease. The number of operations performed at these below-threshold institutions also varied, from 7% of all cases for cholecystectomy

to 64% of the operations for repair of perforated peptic ulcer disease.

DISCUSSION

Consistent with the study's primary hypothesis, higher hospital emergency operative volume was independently and significantly associated with higher probability of survival for patients aged 65 years and older undergoing each of 10 urgent/emergency EGS operations. For each procedure, hospital emergency operative volume reaches a specific threshold above which nearly all hospitals achieve at or better than average risk-adjusted survival. This volume threshold provides an operationally defined, empirically based, objective indicator of operative performance. These results suggest that hospital operative volume is an important metric of surgical quality for older patients undergoing emergency operations.

The ACS CQGS is working to create verifiable hospital-based standards to improve outcomes for older surgical patients. In a recent publication,[38] a modified RAND-UCLA Appropriateness Method was used to establish a list of valid standards to improve the surgical care of older adults. Hospital operative volume was not on this list. This is understandable, as using hospital operative volume as a benchmark criterion for surgical quality is not perfect, and has its critics.[39] However, based on the current study, the CQGS should consider establishing hospital operative volume as one of the fundamental benchmarks of high-quality emergency surgical care and including volume in the accreditation process for geriatric surgical centers. This criterion has been successfully implemented for other

Table 3. Hospital Operative Volume Threshold Analysis

Operation	Average risk-adjusted mortality, %	Mortality rate, %		Hospital volume threshold with 95% chance of being better than average mortality*	Total no. of hospitals	Hospital not achieving volume threshold, %	Total operative volume	Operation performed at hospital below volume threshold	
		Lowest-volume hospital	Highest-volume hospital					n	%
Appendectomy	5.5	22.0	0.7	11	267	35	4,857	609	13
Cholecystectomy	3.9	18.2	0.7	28	298	30	17,427	1,187	7
Colectomy	17.9	36.4	11.5	38	274	76	6,727	3264	49
Inguinal and femoral hernia repair	9.8	23.3	2.9	8	222	48	1,978	490	25
Lysis of adhesion	11.5	31.4	4.1	12	252	49	3,910	800	20
Necrotizing soft-tissue infection excision	20.7	37.0	10.9	7	131	77	666	403	61
Repair of perforated peptic ulcer disease	25.5	40.8	14.4	8	156	81	871	560	64
Small bowel resection	17.3	37.6	7.2	19	256	68	4,008	1,574	39
Umbilical hernia repair	13.5	24.3	7.3	5	62	65	268	137	51
Ventral hernia repair	11.2	19.2	4.0	6	170	49	1,148	320	28

*Hospital operative volume that optimizes probability of survival for a given operation, defined as the 2-year volume above which 95% of hospitals have better than average risk-adjusted mortality.

surgical subspecialties, such as bariatrics,[23] trauma,[24] and pediatric surgery,[25] which use hospital volume as one of the standards for the verification process.

Variability is inherent to any end point in medicine and surgery.[40] One of the goals of quality improvement initiatives is to minimize this variability so that outcomes are more predictable, saving lives and decreasing morbidity. Part of the survival variability in the current study is explained by hospital operative volume, which turns out to be the most significant predictor of survival for all EGS operations in this geriatric cohort. For some EGS operations, the survival variability is also explained by patient-level characteristics (see Appendix C), though their relative importance was less consistent. Patient characteristics, such as comorbidity status (for cholecystectomy, colectomy, lysis of adhesions, and small bowel resection) and age (for appendectomy, repair of perforated peptic ulcers, and umbilical hernia repair) were significantly associated with mortality.

The differences observed between procedure volume and patient characteristics on in-hospital mortality after EGS operations demonstrate that predicting outcomes in an older population is operation-dependent. Given the lack of consistency in associations for patient characteristics in the regression models, the results might also mean that traditional patient-level metrics of risk-adjustment (eg age, sex, race, and comorbidities) lack specificity in an older population. Future outcomes research on older populations should look beyond these traditional metrics and assess more geriatric-centered variables (eg frailty, function, and cognition), which might better characterize an aged population. In the SID data set that was used for the current study, such geriatric-specific variables were not available.

The survival variability seen among hospitals in this study is also likely due to processes of care and institutional cultures (such as highly reliable organizations) that are characteristic of certain medical centers. Although such indices are best measured with qualitative data, they are inherently captured—though not quantified—in the β-regression models that use the hospital as the unit of analysis. This is a distinct strength of the current study, though additional qualitative investigation is needed to specifically define these processes, structures, and cultures.

The use of an ecological analysis, with end point as a hospital's mortality incidence rate rather than a patient's probability of death, is a strength of this study. It allows the comparison of hospitals as a function of procedure volume rather than comparing patient types within or between hospitals. The risk of mortality for individual patients within hospitals via multilevel models with random hospital effects was not modeled, as this would assume conditional independence of patient outcomes within hospitals. Such a modeling paradigm ignores contextual effects on mortality risk; for example, if you were the only high-risk patient at a hospital, or among exclusively high-risk patients at a hospital with the same volume, you would have the same risk of procedure failure. In addition to multilevel models with random hospital effects, another alternative to β-regression would be generalized estimating equations with "sandwich" variance estimation. Such a model, however, assumes all patients are from the same population, but adjusts variance estimates to acknowledge that there are correlated, not independent, observations. Relative to these alternative analytic strategies, ecological analysis is a more reasonable approach for modeling the true relationship between hospital operative volume and mortality proportion.

Several issues about emergency operative intervention in an older population warrant additional discussion. The first is the transfer of patients between institutions. Based on the volume-threshold definitions, the results suggest that 22% of geriatric EGS patients, approximately 9,344 people during the 2-year study period in California, would potentially have benefited from transfer to a higher-volume institution for their operation. This could be problematic, as it has the potential to overwhelm higher-volume centers. In addition, emergency surgical conditions are inherently time-sensitive diagnoses requiring time-sensitive operations. As such, delaying an urgent/emergent operation with a transfer can also be potentially problematic, especially given the evidence that transferred patients have poorer outcomes for time-sensitive surgical emergencies.[41,42] However, there are few reliable data to support these claims in the geriatric EGS population. Given the underappreciated complexity of emergency operations in older patients, some have advocated that urgent/emergent EGS operations should be daytime-only procedures.[43] Taken together, based on the present knowledge of EGS disease processes, there might exist a safe window of time during which a majority of older patients with EGS conditions could be temporized with standard medical treatment and transferred to higher-volume centers for operative intervention, perhaps within 6 to 12 hours of presentation and diagnosis. Additional investigation is necessary and warranted.

The second consideration, which builds on the first and is based on the fact that most rural hospitals are lower operative volume institutions, is the practical limitation of emergency surgical care in more remote settings. A structured system of EGS care that mandates transfer of older patients away from rural areas might not prove beneficial, as the attendant delays to therapy can negate the benefits of a higher-volume center. Therefore,

examining the reasons that some hospitals performing less-complex cases, such as appendectomy and cholecystectomy, have higher mortality in geriatric patients is important; these data seem to imply that "low-risk" emergency operations are not uniformly low risk at all hospitals, and can become "high-risk" operations in certain institutions. The ACS CQGS should prioritize such research. The overall goal should be to investigate best practices and establish standards to allow lower-volume hospitals to achieve acceptable outcomes for less-complex operations in older patients.

The third consideration is the influence of individual surgeon volume to outcomes in geriatric EGS patients. In the elective surgical literature, much has been written about the value of both hospital volume[44-50] and surgeon volume[50-52]; these relationships continue to be explored, clarified, and researched today. Unlike elective general surgery, where patients can choose their surgeon ahead of an operation, this is rare in unplanned non-elective surgical situations. Therefore, akin to the exceedingly safe field of anesthesia, the field of general surgery should strive to make EGS operations in older patients safe regardless of individual surgeon experience or volume. It is justified not to investigate the individual surgeon level in a setting where a patient cannot choose their individual surgeon; to do so would be incongruent with the real-world setting of emergency surgical care. Additionally, given the limitations of the SID Healthcare Cost and Utilization Project data sets, information on individual surgeons was not available.

The current study has several limitations. First, it used a retrospective administrative data set, so the results should be interpreted in that context. For example, information was not available on cause of death or type of anesthesia used during the operation. Second, the ability to risk-adjust the data did not include physiologic parameters (such as heart rate or blood pressure) or geriatric-specific characteristics (such as frailty or functional independence) due to limitation of the SID Healthcare Cost and Utilization Project data; the current study was additionally unable to assess involvement of geriatricians in postoperative care as well as DNR status in the perioperative period. Third, an "emergency" patient is a construct of the Healthcare Cost and Utilization Project and the current study, and generalizing to all older patients requiring an urgent/emergency operation might not be valid. Fourth, due to the nature of the California SID database, the current study could only evaluate in-hospital mortality. Because variations in timing of patient discharge across hospitals can influence rates of in-hospital mortality, 30-day and 90-day mortality outcomes are considered more accurate metrics. Fifth, the data are from the state of California beginning 8 years ago, and

generalizations to a national level and current practice patterns might not be valid. Lastly, the hospital-volume thresholds defined here are a construct of the study itself. Although the study defined the benchmark calculation a priori, there might be other potential methodologies to define a volume threshold.

CONCLUSIONS

Across the spectrum of EGS, survival rates for geriatric patients were associated with significant improvement when emergency operations were performed at hospitals with higher emergency geriatric operative volumes. Operative volume for older EGS patients therefore seems to be a key quality indicator and determinant of survival, as well as a principal driver of variation in EGS hospital performance. To lessen the negative impact of the wide variation in survival rates at lower-volume hospitals, geriatric patients can benefit from a formal system of emergency surgical care that consolidates operative emergencies to higher-volume accredited surgery centers, as defined by the volume-threshold benchmark. Additional investigation needs to be conducted to define and validate other important determinants of morbidity and mortality in geriatric patients undergoing surgical emergencies.

Author Contributions

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Invited Commentary

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Care of the emergency general surgery (EGS) patient has been undergoing a slow but persistent change since early in the year 2000, as the concept of the model of acute care surgery (ACS) has become more popular. Slow and steady evaluation of the current processes involved in the management of acute nontraumatic surgical illness mirrors the response to trauma care that began in the 1980s. That research into trauma care has matured to the degree that we now enjoy. We are now consistently seeing the benefits derived from similar scrutiny and research applied to EGS patients.

Dr Becher and colleagues deserve credit for beginning to tackle this very difficult question in a lofty attempt to underscore the risk of emergent operation in the geriatric patient and how best to not only identify the drivers of that risk, but also to introduce solutions to ameliorate that risk. There is mounting evidence that EGS patients are a distinct cohort of patients and should be treated as such.[1] There is widespread agreement that the EGS patients experience a higher incidence of morbidity and mortality in general when compared with the cohort of elective patients who undergo similar procedures.[1]

This study attempts to identify the volume of emergency operations in the geriatric population at the hospital level as a driver of patient safety and quality within the context of the inherent challenges in the care of the EGS patient. The volume-outcome relationship is consistent with the concept that "practice makes perfect." Despite conflicting views in the literature, the general consensus is that hospital volume is important for certain procedures and certain patient cohorts. This novel study looked at the effects of hospital volume in the state of California on morbidity and mortality of the geriatric EGS patient.

However, like everything in medicine, there are a multitude of factors that go into the delivery of quality care, and volume will be one of them. The challenge is in teasing out the impact of volume from the care delivery model, the other services available at the hospital, the culture of safety, and the practice guidelines already in place that determine quality care.

Some of the limitations of this study do not allow one to drill down to how that volume is managed at the hospital level. Perhaps higher patient volume is a surrogate for the presence of a quality system already in place that can handle that volume with aplomb. The ability to determine if these higher volume hospitals have a mature ACS service, with all the benefits that come with that, was not built into the study, so we cannot tease out that contribution. There are recent data to suggest that the ACS model is associated with a significant reduction in mortality of 31% in those EGS patients.[2] The presence of a mature ACS service with resources to care for the critically ill may play a part in these favorable results[3] as a hospital obtains a reputation as a destination for sick patients and perhaps even be staffed with geriatricians on the ACS service, which has been shown to reduce cost and length of stay.[4] The presence of a high functioning trauma service alongside a robust EGS component may also underscore the "all boats float on a rising tide" philosophy.[3] The institutions so designated have achieved those goals as set out by the American College of Surgeons and include in-house ACS surgeons, massive transfusion protocols, excellent teamwork, embedded quality efforts, research, and a standard across the institution for the care of sick and injured patients. A basic minimum for level I trauma verification is a registry volume > 1,200 patients per year.

Future research will be needed to determine the additional factors that contribute to favorable outcomes in the EGS patients in addition to a certain threshold volume. Often, the very patients who need immediate surgical resources for care end up in those centers based on close proximity and not on outcomes for the specific illness. They may not have the means to select a center based on volume and experience for an optimal outcome. The challenge will then be identifying the key elements that contribute to those favorable outcomes in lower volume centers, and hopefully apply those interventions to guarantee quality access for all. Perhaps a similar approach to the relationship with level I trauma centers and the "level III" equivalent EGS centers will practice early recognition of certain elements dictating high-risk, immediate stabilization, and then rapid transfer to the closest appropriately staffed facility.