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Can the Emergency Surgery Score (ESS) predict outcomes in emergency general surgery patients with missing data elements? A nationwide analysis

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ABSTRACT

Background: The Emergency Surgery Score (ESS) is an accurate mortality risk calculator for emergency general surgery (EGS). We sought to assess whether ESS can accurately predict 30-day morbidity, mortality, and requirement for postoperative Intensive Care Unit (ICU) care in patients with missing data variables.

Methods: All EGS patients with one or more missing ESS variables in the 2007–2015 ACS-NSQIP database were included. ESS was calculated assuming that a missing variable is normal (i.e. no additional ESS points). The correlation between ESS and morbidity, mortality, and postoperative ICU level of care was assessed using the c-statistics methodology.

Results: Out of a total of 4,456,809 patients, 359,849 were EGS, and of those 256,278 (71.2%) patients had at least one ESS variable missing. ESS correlated extremely well with mortality (c-statistic = 0.94) and postoperative requirement of ICU care (c-statistic = 0.91) and well with morbidity (c-statistic = 0.77).

Conclusion: ESS performs well in predicting outcomes in EGS patients even when one or more data elements are missing and remains a useful bedside tool for counseling EGS patients and for benchmarking the quality of EGS care.

Introduction

The burden of emergency general surgery (EGS) has been steadily increasing over the years, with EGS now accounting for 7–11% of all hospital admissions in the United States.[1–5] Similarly, the healthcare costs associated with EGS are increasing and are expected to continue to rise in the years to come.[6–8] When compared to elective general surgery, EGS is associated with a significantly higher risk of postoperative morbidity and mortality.[9–13] The heterogenous nature of EGS patient population has made prediction of the outcome of this patient population difficult and benchmarking of the quality of their surgical care challenging.[3,4,14]

Our research team recently developed and validated a novel score called the Emergency Surgery Score (ESS, previously ESAS) for prediction of postoperative mortality.[15] ESS is a point-based score, ranging from 0 to 29, that derives from 3 demographic, 10 comorbidities and 9 laboratory data variables. Patients with missing data were not included in the analysis for the derivation and validation study.[15] Since its inception, ESS has been retrospectively validated as an accurate, reliable and stepwise predictor of mortality, morbidity, infection and the need for intensive care in EGS patients.[15–19,40] In all previously mentioned studies higher ESS has been correlated with worse EGS patient outcomes.[15–19,40]

One of the criticisms of ESS is the large number of variables needed for its calculation, specifically when some of these variables (e.g. laboratory variables) might not be known or readily available preoperatively. In other words, the predictive accuracy of ESS in the setting of missing data elements remains unknown. In this study, we aimed to examine whether ESS can accurately predict postoperative morbidity, mortality, and need for postoperative Intensive Care Unit (ICU) level of care in patients with missing data points, if all missing variables are assumed to be normal (i.e. the

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default value; no additional ESS points).

Material and methods

To assess the predictive value of ESS in EGS patients with missing data, we used the 2007–2015 American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP). The ACS-NSQIP is a well-validated national database that includes more than 400 hospitals. It collects de-identified information for patients undergoing surgical procedures (except transplant and trauma procedures), capturing preoperative, intraoperative and 30-days postoperative data.[20–22] Definitions of the variables are standardized and distributed to all participating hospitals.[23]

Patient population

EGS was defined using the ACS-NSQIP variables "SURGSPEC" and "EMERGENCY". ACS-NSQIP defines emergency operation as a case performed within a short interval of time between patient diagnosis or the onset of related preoperative symptomatology, otherwise the patient's well-being and outcomes are potentially threatened by unnecessary delay and the patient's status could deteriorate unpredictably or rapidly. Cases coded as emergency and performed by a general surgeon were included in the analysis.

Calculating ESS

Patients that did not have any missing data for ESS calculation were excluded from the analysis. Statistical algorithms were created to calculate ESS score for each patient using the demographic data, comorbidities and laboratory values captured in the ACS-NSQIP database. Demographic and comorbidity data were dichotomized, while preoperative laboratory values were classified as low, normal or high based on the cutoffs used in ESS. Variables with missing data were assumed to have the default value; i.e. they were assigned the value that did not increase the final ESS value.

Defining 30-day postoperative morbidity and mortality

The definition of 30-day postoperative morbidity included the presence of one or more of the postoperative complications documented in ACS-NSQIP. These included deep venous thrombosis, pulmonary embolism, superficial, deep, and organ/space surgical site infections, wound dehiscence, pneumonia, unplanned intubation, progressive renal insufficiency, acute renal failure, urinary tract infection, cerebrovascular accident (stroke), cardiac arrest requiring cardiopulmonary resuscitation, myocardial infarction, bleeding necessitating postoperative blood transfusions, sepsis, septic shock, ventilator required for >48 h, coma >24 h, peripheral nerve injury and graft/prosthesis/flap failure. The ACS-NSQIP variable "DOPERTOD" was used to identify patients that died in the 30-days period following the procedure.

Defining need for postoperative ICU level of care

The definition of postoperative need for ICU level of care was based on Kongkaewpaisan et al. and included presence of any of the following: 30-day mortality, unplanned intubation, postoperative ventilator requirement >48 h, cardiac arrest requiring cardiopulmonary resuscitation, septic shock, and coma >24 h.[19] This definition was derived from a panel of 6 board-certified surgical critical care experts that reviewed all the postoperative complication included in ACS-NSQIP.

ESS versus 30-day morbidity, mortality, and postoperative ICU level of care

We assessed the ability of ESS to accurately predict 30-day morbidity, mortality, and postoperative requirement for ICU level of care in patients undergoing an EGS procedure. The receiver operative characteristic curve was computed and the c-statistic [area under the curve (AUROC)] was determined. C-statistic represents the probability that a randomly chosen subject with the studied outcome receives a higher score than a randomly chosen subject without the studied outcome (30-day complications or mortality).[24] Multivariable regression models were constructed to assess which of the variables included in ESS calculation are independent predictors of morbidity and mortality in this subset of patients with missing variables.

Sensitivity analyses

As a sensitivity analysis, we first conducted the same analysis for the patients missing a maximum of 4 ESS variables and subsequently for the patients that had a minimum of 5 ESS variables missing. We decided to choose 4 variables as the cut-off for this analysis, since the vast majority of EGS patients included in ACS-NSQIP were missing up to 4 variables. To quantify the impact of missing variables on AUROC, we then repeated the same analysis in the ACS-NSQIP subset of patients with no missing variables assuming that the 5 most common missing variables were indeed not available, simultaneously (i.e. the 5 most common variables turned into missing for all these patients).

Statistical analyses

The variables are presented using frequencies and percentages. All statistical analysis was performed by using the Stata v15.1 (StataCorp 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

Ethical oversight

The institutional review board (IRB) at our institution waived permission as this is a deidentified national database.

Table 1
Emergency general surgery procedures performed in the patients included in our analysis.

Procedure	Number of patients (%)
Laparoscopic appendectomy	119,210 (46.5%)
Open appendectomy	17,225 (6.7%)
Laparoscopic cholecystectomy	20,087 (7.8%)
Open cholecystectomy	2,091 (0.8%)
Colectomy	25,347 (9.9%)
Hernia repair	15,700 (6.1%)
Small bowel resection	10,216 (4.0%)
Lysis of adhesions	7,450 (2.9%)
Drainage of abscess/hematoma/fluid collections	6,550 (2.5%)
Gastrointestinal tract perforation	4,562 (1.8%)
Exploratory laparotomy	4,535 (1.8%)
Debridement of soft tissues	2,797 (1.1%)
Volvulus/Internal hernia	1,308 (0.5%)
Breast surgery	839 (0.3%)
Miscellaneous	18,687 (7.3%)

Table 2
Preoperative characteristics of patients with missing data.

Variables	Points	Number of patients (%)
Demographics		
Age > 60 years	2	67,252 (26.2%)
White race	1	171,742 (67.0%)
Transfer status		
Outside emergency department	1	10,909 (4.3%)
Acute care hospital inpatient facility	1	8,271 (3.2%)
Comorbidities		
Ascites	1	3,888 (1.5%)
BMI < 20 kg/m^2	1	28,907 (11.3%)
Disseminated cancer	3	3,811 (1.5%)
Dyspnea	1	10,591 (4.1%)
Functional dependence	1	12,786 (5.0%)
History of COPD	1	8,680 (3.4%)
Hypertension	1	70,684 (27.6%)
Steroid use	1	7,357 (2.8%)
Ventilator requirement within 48 h preoperatively	3	4,378 (1.7%)
Weight loss > 10% in the preceding 6 months	1	3,271 (1.3%)
Laboratory values		
Albumin <3.0 U/L	1	16,593 (6.5%)
Alkaline phosphatase > 125 U/L	1	18,115 (7.1%)
Blood urea nitrogen > 40 mg/dL	1	9,281 (3.6%)
Creatinine > 1.2 mg/dL	2	30,204 (11.8%)
International normalized ratio > 1.5	1	5,283 (2.1%)
Platelets < 150 × 10^3/μL	1	16,193 (6.3%)
SGOT > 40 U/L	1	23,336 (9.1%)
Sodium > 145 mmol/L	1	2,380 (0.9%)
WBC 10^3/μL		
<4.5	1	6,413 (2.5%)
>15 and ≤ 25	1	64,884 (25.3%)
>25	2	5,482 (2.1%)

Results

Out of a total of 4,456,809 patients, 359,849 underwent an EGS, and of those 256,278 (71.2%) patients had at least one missing data point for the calculation of ESS, thus meeting our inclusion criteria. The most common procedures performed in the patients included in our analysis are summarized in Table 1. The 5 variables that were most often missing were preoperative INR (192,140 patients), preoperative albumin (97,153 patients), preoperative SGOT (73,268 patients), preoperative ALP (66,590 patients) and race (50,782 patients). The range of number of missing variables was 1–12, with 91% of patients missing 1–4 variables. The mean age of the population was 47 years, 48% were males and 67% were white (Table 2). The vast majority (98%) of patients had an ESS less than 10 and only 21 patients had a score from 19 to 22 (Fig. 1). No patients had an ESS higher than 22. Briefly, higher ESS was associated with worse clinical outcomes in EGS patients with missing at least one data element used in its calculation.

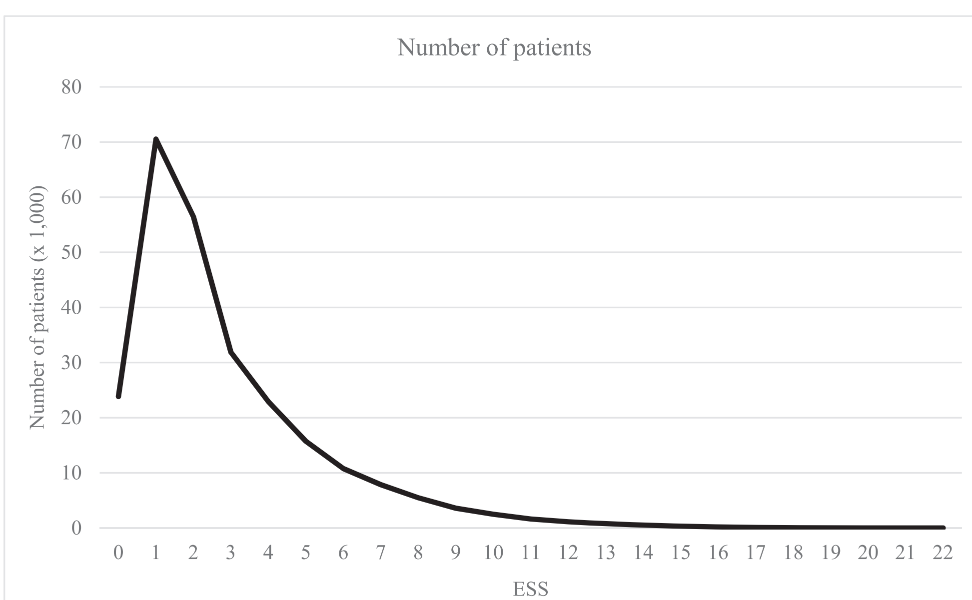

Fig. 1. Number of patients in each ESS score group.

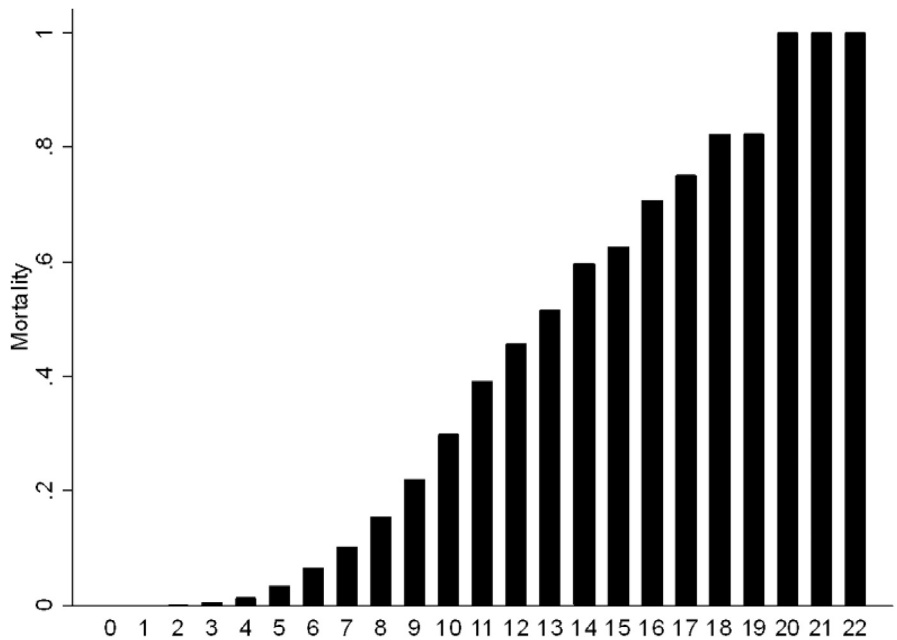

Fig. 2. The ESS score versus mortality.

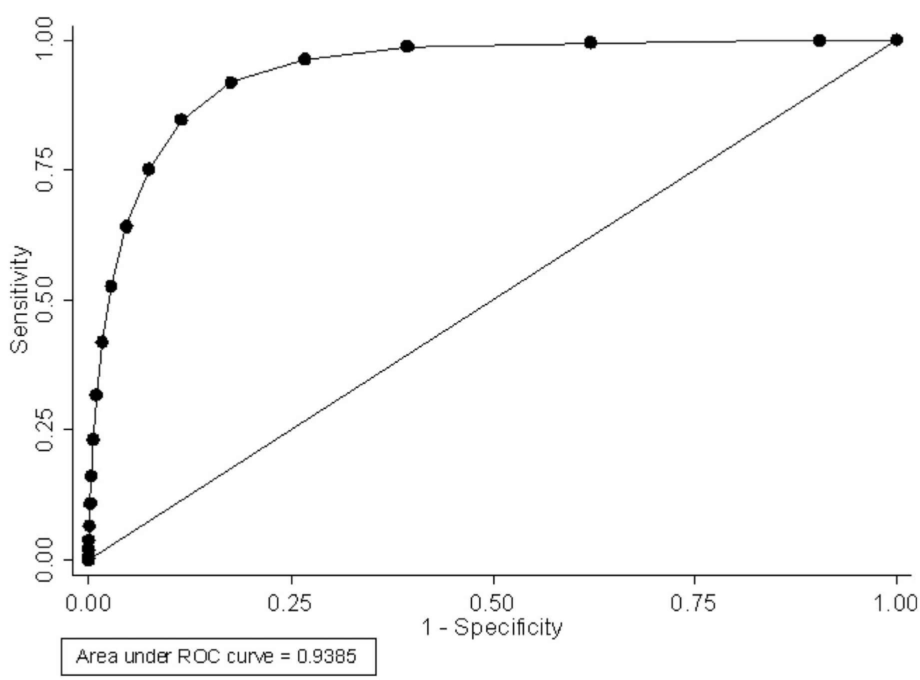

Fig. 3. Receiver operative characteristic (ROC) curves for the Emergency Surgery Score (ESS) versus 30-day postoperative mortality.

ESS vs. Mortality

The overall mortality was 2.9%. Fig. 2 shows the association of ESS with mortality in this subset of patients with missing data. Mortality rates steadily and gradually increased with higher ESS and reached 100% in patients with an ESS higher than 20. For example, ESS of 1, 10, 12 and 22 correlated with mortality rates of 0.1%, 30%, 46% and 100%, respectively. The c-statistic for the prediction of postoperative mortality was 0.94 (Fig. 3).

ESS vs. Morbidity

Table 3 shows the incidence of specific complications included in our study definition. Fig. 4 shows the association between ESS and morbidity. In summary, morbidity rates increased in a stepwise fashion as ESS increased from 1 to 12, with a plateau reached in patients with scores higher than 12. For example, ESS of 1, 10, 12 and 22 were associated with morbidity rates of 7%, 73%, 81% and 100%, respectively. The c-statistic for the prediction of

Table 3
Postoperative complication rates.

Postoperative complications	Number of patients (%)
Deep venous thrombosis	1,869 (0.7%)
Pulmonary embolism	876 (0.3%)
Superficial surgical site infections	7,067 (2.8%)
Deep surgical site infections	2,201 (0.9%)
Organ/space surgical site infections	7,005 (2.7%)
Wound dehiscence	1,794 (0.7%)
Pneumonia	6,297 (2.5%)
Unplanned intubation	4,282 (1.7%)
Progressive renal insufficiency	1,043 (0.4%)
Acute renal failure	4,219 (1.7%)
Urinary tract infection	3,522 (1.4%)
Cerebrovascular accident (stroke)	512 (0.2%)
Cardiac arrest requiring cardiopulmonary resuscitation	1,537 (0.6%)
Myocardial infarction	1,187 (0.5%)
Bleeding necessitating postoperative blood transfusions	9,910 (3.9%)
Sepsis	10,406 (4.1%)
Septic shock	7,226 (2.8%)
Ventilator required for >48 h	9,611 (3.8%)
Coma >24 h	196 (0.2%)
Peripheral nerve injury	13 (0.01%)
Graft/prosthesis/flap failure	20 (0.01%)

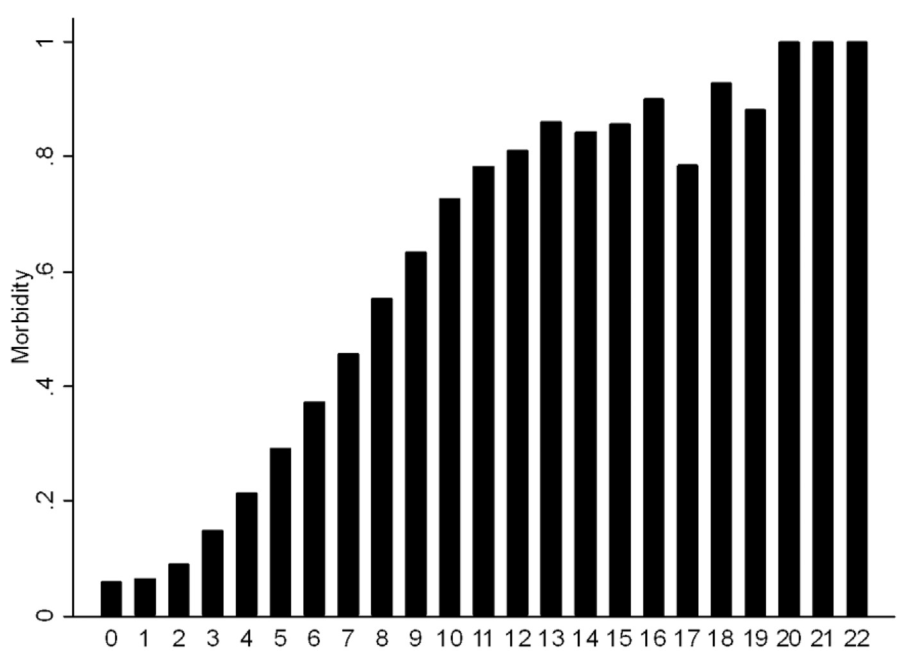

Fig. 4. The ESS score versus morbidity.

postoperative morbidity was 0.77 (Fig. 5).

ESS vs. postoperative need for ICU level of care

Fig. 6 shows the association between ESS and postoperative requirement of ICU level of care. Briefly, rates of postoperative required ICU level of care increased gradually as ESS increased with a plateau reached at scores ≥13. Interestingly, out of the almost 2,000 patients that had an ESS≥13, 1,762 patients (88.2%) had a postoperative event that required ICU level of care. The c-statistic for the prediction of ICU required level of care was 0.91 (Fig. 7).

Multivariable analyses

Tables 4 and 5 summarize the multivariable regression models constructed for mortality and morbidity. In summary, all 22 ESS variables independently predicted mortality, and 21 out of the 22 ESS variables independently predicted morbidity in the subset of EGS patients with missing variables.

Sensitivity analysis

The vast majority of patients included in ACS-NSQIP (91%) undergoing EGS had 1-4 missing ESS variables. Therefore, we

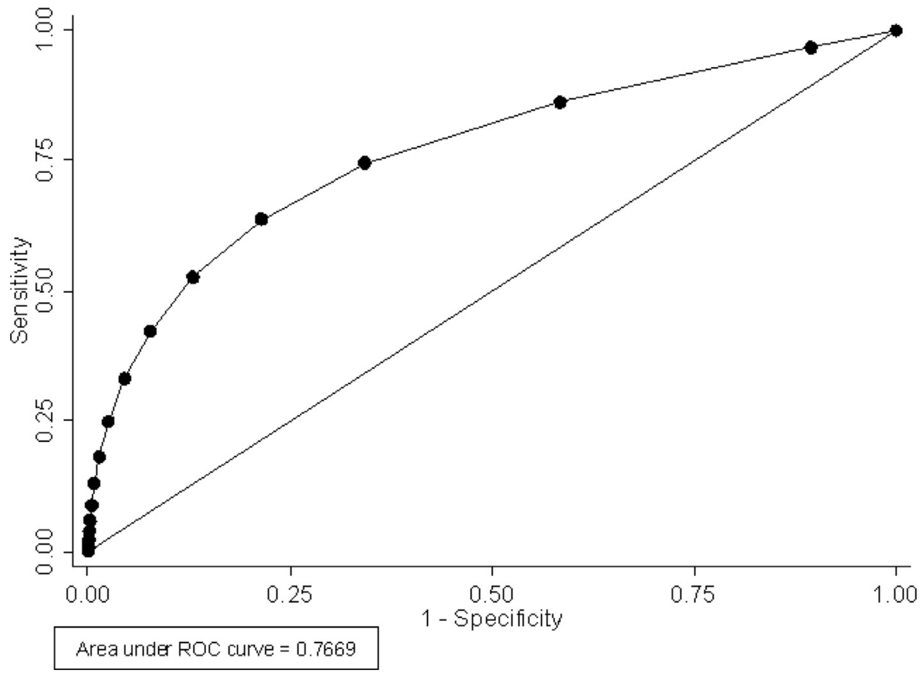

Fig. 5. Receiver operative characteristic (ROC) curves for the Emergency Surgery Score (ESS) versus 30-day postoperative morbidity.

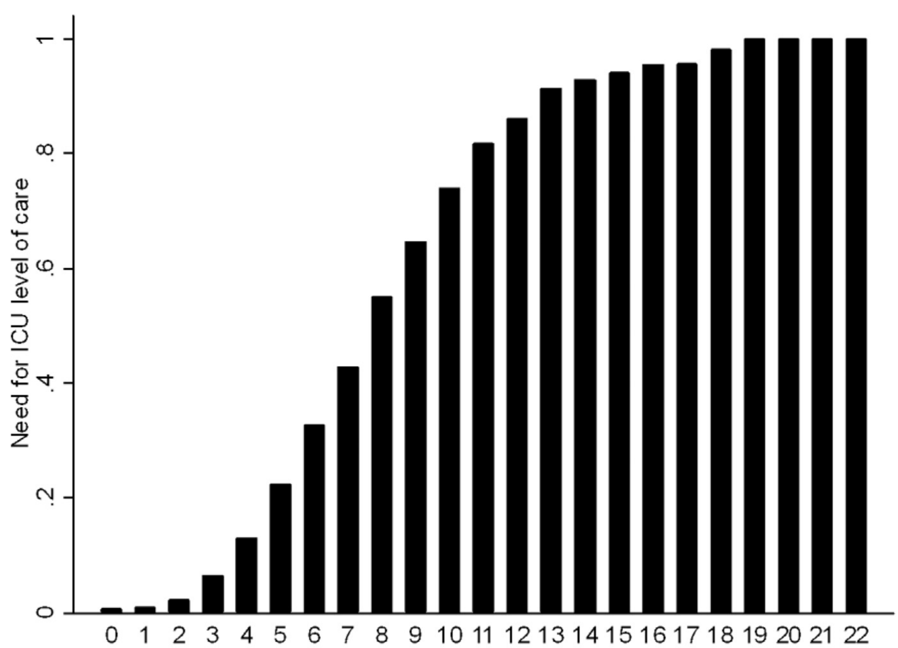

Fig. 6. The ESS score versus need for postoperative ICU level of care.

initially plotted the AUROC curves for patients missing 1–4 variables (n = 232,576) and the c-statistics were nearly unchanged at 0.94, 0.77, and 0.90 for mortality, morbidity, and postoperative requirement for ICU level of care respectively (Fig. 8). Subsequently, we plotted the AUROC curves for patients missing at least 5 variables (n = 23,702) and the c-statistics were 0.93, 0.70, and 0.88 for mortality, morbidity, and postoperative requirement for ICU level of care, respectively.

In the subset of patients that had no missing data (n = 103,571 patients), the 5 most common missing variables (INR, albumin, SGOT, ALP and race) were all considered to be missing simultaneously from all patients (i.e. their value was assumed to be normal; the null value). ESS still correlated very well with mortality (c-statistic = 0.86), morbidity (c-statistic = 0.78), and need for ICU level of care (c-statistic = 0.85), in accordance with its original derivation and validation studies.[15,19]

Discussion

In this study, we demonstrate that ESS can still accurately

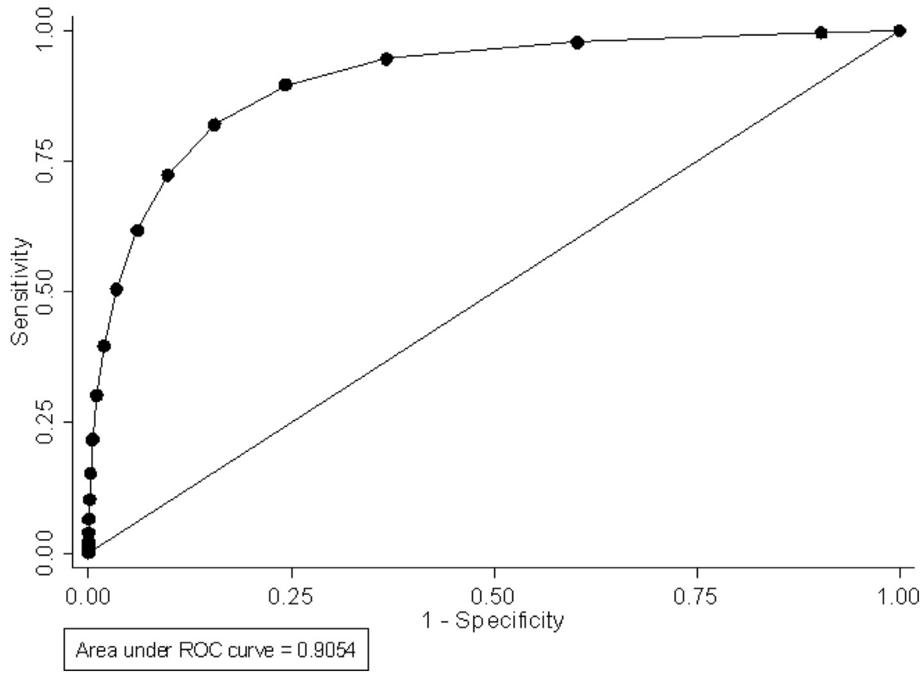

Fig. 7. Receiver operative characteristic (ROC) curves for the Emergency Surgery Score (ESS) versus postoperative requirement for ICU level of care.

Table 4
Multivariable regression model for mortality.

Mortality	Odds Ratio	p-value	95% Confidence Intervals
Age >60 years	4.39	<0.001	4.09–4.70
White	1.17	<0.001	1.10–1.24
Transfer from outside emergency department	1.51	<0.001	1.36–1.68
Transfer from an acute care hospital inpatient facility	1.26	<0.001	1.15–1.39
Ascites	2.35	<0.001	2.11–2.61
BMI <20 kg/m^2	1.69	<0.001	1.57–1.82
Disseminated cancer	3.97	<0.001	3.59–4.40
Dyspnea	1.53	<0.001	1.42–1.65
Functional dependence	2.51	<0.001	2.35–2.68
History of COPD	1.76	<0.001	1.63–1.91
Hypertension	1.38	<0.001	1.30–1.47
Steroid use	1.59	<0.001	1.44–1.74
Ventilator requirement within 48 h preoperatively	4.08	<0.001	3.73–4.46
Weight loss >10% in the preceding 6 months	2.16	<0.001	1.92–2.43
Albumin <3.0 U/L	2.15	<0.001	2.01–2.29
Alkaline phosphatase >125 U/L	1.42	<0.001	1.32–1.53
Blood urea nitrogen >40 mg/dL	1.72	<0.001	1.59–1.86
Creatinine >1.2 mg/dL	2.57	<0.001	2.41–2.75
International normalized ratio >1.5	2.68	<0.001	2.46–2.92
Platelets <150 × 10^3/μL	1.51	<0.001	1.41–1.63
SGOT >40 U/L	1.45	<0.001	1.34–1.56
Sodium >145 mmol/L	1.87	<0.001	1.63–2.14
WBC <4.5 10^3/μL	1.96	<0.001	1.76–2.18
WBC >15 and ≤ 25,10^3/μL	1.15	<0.001	1.07–1.23
WBC >25,10^3/μL	1.78	<0.001	1.60–1.98

predict postoperative morbidity, mortality, and requirement for ICU level of care in EGS patients with missing variables, if all missing data points are replaced with the null value. In other words, when a real-life patient does not have all the data elements needed to calculate ESS, as a result of bedside clinical judgment, limited resources or simply the urgency of the clinical situation, assuming that these missing data points are null is safe and does not negatively impact the accuracy of ESS. The c-statistics for morbidity and mortality documented in this analysis were even higher than the original derivation and validation study of ESS (c-statistic of 0.78 and 0.86 for morbidity and mortality, respectively), likely due to the higher number of patients included.[15,16] Furthermore, the multivariable regression models constructed confirmed that ESS's predictive value is not based on a few select variables driving the association with morbidity and mortality, but all of them.

The shared surgical decision-making model requires that both the patients and the surgeons have a reasonable understanding and judgment of the potential postoperative risks and alternatives. In the literature, the existing risk scoring systems commonly focus on certain procedures or elective surgery.[25,26] Such systems (e.g. American Society of Anesthesiologists, ACS

Table 5
Multivariable regression model for morbidity.

Morbidity	Odds Ratio	p-value	95% Confidence Intervals
Age >60 years	1.86	<0.001	1.81–1.91
White	0.86	<0.001	0.84–0.88
Transfer from outside emergency department	1.52	<0.001	1.45–1.60
Transfer from an acute care hospital inpatient facility	1.76	<0.001	1.67–1.87
Ascites	1.68	<0.001	1.55–1.82
BMI <20 kg/m^2	1.03	0.071	1.00–1.07
Disseminated cancer	2.08	<0.001	1.93–2.24
Dyspnea	1.44	<0.001	1.37–1.51
Functional dependence	2.01	<0.001	1.92–2.10
History of COPD	1.70	<0.001	1.61–1.79
Hypertension	1.45	<0.001	1.41–1.49
Steroid use	1.76	<0.001	1.66–1.86
Ventilator requirement within 48 h preoperatively	4.44	<0.001	4.03–4.89
Weight loss >10% in the preceding 6 months	1.91	<0.001	1.76–2.08
Albumin <3.0 U/L	2.70	<0.001	2.59–2.81
Alkaline phosphatase >125 U/L	1.29	<0.001	1.24–1.35
Blood urea nitrogen >40 mg/dL	2.21	<0.001	2.09–2.33
Creatinine >1.2 mg/dL	1.96	<0.001	1.90–2.03
International normalized ratio >1.5	1.94	<0.001	1.80–2.08
Platelets <150 × 10^3/μL	1.17	<0.001	1.12–1.23
SGOT >40 U/L	1.04	0.038	1.01–1.09
Sodium >145 mmol/L	1.55	<0.001	1.40–1.73
WBC <4.5 10^3/μL	1.93	<0.001	1.81–2.05
WBC >15 and ≤ 25,10^3/μL	1.41	<0.001	1.38–1.45
WBC >25,10^3/μL	2.91	<0.001	2.72–3.11

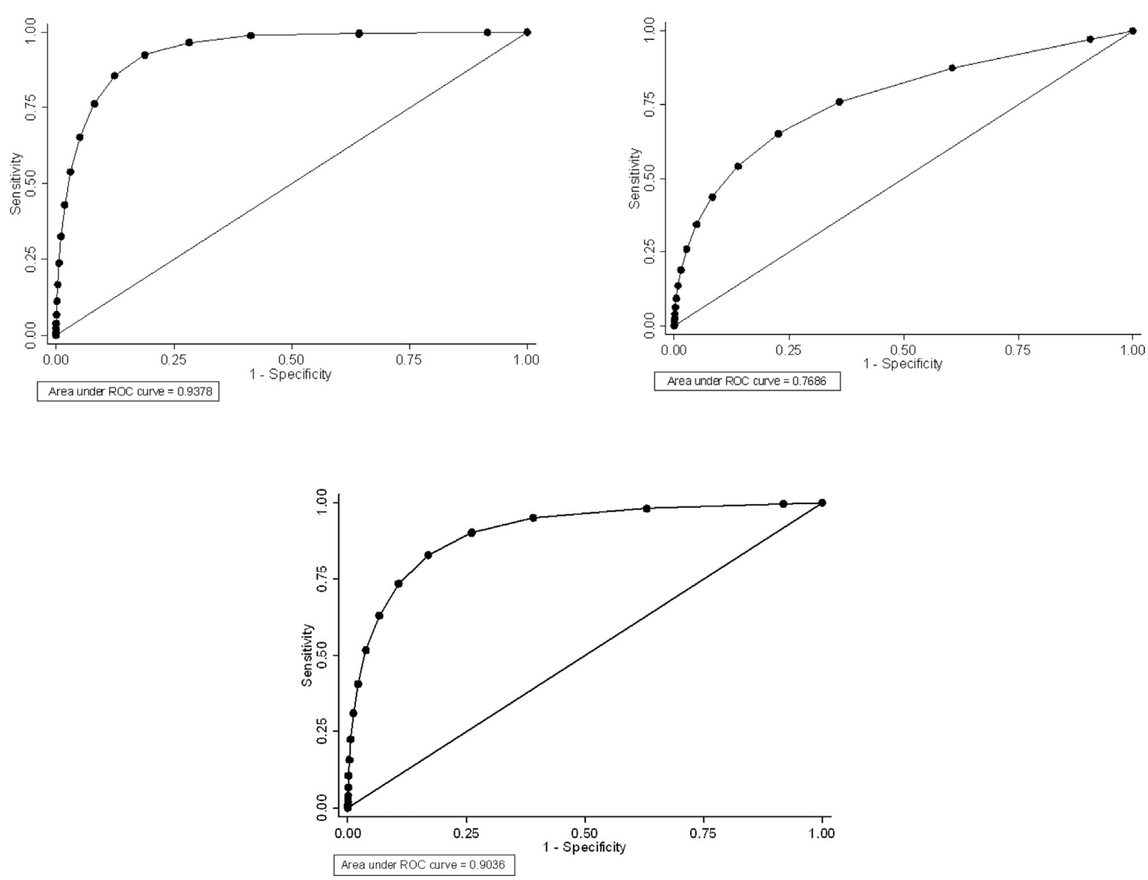

Fig. 8. Receiver operative characteristic (ROC) curves for the Emergency Surgery Score (ESS) versus 30-day postoperative mortality, morbidity, and postoperative requirement for ICU level of care in patients with 1–4 missing variables.

colorectal surgery risk calculator, APACHE, P-POSSUM, SORT and the Surgical Risk Scale) have been shown to predict morbidity and mortality in select groups of hospitalized patients but most fail to account for the disease acuity at presentation, a major factor that affects outcome in EGS patients.[27–30] Specifically, patients undergoing an emergency procedure often have an altered disease pathophysiology that drives the increase in postoperative morbidity and mortality, when compared to patients undergoing an elective procedure.[9–13] ESS's focus on emergency surgery is still its major strength and what makes it stand out from all other risk calculators: it is derived from and for EGS patients.

The ACS-NSQIP Surgical Risk Calculator has contradictory results in patients undergoing different surgical procedures, with Golden et al. showing that its performance (c-statistic) in predicting post-operative morbidity and mortality in the acute care surgery setting is reasonable but falls short of ESS performance.[31–36] As importantly, the ACS-NSQIP Surgical Risk Calculator fails to account for the different impact of different risk factors on outcome in the elective vs. emergent setting.[37]

The Centers for Medicare and Medicaid Services are taking steps towards "outcome-based funding".[38] As such, deriving accurate risk-prediction tools specific for EGS, such as ESS, is crucial for acute care surgeons across the country. Otherwise, if the care of EGS is lumped with the elective surgery practice, we risk penalizing clinically and financially the surgeons that take care of the highest risk patients, specifically acute care surgeons. This can subsequently provide a perverse incentive for some to avoid the care of these patients who need care the most, by encouraging cherry-picking and transfer of the higher-risk patients to other hospitals. Our data provides additional strong evidence of the usefulness of ESS in risk modeling and benchmarking the quality of care of the EGS patient. Similarly, recent efforts using artificial intelligence and machine learning techniques, such as the "Predictive OpTimal Trees in Emergency Surgery Risk" (POTTER) calculator, are promising in providing even more advanced tools for risk prediction in EGS.[39]

Our study has a few limitations. First, it is a retrospective analysis of a prospectively collected national database. Second, the definition of EGS was based on the variables coded in ACS-NSQIP that are subject to documentation error and differ from the American Association for the Surgery of Trauma (AAST) definition of emergency surgery. Third, preoperative data collected and reported by ACS-NSQIP do not cover all potentially residual confounders that may affect clinical outcomes.

Conclusions

Our study suggests that ESS performs well in predicting morbidity, mortality, and need for postoperative requirement of ICU level of care in EGS patients with missing data elements, and thus maintains its value as a bedside tool for counseling EGS patients and families, as well as for benchmarking quality of care. Assuming the missing data elements are null (thus adding no extra points to the ESS calculation) is safe and does not affect the accuracy of ESS in predicting the outcome of the EGS patient.

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Disclosure

We have no disclosures.

Declaration of competing interest

We have no conflicts of interest to report.

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None.

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