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Surgical errors and the relationships of disease, risks, and adverse events

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ABSTRACT

Background: Relationships between surgical errors and adverse events have not been fully explored and were examined in this study.
Materials and methods: This retrospective cohort study reviewed records of deceased surgical patients over 12 months. Bivariate associations between predictors and errors were examined.
Results: 84 deaths occurred following 5,209 operations. Errors in care (63%) compared to those without had significantly more adverse events, (98% vs 80% respectively, $p = 0.004$). Significant association occurred between error and emergency status, $p = 0.016$); length of stay >10 days, $p = 0.011$; adverse events, $p = 0.005$). Regression results indicated number of adverse events (OR = 1.27, 95% CI (1.08–1.49), $p = 0.003$) and length of stay (OR = 1.05, 95% CI (1.01–1.09), $p = 0.008$) were associated with surgical errors.
Conclusions: Examining postoperative adverse events in error cases identified opportunities for improvement. Reducing medical errors requires measuring medical errors.

Introduction

In 2000, the Institute of Medicine reported 44,000 to 98,000 patients died from errors in American hospitals.[1] By 2010, a study using the Global Trigger Tool revealed that adverse events (AEs) in hospitals occurred ten times more frequently than previously determined.[2] These estimates could account for 400,000 deaths a year from AEs and errors in American hospitals.[3] It is important, however, not to conflate errors and AEs. Many surgical subspecialties[4–9] provide well-developed AE benchmarks and have advocated for[10] or implemented voluntary error reporting[11,12]; however scant research provides data on errors in hospitalized surgical patients. Errors have been identified during hospitalizations through sporadic observation[13] or more commonly, a single type of error (e.g. technical error in the operating room (OR)[14] or medication errors),[15] has been measured. AE triggers have been used for case selection in error review,[16–18] but by Institute for Healthcare Improvement's definition errors that do not produce harm are excluded from review.[19] To date no studies were identified that enumerated AEs in the hospital care of consecutive surgical patients exposed to errors in care.

Our study identified, reconciled, and analyzed preoperative comorbidities and AEs among patients who did and did not experience an error in care. To our knowledge, this is the first study to assess errors, risks, and AEs in a replicable, systematic and comprehensive manner in postoperative patients. We hypothesized patients who experienced errors in care, compared to patients without an error, would have significantly more AEs.

Methods

This retrospective cohort study of consecutive deceased surgical patients at a single academic quaternary care institution included procedures performed from May 1, 2014 through April 30, 2015. The University of Virginia (UVA) Mortality Dashboard identified patients who died in the hospital on the Department of Surgery sub-specialty services. Medical records were reviewed of patients 18 years of age or older on the following services: Trauma and Emergency General Surgery, Cardiac Surgery, Vascular Surgery, Colorectal Surgery, Hepatobiliary and Pancreatic Surgery, Transplant Surgery, Thoracic Surgery, Breast Surgery, Endocrine Surgery,

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Abbreviations

AEs	adverse events
ASA	American Society of Anesthesiology
CI	confidence interval
CPT	Current Procedural Terminology
ICD-9-CM	International Classification of Diseases, Ninth revision, Clinical Modification
ICU	Intensive Care Unit
IQR	interquartile range
OR	Operating Room
RVU	Relative Value Units

and Bariatric Surgery. Vizient[20] Intensive Care Unit (ICU) days and cost data were merged with the study dataset.

Patients underwent operations in the main hospital OR, the hybrid surgery-radiology OR, the emergency room, or the ICU bedsides. Relative Value Units (RVU) represented complexity of operations. Patients who underwent tracheostomies, tube thoracostomies, and percutaneous endoscopic gastrostomies when done as a single procedure for supportive care were excluded.

In addition to patient demographics we recorded, elective versus emergency status, principal diagnosis, pre-operative risk factors, operations, postoperative AEs, and whether the patient died of the index disease. Senior surgeons (RSJ, WGS) judged whether diagnostic error, judgement error, technique error, omission error, system error, medication error, or other errors occurred, using algorithms developed *a priori* but modified as unaccounted for scenarios occurred.

Errors in diagnosis occurred when operative findings or the pathology report failed to concur with the preoperative diagnosis. In the postoperative period, failure to correctly recognize AEs represented an error in diagnosis. Failure to recognize and to interpret correctly signs and symptoms, test results, or imaging information constituted or contributed to errors in diagnosis. For example, an elderly patient with delirium, tachycardia, acidosis, abdominal pain, and leukocytosis diagnosed with sigmoid volvulus underwent emergency laparotomy. No intraabdominal pathology is identified and after persistent sepsis, death occurs from an epidural abscess.

Errors in judgement occurred in deciding whether to do or not do an operation, choosing the correct operation, and in evaluating the risk/benefit of a proposed procedure. Errors in judgement occurred intraoperatively causing surgeons to do too much, too little, or the wrong procedure. For example, performing a second elective procedure during the same case when significant blood loss and vital sign instability occurs with the first procedure.

Errors in technique included unintended organ injuries such as intestinal lacerations or punctures and vascular lacerations or punctures. Leaving organs mal-aligned, under tension, or ischemic also constituted errors in technique.

Errors of omission occurred when a "standard" test or process was not performed. For example, a patient admitted with sepsis and partial small bowel obstruction had necrotic segments of ileum resected. The right iliac pulse could not be palpated. The next day a major small bowel resection, femoral-femoral artery bypass graft, and an above the knee amputation were performed. The remaining right lower extremity and hip developed ischemic necrosis and the patient died. With several operations for complex visceral and extremity ischemia no arteriogram was performed.

Medication errors occurred when the patient received the wrong drug, the wrong drug dose, or failed to get the ordered drug. System errors included equipment failure, communication failure among care providers, and failure to follow protocols or guidelines. For example, a consult was placed but the consulting team failed to assess the patient within 24 h. Other errors included any deficiencies in care not described above.

Five-step ordinal scales (strongly agree, agree, neutral, disagree, strongly disagree) noted errors and whether error contributed to the patient's death. Hospital location of death and cause of death were recorded. Two senior surgeons (WGS and RSJ) reviewed the medical records (history and physical, progress notes, discharge summary, laboratory values, pathology report, medication list, and imaging studies) of all patients independently to enumerate AEs, errors, and causes of death. The two surgeons and an arbitrator (FET) discussed cases with discrepancies in coding and resolved the differences. The arbitrator recorded the justification for decisions to apply the rationale consistently across cases.

An AE was defined as, an injury caused by medical management (rather than by the underlying disease) prolonging hospitalization, producing disability at discharge, or both.[21] Errors were defined as "occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency".[22] An AE could occur without an error. An error could occur without an AE or could cause an AE. We defined AEs with International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes.[23] A general taxonomy, classification, and criterion for errors was established prior to the study. The reviewers subsequently reconciled score differences by in-depth review and discussion.

The operation for which the patient was admitted, defined the index operation. For evaluation we organized the operations by 2015 Current Procedural Terminology (CPT) code groupings.[24] We grouped reason for admission, risk factors, AEs, and cause of death by ICD-9-CM classifications. ICD-9 codes were grouped into 15 categories: cardiac, respiratory, renal, shock, gastrointestinal, vascular, sepsis, central nervous system, hemorrhage, hepatobiliary, metabolic, infection, hematologic, neoplasm, and musculoskeletal.

Descriptive statistics were used to summarize risks, errors, and outcomes. Interrater reliability between surgeon evaluators was measured with Cohen's kappa statistic. Sample size calculations for cohorts with 95% Confidence Interval (CI) and 80% power and 1:1 ratio of unexposed to exposed, determined sample size of unexposed and exposed to be 31 for a total sample size of 62, with an estimated error rate of 68%.

Because the data set was small, we looked at bivariate associations between hypothesized predictors and surgical errors. We used chi-square test for categorical and logistic regression for continuous variables. Binary logistic regression analysis tested if perioperative variables were significantly associated with surgical errors. The interaction between preoperative risk and emergency status and relative value unit and emergency status was evaluated. *P*-value 0.05 was the threshold for statistical significance. Analysis was performed using SAS software 9.4, SAS Institute Inc., Cary, NC, USA. The Institutional Review Board for Health Sciences Research approved the protocol (UVA #21986).

Results

During the study period, 5,209 patients underwent surgery on sub-specialty services and of those, 84 patients died during their hospital course. Patients experiencing an error in care ($n = 53$), compared to those who did not ($n = 31$), had similar preoperative characteristics with no differences in age, sex, preoperative risks, or American Society of Anesthesiology (ASA) scores. The two groups differed significantly on emergency status with patients experiencing an error less likely to undergo emergency surgery. Patients experiencing errors in care had significantly more ICU days, AEs, longer length of stay, and higher costs (Table 1). Consecutive deaths during the study period were examined with no loss to follow up.

Errors

Ninety-six errors occurred in the care of the 84 patients who died following an operation (Fig. 1). The frequency rank order for errors was Judgement (35), Technique (21), Diagnosis (16), Other (8), System (7), Omission (5), and Medication (4). Thirty-one patients had no errors, the 96 errors occurred in 53 patients. Of those, 25 patients had 1 error and 28 patients had 2-5 errors. The inter-rater reliability between surgeons evaluating errors revealed a kappa score of 0.6, a moderate level of agreement.[25] Of the 53 patients with an error, 52 also had an AE. Seven patients died with no error or AE of whom 4 died within 1 day of admission.

Reviewers agreed or strongly agreed that error contributed to the death of 31.0% of patients. These patients had 19 errors in judgement, 17 errors in technique, 10 errors in diagnosis, 4 errors of omission, 3 system errors, and 2 medication errors for a mean of 2.12 errors per patient. A mean of 0.5 errors per patient occurred for those who did not die of error.

Reviewers agreed or strongly agreed that 81.0% of patients died of the disease for which they underwent the operation. These patients had 27 errors in judgement, 15 errors in technique, 11 errors in diagnosis, 6 system errors, 3 errors of omission, and 3 medication errors or a mean of 0.96 errors per patient. For 14 patients who died of disease, errors also contributed to their deaths. Patients who did not die of disease had 23 errors for 16 patients or a mean of 1.44 errors per patient.

Post-operative deaths

Deaths occurred following 4,281 operations performed on 7 sub-specialty services: Trauma and Emergency General Surgery, Cardiac Surgery, Vascular Surgery, Colorectal Surgery, Hepatobiliary and Pancreatic Surgery, Transplant Surgery, and Thoracic Surgery. No deaths occurred among the 928 patients who underwent Endocrine, Breast, or Bariatric Surgery. The postoperative in-hospital mortality rate was 1.6%, with deaths occurring a median of 11.0 days (interquartile range (IQR): 4–26) following initial operation. The median age of deceased patients was 64.5 years (IQR: 53.8–80.0) and 61.9% were male. Thirty-three surgeons from the Department of Surgery (80 operations) and 2 surgeons (4 operations) from the Department of Neurosurgery performed the 84 Index Operations. Trauma and Emergency General Surgery had the highest mortality rate (3.9%) and Thoracic Surgery the lowest (0.3%).

Preoperative risk factors

Deceased patients had 492 preoperative risk factors. Cardiac, metabolic (diabetes, hyperlipidemia, obesity), vascular, and respiratory categories represented 56.1% of preoperative risk factors for all patients. The median number of risk factors per patient was 5.5 (IQR: 4–8). The median ASA score was 4 (IQR: 3–4). No patient had an ASA score of 1.

Operations

Of the 84 patients, undergoing operation 57 had a single procedure performed during the operation and 27 had 2-4 additional procedures performed during the Index Operation. Observing the work RVU of the 126 CPT codes listed for the 84 Index Operations revealed a median of 25.3 (IQR: 17.2–52.2) with values ranging from 4.23 to 89.50. The median RVU for the Index Operations was 22.6 (IQR: 15.8–35.3). Thirty-five patients had an operation subsequent to the Index Operation. Five of those returned to the OR on the day of the Index Operation. Thirteen patients had one reoperation. Twenty-two patients had 2-11 subsequent operations, with the highest number of reoperations for repeated debridements.

Table 1
Characteristics and outcomes of patients who died with and without errors in care.

	All patients n = 84 (100%)	Error n = 53 (63%)	No Error n = 31 (37%)	*P*-value
Age, median, IQR	64.5 (53.7–80.0)	64 (51–79)	65 (54.5–80)	0.8
Sex, male, n (%)	52 (61)	33 (62)	19 (61)	0.8
Race, Caucasian	66 (79)	41 (77)	25 (80)	0.7
Black	14 (17)	11 (22)	3 (10)	
Asian	1 (1)	0 (0)	1 (4)	
Unknown	3 (3)	1 (1)	2 (6)	
Preoperative risk	5.5 (4–8)	6 (5–8)	5 (3–7.5)	0.2
ASA	4 (3–4)	4 (3–4)	4 (4–4)	0.7
Emergency	48 (57)	25 (47)	23 (74)	0.01
RVU primary	22.6 (15.8–35.3)	22.59 (17.2–39.0)	22.7 (14.1–30.1)	0.8
Surgical Service				0.1
Trauma and Emergency General Surgery	32 cases	20 (62)	12 (38)	
Cardiac Surgery	21 cases	15 (71)	6 (29)	
Vascular Surgery	11 cases	6 (55)	5 (45)	
Colorectal Surgery	8 cases	6 (75)	2 (25)	
Hepatobiliary and Pancreatic Surgery	6 cases	3 (50)	3 (50)	
Transplant Surgery	4 cases	2 (50)	2 (50)	
Thoracic Surgery	2 cases	1 (50)	1 (50)	
ICU Days	8 (3–18)	11 (4–23.5)	4 (2–9.5)	0.03
Adverse events	77 (91)	52 (98)	25 (80)	0.004
Adverse events, median	5 (2–7.2)	6 (4–9)	4 (1–6)	0.004
Died of disease	68 (80)	40 (75)	28 (90)	0.09
Length Of Stay	11 (4–26)	14 (5–29)	8 (2–14)	0.002
Observed Cost	74,247 (39,351–157,337)	89,081 (50,125–196,451)	43,302 (24,996–82586)	0.013

ASA: American Society of Anesthesiology; ICU: Intensive Care Unit; IQR: Interquartile Range; RVU: Relative Value Unit.

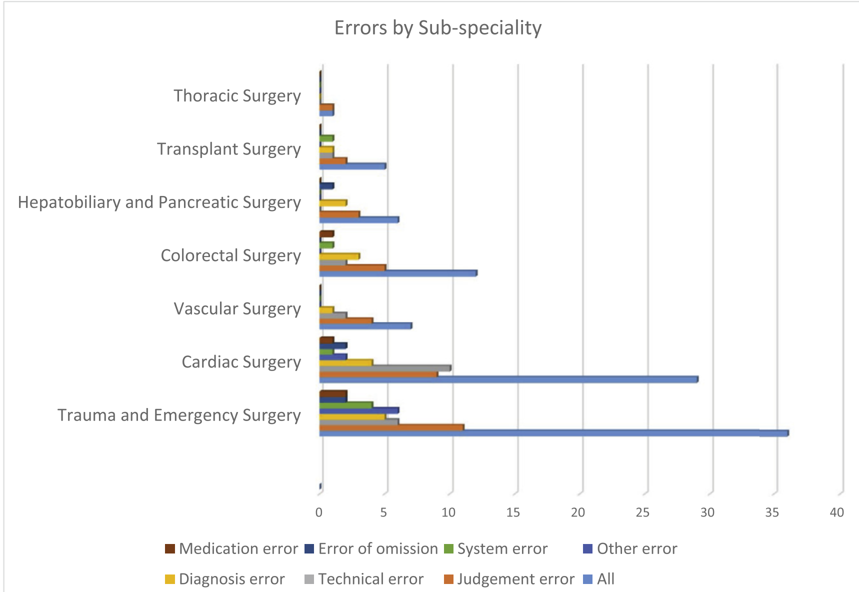

Fig. 1. Surgical errors by sub-specialty service.

Emergency cases

Emergency cases accounted for 54.8% of Index Operations. Trauma and Emergency General Surgery had more emergency cases 56.0% than any sub-specialty and the highest proportion of their cases were emergent 81.2% while Thoracic Surgery and Colorectal Surgery contributed the fewest emergency cases, 2.2% for each service.

Adverse events

Patients experiencing errors in care, compared to those who did not, were significantly more likely to have AEs related to the gastrointestinal tract. There were no differences in other AEs between the two groups (Table 2). Deceased patients had 424 AEs, the most common being cardiac (myocardial infarction, cardiac arrest, arrhythmia, failure) 19.7% and respiratory (pneumonia, atelectasis, pneumothorax) 18.5%. There was a median of 5.0 AEs per patient (IQR: 2–7.3). Seven patients had no postoperative AEs (6 of 7 also had no errors identified in their care). Twelve patients had 1 AE and 65 patients had 2-15 AEs. AEs contributed to the deaths of 43 patients.

Heart failure was most often the cause of death (11.9%), followed by sepsis (9.5%), and shock (9.5%). Fifty-five patients died in an ICU, six died in the OR, five died on a floor, and three died in the Emergency Department. The remaining 15 patients died in palliative care. (Additional data tables can be accessed in Supplemental Material).

There was a significant relationship between surgical error and emergency status, $p = 0.016$; length of stay >10 days, $p = 0.011$; and AEs, $p = 0.005$. Patients who underwent emergency surgery, were hospitalized more than 10 days, or had an AE were more likely to experience a surgical error. No association was found between surgical error and gender, $p = 0.929$; race, $p = 0.723$; age $\geq$65 years, $p = 0.875$; or ASA $\geq$4, $p = 0.276$).

Regression results indicated number of AEs (Odds Ratio (OR) = 1.27 per AE, 95% CI (1.08–1.49), $p = 0.003$) and length of stay in days (OR = 1.05 per day, 95% CI (1.01–1.09), $p = 0.008$) were associated with surgical error. While RVU (OR = 1.01 per RVU, CI (0.99–1.02), $p = 0.15$); number of preoperative risks (OR = 1.02 per risk factor, CI (0.88–1.203, $p = 0.719$); and age in years (OR = 0.99 per year, CI (0.97–1.02), $p = 0.81$) were not associated with error. The regression modeled with preoperative risk, emergency status, and the interaction term of preoperative risk and emergency status were not associated with surgical error (OR = 1.14, CI (0.79–1.64), $p = 0.46$), nor was the model with RVU, emergency status, and the interaction term of RVU and emergency status (OR = 0.97, CI (0.94–1.01), $p = 0.18$) (Table 3).

Discussion

Errors

In our study, 98% of patients judged to have had an error in care suffered an AE, 31 patients had no errors. The error rate for patients who died postoperatively was 63.0%. This is similar to error related events in other studies where 23 of 119 surgical deaths were suspicious for an AE and 15 of these deaths (65.2%) followed an error in care; although the AE rate was significantly lower than in our study (19% vs 92% respectively, $p < 0.001$).[17] A 45.8% error rate (although the study refers to AEs, the examples given describe errors e.g. failure to order a white blood count in a patient with symptoms of appendicitis) is reported in a prospective observational study of ICU and surgical care ward patients[13,26] and surgical cases presented at Morbidity and Mortality conference had a 59% error rate.[16] Errors in management for patients hospitalized due to accidental injury accounted for 58% of all AEs but an error rate related to mortality was not reported.[27] In our study we abstracted errors on all patients, not those with AEs, but did find the vast majority of patients who experienced an error in care also had an AE. Thus underscoring the feasibility of using an AE as a trigger for case review; efforts are underway to test the efficacy of this approach in error detection and case selection in a cohort including surgery survivors.

When error contributed to patients' deaths the error rank order was Judgement, Technical, and Diagnosis. Other studies have found errors in technique to be most common.[17,27] Laparoscopy has permitted quantification of intra-operative errors, particularly technical errors.[14,28] Differences in our findings are likely due to the

Table 2
Postoperative adverse events for patients who did and did not experience errors in care.

Adverse Events	All patients n = 84 (100%) n = 424	Error n = 53 (63%) n = 313	No Error n = 31 (37%) AE = 111	*P*-value
Cardiac	84 (19.7)	57 (18.2)	20 (18.0)	0.96
Respiratory	79 (18.5)	56 (17.8)	22 (19.8)	0.64
Renal	43 (10.1)	28 (8.9)	10 (9.0)	0.97
Shock	38 (8.9)	32 (10.2)	9 (8.1)	0.52
Gastro-intestinal	38 (8.9)	16 (5.1)	0	0.01
Metabolic	28 (6.6)	20 (6.3)	9 (8.1)	0.51
Central Nervous System	28 (6.3)	11 (3.5)	7 (6.3)	0.20
Vascular	20 (4.7)	29 (9.2)	10 (9.0)	0.95
Hepatobiliary	18 (4.2)	8 (2.5)	7 (6.3)	0.06
Sepsis	16 (3.7)	12 (3.8)	4 (3.6)	0.92
Hemorrhage	16 (3.7)	23 (7.3)	4 (3.6)	0.16
Hematologic	15 (3.5)	14 (4.4)	6 (5.4)	0.66
Integumentary, musculoskeletal	10 (2.3)	7 (2.2)	3 (2.7)	0.76

fact that we followed patients throughout their hospitalization and did not limit review to the OR. Technical errors produced the fewest discrepancies between reviewers in our study. The level of clinical expertise needed to identify and evaluate errors in surgical diagnosis, judgment, and omission in particular, requires further exploration.

Identifying errors is an essential and necessary first step, but it is not enough to improve care. A process to discuss errors (not place blame) at Morbidity and Mortality conference is needed with a focus on system changes required to prevent future occurrences,[26] as well as incorporating useful feedback into faculty and resident performance evaluation.[29] Implementing change is difficult, a structured way to address adverse events, errors, and clinical outcomes is by including them as a component of hospital credentialing.[30] Admittedly, adverse events and errors occur in a complex environment with diverse team members and the intention should not be attributing errors to a particular person. A systems approach to surgical quality improvement allows for a more robust understanding of outcomes[31] and the surgeon (educated in quality improvement techniques) can be an optimal quality initiative leader.[32] Additionally, addressing clinical quality in a sustainable fashion requires an institutional commitment to infrastructure (quality database and abstractors,[33] visualizing data via dashboards,[34] and performance improvement personnel)[35]; comprehensive resources detailing implementation of surgical quality programs are readily available.[36]

Detecting errors and determining their contribution to patient harm can be subjective and fraught with hind-sight bias. The variability of reviewers' cognitive content and clinical experiences can produce varying judgements about errors. Clear definitions with vignette examples assisted with consistency in error identification. We identified errors by review of operative notes, discharge summaries, and progress notes in the medical record. The reviewers formed an opinion whether an error contributed to death. When disagreement in error assignment occurred the surgeons discussed the issues, presented evidence to support their decision, and reached consensus. The mediator recorded decisions and the associated reasoning. Applying the same logic to subsequent cases assisted with resolution of differences between surgeons. Replicating this process at institutions of varying type and size warrants further exploration.

Adverse events

Ninety-two percent of the cohort experienced an AE. This differs from several studies in the literature where 48% of AEs resulted from operations in New York hospitals[27] and 3.0% of AEs for patients having an operation or bearing a child in Colorado and Utah hospitals.[37] The present study included only patients who died in the hospital, with most undergoing emergent procedures, thus our study population was smaller and had a high acuity.

We found significant association between AEs and errors. This is similar to Kaafarani and colleagues findings that major intraoperative AEs were significantly associated with postoperative complications, but not postoperative deaths.[38] Ramly et al. performed a similar study on patients undergoing emergency operations and found that intraoperative errors significantly increased postoperative AEs but failed to increase postoperative deaths.[39] This differs from our study in which technical errors contributed to the patient's death 81.0% of the time. However, our study assessed errors that occurred throughout the patients' hospitalization; the scope was not limited to the OR. Further study is needed to evaluate the effectiveness of interventions to reduce errors outside of the OR, such as an "error prevention" team to review the

Table 3
Multivariable logistic regression variables associated with surgical errors.

	Odd's Ratio	95% Confidence Interval	*P*
Adverse events	1.27	1.08–1.49	0.003
Length of stay	1.05	1.01–1.09	0.008
RVU	1.01	0.99–1.02	0.158
Preoperative Risk	1.02	0.88–1.20	0.71
Age	0.99	0.97–1.02	0.81
Interaction terms			
Preoperative risk * Emergency status	1.14	0.79–1.64	0.46
RVU * Emergency status	0.97	0.94–1.01	0.18

RVU: Relative Value Unit.

care of patients who have sustained an AE or aggressive care coordination to manage high-risk patients particularly those hospitalized greater than 10 days.

Seventy-seven of the 84 operated patients had at least 1 postoperative AE. The 7 without AEs either died during operation or soon thereafter. AEs occurred 4 times more frequently than errors and many errors did not harm patients. By definition AEs harm patients. Of 5,209 study patients who underwent operation an AE contributed to the death of 0.8% of patients and an error contributed to the death of 0.5% of patients. This is similar to Calland et al. findings where error contributed to the death of 0.3% of patients who died 30 days postoperatively.[17] Further examination of errors and AEs in surgical patients who live and die is warranted.

Emergency

While Trauma Emergency General Surgery, Cardiac Surgery, and Vascular Surgery Services cared for most emergency cases, all services with deaths participated in emergency care (54.8%). Emergency status was associated with surgical error in our study. In other studies, emergency status significantly increased patients' mortality risk when considering all surgical services.[17] And Emergency General Surgery Services 30-day mortality rate was significantly higher when compared with Non-Emergency General Surgery Services (12.5% versus 2.7% respectfully); Emergency General Surgery was an independent risk factor for death and postoperative complications.[40] Efforts to reduce surgical morbidity and errors could focus on mentoring surgeons in decision-making and having experienced surgeons readily available for intraoperative consultation of patients with Trauma, Emergency General Surgery, and Cardiovascular emergencies. Summaries of these discussions and any errors detected could be included in Morbidity and Mortality conference presentations to inform and educate residents and faculty.

Strengths and limitations

Study strengths include data abstraction by experienced surgeons using a standardized process with variables defined *a priori* to examine consecutive surgical deaths. Study limitations included data from a single institution, reducing generalizability, and not including surgical sub-specialties such as Neurosurgery, Orthopedics, or Urology. Additionally, the study population was restricted to inpatient deceased patients and this is likely the "tip of the iceberg". We did not attribute errors to a particular person or role e.g attending, resident, nurse but examining errors by role may allow for evaluation of resident supervision. Confounding and bias are also concerns in retrospective cohort study design. Future research could explore the clinician level needed to abstract error data, as well as implementation and validation of the error review process at rural, community, and academic health care institutions. Exploration of post-discharge deaths as well as readmissions following inpatient surgery would likely be robust avenues of research.

Conclusions

Examining AEs in a cohort of deceased postoperative patients experiencing errors in care provides insights into clinical care deficiencies and opportunities for improvement. Using an AE as a trigger for case selection and error review is efficacious in this subset of deceased patients and future research could test this in a population that includes survivors. These processes can aid surgeons in improving the safety and quality of the care they provide. Reducing medical errors however, will require measuring medical errors.

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Declaration of competing interest

The Authors declare that there is no conflict of interest.

CRediT authorship contribution statement

Florence E. Turrentine: Formal analysis, Writing - original draft. **Worthington G. Schenk:** Writing - review & editing, Validation, Investigation. **Timothy L. McMurry:** Formal analysis. **Carlos A. Tache-Leon:** Writing - review & editing, Investigation. **R. Scott Jones:** Writing - review & editing, Validation, Investigation, Conceptualization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amjsurg.2020.05.004.

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