Original Article

An esophagectomy surgical Apgar score-based nomogram—a risk-based postoperative triage system: a phase II randomised trial

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Background: The esophagectomy surgical Apgar score (eSAS) has been found to be a predictor of postoperative complications in esophagectomy. In our previous study, we built a graphic nomogram based on eSAS and demonstrated that it can effectively predict the risk of major morbidity after esophagectomy. In this study, we aimed to assess the benefits of using an eSAS-based nomogram model as a postoperative risk-based triage system for patients undergoing esophagectomy.

Methods: We enrolled 119 patients diagnosed with esophageal carcinoma and randomly assigned them to a nomogram group (NG) or control group (CG) from January 2019 to December 2020. Patients in the NG were assigned to a low-risk group and high-risk group based on the nomogram. Patients in the high-risk group were admitted to the intensive care unit (ICU) after esophagectomy. Risk estimation in the CG patients was based on the surgeon's clinical experience. Thirty-day major complications, postoperative hospital stay, hospital costs, and quality of life (QOL) during the follow-up were compared between the two groups.

Results: Baseline clinicopathological characteristics were comparable between the NG (n=58) and CG (n=61). All patients underwent esophagectomy. Postoperative complications were significantly higher in the CG (30, 49.2%) than in the NG (14, 24.1%) (P=0.008), with pneumonia being the most common (CG: 23, 37.7%; NG: 12, 20.7%; P=0.042). There was no significant difference in anastomotic leakage (NG: 1, 1.7%; CG: 6, 9.8%; P=0.12). Postoperative median hospital stay was shorter in the NG (14 days) than in the CG (16 days) (P=0.041). Hospital costs (NG: ¥60,045.1; CG: ¥63,961.5; P=0.21) and postoperative QOL did not differ significantly between groups.

Conclusions: An eSAS-based nomogram as a triage system can reduce the overall occurrence of postoperative complications and shorten postoperative hospital stay without increasing hospital costs.

Trial Registration: Chinese Clinical Trial Registry ChiCTR1900021636.

Keywords: Esophagectomy surgical Apgar score-based nomogram (eSAS-based nomogram); esophagectomy; postoperative triage; intensive care unit admission (ICU admission); postoperative complications

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Introduction

Esophageal cancer ranks as the seventh leading cause of cancer-related death worldwide, with China experiencing a particularly high incidence and mortality rate (1). Currently, despite advancements in surgical techniques such as minimally invasive surgery and perioperative care, the morbidity rate after esophagectomy remains high, impacting patients' postoperative quality of life (QOL) (2).

Previously, the reliability of many risk factors in risk prediction models for postoperative complications was limited (3). Given that surgical invasiveness greatly influences short-term morbidity, the surgical Apgar score (SAS) system, which contains three intraoperative factors, including the lowest heart rate (HR), lowest mean arterial pressure (MAP), and estimated blood loss (EBL), was developed by Gawande in 2007 as a simple and objective scoring system (4) and first used in an esophagectomy SAS (eSAS) by Janowak and colleagues in 2015 (5). Several studies have shown that eSAS can predict major postoperative complications after esophagectomy (6,7). In our previous retrospective study, we identified body mass index (BMI), American Society of Anesthesiologists (ASA) classification, diabetes mellitus, and eSAS to be powerful risk predictors in multivariable regression analysis, which is consistent with other recent research (8). Based on these factors, a graphic eSAS-based nomogram was built (*Figure 1*) (9), which can effectively predict the risk of major morbidity after esophagectomy, with an area under the receiver operating characteristics curve higher than 0.9 for both internal and external validation (9).

Highlight box

Key findings

- There were significantly fewer major complications and shorter postoperative hospital length of stay in the nomogram group compared with the control group.

What is known and what is new?

- The esophagectomy surgical Apgar score (eSAS) is a powerful predictor of postoperative complications in esophagectomy.
- The eSAS-based nomogram as a triage tool can reduce the overall occurrence of postoperative complications and shorten postoperative hospital stay without increasing hospital costs.

What is the implication, and what should change now?

- Risk-based triage and postoperative care modification based on our nomogram can improve the perioperative outcome and can be used in clinical practice.

Admission to the intensive care unit (ICU) following surgery is often considered a crucial element of a safe and effective protocol for preventing, promptly identifying, and managing life-threatening complications that may arise immediately after the operation (10). However, in the current Chinese healthcare system, some patients after esophagectomy can only return to the general ward due to shortage of the beds in the ICU. It is known that selective ICU admission after major surgery reduces short-term mortality and morbidity, particularly for complex procedures with prolonged operating time (5,11). Nonetheless, postoperative ICU admission may negatively impact postoperative hospital length of stay and costs (12). Janowak *et al.* reported that hospital resources and cost can be saved by sending low-risk patients to the ward after surgery (5). Moreover, high-risk patients undergoing esophagectomy may fail to be identified as ICU candidates, leading to potential complications. Hence, the accurate identification of high-risk patients and implementing personalized postoperative triage are a critical need. Owing to its high precision demonstrated in our previous study, our nomogram system was considered to be a practically powerful risk-based postoperative triage tool with the potential to provide perioperative benefits to patients.

In this study, we conducted a randomized controlled trial to assess the potential benefits of implementing an eSAS-based nomogram model as a postoperative triage system following esophagectomy. The outcomes evaluated included postoperative complications, length of hospital stay, hospital costs, and patients' QOL after esophagectomy. We present this article in accordance with the CONSORT reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-451/rc).

Methods

Ethical statement

This study was approved by the Ethics Committee of Ningbo Medical Center, Lihuili Hospital on January 16, 2019 (No. DYLL2018075). Written informed consent was obtained from each patient. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Study design and participants

This study was an open, randomized, stratified, two-arm,

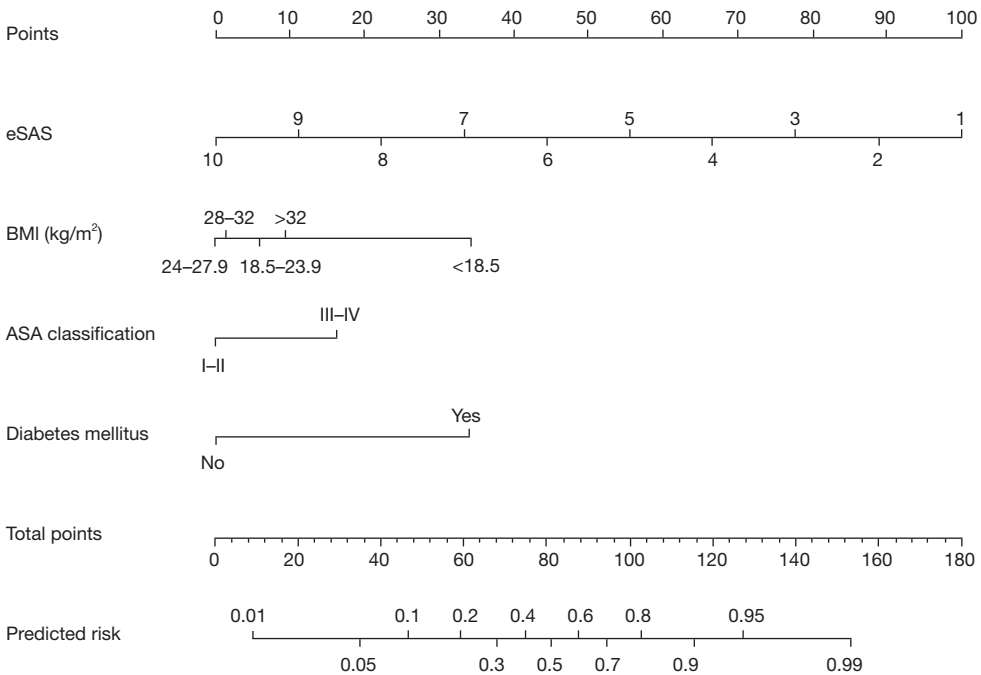

Figure 1 The graphic eSAS-based nomogram. eSAS, esophagectomy surgical Apgar score; BMI, body mass index; ASA, American Society of Anesthesiologists.

single-center phase II clinical trial conducted at Ningbo Medical Center, Lihuili Hospital, beginning in January 2019.

The inclusion criteria for patients were the following: (I) pathology-confirmed esophageal carcinoma; (II) an age of 40–75 years, an Eastern Cooperative Oncology Group performance status 0–1, and an estimated survival ≥12 months; (III) no major organ dysfunction (the requirements for inclusion in laboratory testing are presented in Appendix 1); and (IV) the ability to understand this study and provide informed consent.

Meanwhile, the exclusion criteria were the following: pregnancy or lactation; heart, lung, liver, or kidney insufficiency; severe comorbidities; inability to tolerate surgery; and uncontrolled mental illness.

Routine examinations and assessments required for this study are detailed in the supplementary text (Appendix 1). Patients were staged according to the eighth edition of the International Union Against Cancer (UICC) tumor-node-metastasis (TNM) classification system (13).

Randomization and masking

Patients were randomly assigned to either a nomogram group (NG) or a control group (CG) upon registration, with stratification based on age and clinical TNM stage. Random assignment was performed following simple randomization procedures (computerized random numbers) at the Ningbo Medical Center Lihuili Hospital Clinical Trial Center. Investigators at Ningbo Medical Center, Lihuili Hospital enrolled participants. The researcher transferred a card containing the patient's age, clinical TNM stage, and hospitalization number to a separate statistician. This statistician, with no prior patient interaction and no knowledge of the patients' remaining baseline characteristics, allocated the patients to their respective groups based on the generated results. There was no blinding for investigators or patients after final allocation decision was made.

In this phase II clinical trial, we employed a flexible sample size approach. Interim analyses were conducted during the trial to estimate the effect size based on the accumulated data. We continuously calculated the statistical power, and once it reached the desired level of 80%, we made the decision to stop enrolling additional patients.

Procedure

Preoperative characteristics of patients were collected. All

Table 1 eSAS

Intraoperative factors	0 point	1 point	2 points	3 points	4 points
EBL (mL)	>450	301–450	191–300	≤190	–
Lowest MAP (mmHg)	<40	40–54	55–69	≥70	–
Lowest HR (beats/minute)	>85	76–85	66–75	56–65	≤55

Cited from our previous study (9). eSAS, esophagectomy surgical Apgar score; EBL, estimated blood loss; MAP, mean arterial pressure; HR, heart rate.

patients underwent esophagectomy. Surgical techniques included Ivor Lewis esophagectomy and McKeown esophagectomy, performed through open esophagectomy (OE), hybrid thoracotomy and laparoscopy (TT + LS) and hybrid thoracoscopy and laparotomy (TS + LT), or minimally invasive esophagectomy (MIE) (laparoscopy and thoracoscopy). The intraoperative data collected were the following: lowest HR, lowest MAP, and EBL. The EBL values were categorized into quartiles based on our previous study and consistently applied in this study (*Table 1*) (9).

For the NG patients, eSAS was calculated immediately after the surgery was completed, and the nomogram score was calculated before patients left the operating room. Based on our previous study, we used 60 points as the cutoff value to categorize patients into high- and low-risk groups (9). Patients at high risk for postoperative complications were admitted to the ICU immediately, and low risk patients returned to the ward for grade I nursing treatment. Decision to send patients to the ICU or to the ward in the CG was based on the surgeon's empirical assessment of the patient's condition (*Figure 2*).

Patients were managed based on the specific strategy for esophageal cancer in the intensive care department, which included the following: (I) respiratory support; (II) circulation hemodynamic management; (III) strict blood glucose management; (IV) nutritional support; (V) daily chest X-ray and B-ultrasound examinations; and (VI) prophylactic use of antibiotics and acid suppression therapy.

Patients admitted to the ward were managed according to the standard clinical pathway for esophageal cancer surgery in China. In the ward, real-time monitoring of inflammatory markers and bedside chest X-rays are limited, and bronchoscopy suction is rarely performed. Additionally, invasive methods for hemodynamic monitoring are not feasible. Moreover, systematic rounds by ICU physicians, each nurse assigned to 1–2 patients, are achievable in the ICU, a practice not feasible in regular wards.

The Chinese Society of Clinical Oncology (CSCO) Esophageal Cancer Diagnosis and Treatment Guidelines 2019 recommend eligible hospitals conduct preoperative neoadjuvant treatments for esophageal cancer. However, in various towns across China, patients have shown low acceptance and compliance toward delaying surgery for neoadjuvant treatments. Thus, considering the medical context at the time, patients who did not undergo neoadjuvant therapy as per the guidelines were not excluded.

Patients with advanced pathological stage (T3–4 or N1–3) are candidates for adjuvant therapy involving chemotherapy and radiotherapy. Typically, the course is initiated 4 weeks postesophagectomy and modified according to the patient's physical condition, routine blood tests, and biochemical test results.

All patients were followed up at 3 months, 6 months, and 1 year after surgery. If recurrence was detected, the patient underwent appropriate treatment, such as chemotherapy, immunotherapy, mediastinal lymph node-directed radiotherapy, and potentially intracranial Gamma Knife therapy.

Outcomes

The primary endpoint was 30-day major complications. Postoperative events were those defined by the Esophagectomy Complications Consensus Group (ECCG) guidelines (14). Postoperative 30-day major morbidity was determined based on the Society of Thoracic Surgeons General Thoracic Surgery Database (STS GTSD) risk models (15,16). Additional complications not meeting the STS GTSD risk model definitions for major complications were reevaluated according to the Clavien classification (17). Complications classified as Clavien-Dindo grade III or above were also considered major. Postoperative pneumonia was diagnosed through routine blood tests and imaging, specifically chest X-rays or computed tomography (CT) scans (18).

Secondary endpoints were postoperative length of

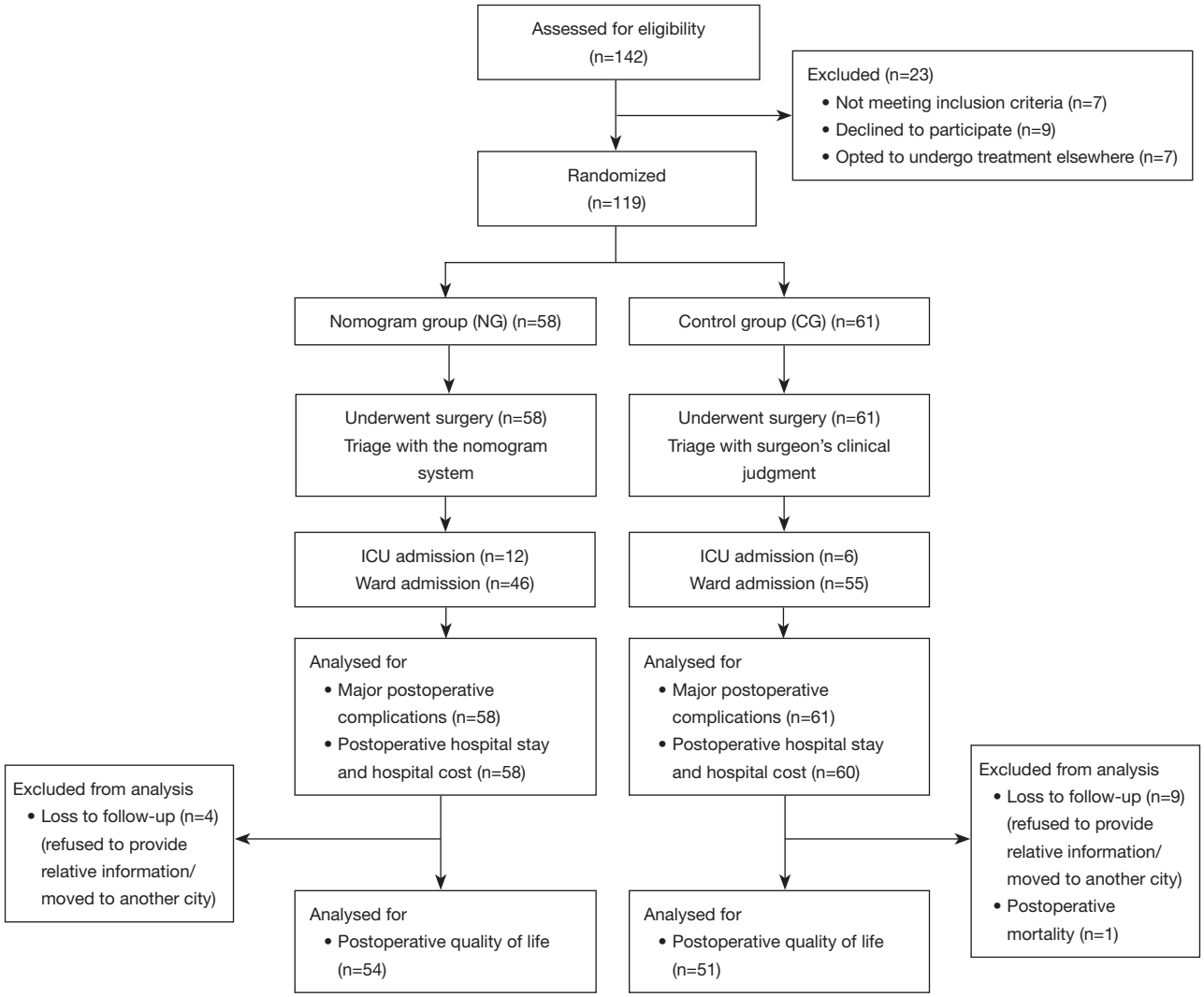

Figure 2 CONSORT diagram. ICU, intensive care unit.

hospital stay, hospital cost, and QOL. Postoperative length of hospital stay was defined as the duration from surgery to discharge. Costs were assessed after discharge. QOL assessment was completed using the Quality of Life Questionnaire (QLQ)-C30 and QLQ-OES18. The QLQ-C30 (19), a comprehensive 30-item questionnaire, can capture various dimensions of QOL, and combining the QLQ-ESO18 with the QLQ-C30 has been recommended for patients with esophageal cancer (20). The items in these two questionnaires are detailed in Table S1. Patients completed preoperative and 6-month postoperative questionnaires via mail, in-person visit, or outpatient consultation in the evaluation of QOL.

Statistical analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Categorical variables were compared using the chi-squared and Fisher exact tests. Additionally, multivariate regression analysis was conducted to account for potential confounding factors, including surgical methods. Continuous variables were compared using the *t*-test. A P value <0.05 was considered statistically significant. QOL scores were transformed to a linear scale [0–100] according to the European Organization for Research and Treatment of Cancer Scoring Manual. Higher scores in global QOL and physical function indicated better

QOL, while higher scores in symptom categories (e.g., fatigue, pain) indicated lower QOL. We used a generalized estimating equation to perform the longitudinal data analysis and determine the effective impact of correlative factors on postoperative QOL. The analysis of QOL was completed using R v. 3.0.1 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Patients

From January 2019 to December 2020, a total of 142 patients were assessed for eligibility. Among them, seven did not meet the criteria, nine declined enrollment, and seven chose not to undergo treatment at our center. Thus, 119 patients were enrolled and randomly allocated to the NG (n=58) and CG (n=61) (*Figure 2*). The baseline clinical characteristics are summarized in *Table 2*. The final statistical power was 82.02%.

Patients were followed up at 3, 6, and 12 months from March 2019 to January 2022 as per the study's design. Contact was lost with 13 patients during follow-up. The 119 patients were analyzed for primary endpoint (major postoperative complications) and 118 (one postoperative mortality) for the two secondary endpoints (postoperative length hospital stay and hospital cost). Postoperative QOL assessment was not completed in 14 patients due loss to follow-up and postoperative mortality (*Figure 2*).

Table 2 Patients' characteristics

Variables	NG (n=58)	CG (n=61)	P value
Age (years), mean	63.57	63.92	0.80
Age, n (%)			0.87
≤60 years	17 (29.3)	16 (26.2)	
>60 years	41 (70.7)	45 (73.8)	
Sex, n (%)			0.43
Male	54 (93.1)	59 (96.7)	
Female	4 (6.9)	2 (3.3)	
ASA classification, n (%)			0.97
I	4 (6.9)	5 (8.2)	
II	54 (93.1)	55 (90.2)	
III or IV	0 (0.0)	1 (1.6)	
BMI (kg/m^2), mean	22.21	22.26	0.92
Abdominal or chest operation history, n (%)	8 (13.8)	9 (14.8)	>0.99
Comorbid disease, n (%)			
Pulmonary disease	5 (8.6)	3 (4.9)	0.48
Cardiovascular disease	23 (39.7)	24 (39.3)	0.97
Chronic renal disease	0 (0.0)	1 (1.6)	>0.99
Chronic liver disease	2 (3.4)	1 (1.6)	0.61
Diabetes mellitus	4 (6.9)	7 (11.5)	0.53
Smoking	40 (69.0)	39 (63.9)	0.56
Alcohol	33 (56.9)	39 (63.9)	0.43
Neoadjuvant therapy (CRT or CT)	10 (17.2)	7 (11.5)	0.53

Table 2 (*continued*)

Table 2 (*continued*)

Variables	NG (n=58)	CG (n=61)	P value
Tumor location, n (%)			0.93
Proximal	6 (10.3)	7 (11.5)	
Middle	34 (58.6)	37 (60.7)	
Lower	18 (31.0)	17 (27.9)	
Clinical stage T, n (%)			0.98
T1	12 (20.7)	10 (16.4)	
T2	9 (15.5)	10 (16.4)	
T3	36 (62.1)	39 (63.9)	
T4	1 (1.7)	2 (3.3)	
Clinical stage N, n (%)			0.85
N0	40 (69.0)	38 (62.3)	
N1	15 (25.9)	19 (31.1)	
N2	2 (3.4)	2 (3.3)	
N3	1 (1.7)	2 (3.3)	
Surgical approach, n (%)			0.90
HYB TT + LS	5 (8.6)	4 (6.6)	
HYB TS + LT	3 (5.2)	5 (8.2)	
MIE	41 (70.7)	42 (68.9)	
OE	9 (15.5)	10 (16.4)	
Operation duration (min), mean	352.7	365.7	0.60
Operation duration, n (%)			0.83
≤5 h	17 (29.3)	20 (32.8)	
>5 h	41 (70.7)	41 (67.2)	
Tumor histology, n (%)			0.20
Squamous cell carcinoma	56 (96.6)	56 (91.8)	
Adenocarcinoma	1 (1.7)	4 (6.6)	
Other type	1 (1.7)	1 (1.6)	

NG, nomogram group; CG, control group; ASA, American Society of Anesthesiologists; BMI, body mass index; CRT, chemoradiotherapy; CT, chemotherapy; HYB TT + LS, hybrid thoracotomy and laparoscopy; HYB TS + LT, hybrid thoracoscopy and laparotomy; MIE, minimally invasive esophagectomy; OE, open esophagectomy.

Surgical outcomes

Surgery was predominantly MIE (5 Ivor Lewis and 78 McKeown). In the NG, the distribution of procedures was as follows: 41 (70.9%) MIE (3 Ivor Lewis and 38 McKeown), 3 (5.2%) hybrid TS + LT, and 5 (8.6%) hybrid TT + LS; meanwhile, the distribution in the CG was as follows: 42 (68.9%) MIE (2 Ivor Lewis and 40 McKeown), 5 (8.2%) hybrid TS + LT, and 4 (6.6%) hybrid TT + LS. A minority of patients received OE, with 9 (15.5%) and 10 (16.4%) of these procedures occurring in the NG and CG, respectively (*Table 2*). In the NG, the nomogram score was calculated immediately after surgery, the results of which

Table 3 Items for calculating the nomogram score in the NG (n=58)

Variables	Value
BMI (kg/m^2), mean (95% CI)	22.21 (21.50–22.92)
ASA classification, n (%)	
I	4 (6.9)
II	54 (93.1)
III or IV	0 (0.0)
Diabetes mellitus, n (%)	4 (6.9)
EBL (mL), median [25%, 75%]	100 [100, 200]
Lowest MAP (mmHg), mean (SD)	68.34 (6.61)
Lowest HR (beats/minute), mean (SD)	60.59 (10.70)
eSAS score, mean (SD)	7.90 (1.44)
Nomogram score, median [25%, 75%]	33.1 [18.0, 51.0]

NG, nomogram group; BMI, body mass index; CI, confidence interval; ASA, American Society of Anesthesiologists; EBL, estimated blood loss; MAP, mean arterial pressure; SD, standard deviation; HR, heart rate; eSAS, esophagectomy surgical Apgar score.

are summarized in *Table 3*. Moreover, 12 patients in the NG and 6 in CG were admitted to the ICU immediately after surgery.

Major postoperative complications

A total of 46 patients experienced major postoperative complications. Significantly fewer complications occurred in the NG compared to the CG, with 14 (24.1%) and 30 (49.2%) complications, respectively (P=0.008). Anastomotic leakage was less frequent in the NG (1, 1.7%) than in the CG (6, 9.8%) (P=0.12). Postoperative pneumonia occurred in 12 (20.7%) patients in the NG and 23 (37.7%) patients in the CG (P=0.042). Other complications were minor and not significantly different. Four (6.9%) and 5 (8.2%) patients in the NG and CG developed recurrent laryngeal nerve paralysis, respectively. One patient in the CG experienced postoperative mortality due to shock and multiple-organ failure. The remaining patients improved after receiving standard treatment and were successfully discharged (*Table 4*). Multivariate analysis substantiated the advantages of employing this nomogram system and revealed MIE to be a significant independent factor associated with reduced postoperative morbidity (*Table 5*).

Postoperative hospital length of stay and hospital cost

Postoperative hospital length of stay was not normally distributed; and the postoperative median hospital length of stay was 15 days (range, 13–18 days) for the entire cohort and was significantly shorter in the NG (median, 14 days; range, 13–17 days) than in the CG (median, 16 days; range, 13–16 days; P=0.041). The single death occurred on the fifth day after surgery, and this patient was not included in the analysis of postoperative length of hospital stay or hospital cost. The total hospital costs were also not normally distributed, and although the cost in the NG (median, ¥60,045.1; IQR, ¥53,375.3–67,369.0) was slightly less than that in the CG (median, ¥63,961.5; IQR, ¥52,548.3–74,169.2), this difference was not statistically significant (P=0.21) (*Table 4*).

Postoperative QOL

The QOL scores were similar between the two groups before operation, and there was also no significant statistical difference in the postoperative QOL between the two groups (*Table 6*). Furthermore, the surgical approach (MIE; hybrid *vs.* OE) independently had a positive impact on patients' postoperative QOL (global QOL, physical function, pain symptoms, and dyspnea symptoms), whereas diabetes mellitus, operation duration, and pathological lymph node stage independently had a negative impact on QOL (*Table 6*).

Discussion

This prospective randomized controlled trial assessed the benefits of implementing an eSAS-based nomogram model as a postoperative triage system following esophagectomy. Our results showed lower complication rates, especially with respect to pulmonary complications, in patients for whom postoperative triage was conducted based on nomogram score.

In the context of esophagectomy procedures, the postoperative complication rate remains a significant concern, with reported rates ranging from 17% to 74%. A previous report indicated that a substantial portion (56.7%) of patients experience multiple complications (21). To minimize postoperative morbidity, it is crucial to identify patients at risk for complications early and perform individualized postoperative arrangements (22). However, there is a

Table 4 Major postoperative complications, postoperative length of hospital stay, and hospital costs

Variables	NG (n=58)	CG (n=61)	RR (95% CI)	P value
Major complication[†], n (%)	14 (24.1)	30 (49.2)	0.33 (0.15–0.72)	0.008
Reintubation	0 (0.0)	1 (1.6)	–	>0.99
Pneumonia	12 (20.7)	23 (37.7)	0.43 (0.19–0.98)	0.042
Pneumonia (without anastomotic leak)	12 (20.7)	20 (32.8)	0.50 (0.22–1.14)	0.10
Anastomotic leak	1 (1.7)	6 (9.8)	0.16 (0.02–1.38)	0.12
Anastomotic leak or pneumonia	13 (22.4)	26 (42.6)	0.39 (0.18–0.87)	0.02
Initial ventilatory support >48 hours	0 (0.0)	0 (0.0)	–	>0.99
Recurrent nerve paresis	4 (6.9)	5 (8.2)	–	>0.99
Chylothorax	0 (0.0)	1 (1.6)	–	>0.99
Dysrhythmia	1 (1.7)	2 (3.3)	–	>0.99
Other Clavien-Dindo class III or IV	0 (0.0)	1 (1.6)	–	>0.99
Postoperative hospital stay[‡] (days), median [25%, 75%]	14 [13, 17]	16 [13, 16]	–	0.041
Hospital cost[§] (¥), median [25%, 75%]	60,045.1 [53,375.3, 67,369.0]	63,961.5 [52,548.3, 74,169.2]	–	0.21

[†], one patient could experience more than one major complication; [‡], one patient who died after surgery was not included in the analysis of postoperative hospital stay and hospital costs; [§], all costs are expressed in Chinese yuan. NG, nomogram group; CG, control group; RR, relative risk; CI, confidence interval.

Table 5 Multivariable analysis for major postoperative complications

Variables	B	Standard error	Ward	Odds ratio (95% CI)	P value
NG	–1.23	0.43	8.13	0.29 (0.13–0.68)	0.004
Age >60 years	0.81	0.51	2.57	2.56 (0.83–6.12)	0.11
Smoking	0.93	0.48	3.73	2.55 (0.99–6.57)	0.053
Abdominal or chest operation history	0.79	0.59	1.78	2.20 (0.69–7.00)	0.18
Neoadjuvant therapy	–0.34	0.65	0.27	0.71 (0.20–2.55)	0.71
Surgical approach					
HYB	–0.85	0.73	1.36	0.43 (0.10–1.79)	0.43
MIE	–1.37	0.58	5.53	0.25 (0.08–0.80)	0.02

CI, confidence interval; NG, nomogram group; HYB, hybrid; MIE, minimally invasive esophagectomy.

scarcity of studies that have investigated the implementation and impact of individual stratification in guiding postoperative triage and care. In one study in the field of quality improvement, interventions produced promising results. Specifically, a customized risk stratification model was found to be able to reduce the rate of postoperative deterioration within 30 days among high-risk patients by informing the modification of perioperative care, which supports the rationale for our study (23).

It has been widely acknowledged that the SAS enables surgeons and anesthesiologists to recognize patients at a higher risk for certain complications or adverse events (7). In our previous study, we built a nomogram system based on the eSAS, and it was demonstrated to be a highly practicable and powerful model for assessing postoperative complications (9,24). However, its potential clinical

Table 6 Analysis of QOL (generalized estimating equation)

Variable	Global QOL		Physical function		Fatigue symptoms		Pain symptoms		Dyspnea symptoms	
	Estimation	P	Estimation	P	Estimation	P	Estimation	P	Estimation	P
Age	−4.553	0.65	−1.942	0.84	−3.911	0.66	0.950	0.81	−3.482	0.30
Sex	0.038	0.90	0.075	0.79	−0.390	0.27	−0.228	0.32	0.138	0.49
BMI	−1.453	0.051	−0.618	0.45	0.919	0.26	−0.269	0.70	−0.631	0.27
Diabetes mellitus	−6.398	0.33	−16.001	0.02*	−2.089	0.66	1.059	0.88	8.682	0.19
Tumor location (M)	−0.471	0.91	2.537	0.59	4.394	0.29	3.391	0.26	4.940	0.09
Tumor location (U)	−4.671	0.50	−3.176	0.69	1.963	0.81	−0.028	0.99	13.882	0.052
Neoadjuvant therapy	−0.821	0.90	−0.325	0.96	−6.492	0.19	−1.298	0.76	−3.835	0.29
Clinical T stage	−9.299	0.08	−8.430	0.20	7.347	0.50	2.007	0.76	−9.266	0.10
Clinical N stage	1.922	0.61	2.046	0.61	2.968	0.56	5.385	0.19	0.028	0.99
Pathological T stage	2.684	0.58	1.905	0.76	−1.776	0.87	1.538	0.79	9.435	0.07
Pathological N stage	−7.971	0.02*	−5.351	0.12	3.687	0.41	0.351	0.91	4.676	0.10
Surgical approach (MIE)	13.234	0.02*	13.900	0.03*	3.332	0.47	−7.949	0.049*	−7.881	0.044*
HYB TT + LS	6.085	0.49	8.173	0.44	18.829	0.11	11.426	0.16	9.257	0.44
HYB TS + LT	8.038	0.31	21.981	0.002*	12.560	0.35	9.207	0.19	−2.373	0.75
Operation duration	−0.052	0.03*	−0.068	0.02*	0.001	0.96	−0.014	0.48	0.055	0.039*
Usage of nomogram system	−2.091	0.60	−0.617	0.89	6.970	0.11	−2.575	0.34	1.074	0.77

*, indicates statistical significance (P<0.05). QOL, quality of life; BMI, body mass index; M, middle; U, upper; MIE, minimally invasive esophagectomy; HYB TT + LS, hybrid thoracotomy and laparoscopy; HYB TS + LT, hybrid thoracoscopy and laparotomy.

benefit as a triage system still required confirmation by a prospective study (5).

In this study, a significant difference in the incidence of major morbidity was observed between the two groups (P=0.008). In the NG, the incidence of postoperative pneumonia was significantly lower compared to that in the CG (P=0.042). Prolonged general anesthesia can result in the formation of airway mucus plugs. In the ICU, fiberoptic bronchoscopy is used for suctioning, and inflammatory markers are closely monitored. Additionally, targeted patient education and diligent nursing interventions effectively promote coughing and expectoration. Studies have also recognized postoperative blood glucose instability to be a risk factor for postoperative pneumonia. In the ICU setting, meticulous blood glucose control contributes to a reduced incidence of pneumonia. Moreover, the availability of bedside ultrasound and X-rays enhances the sensitivity in detecting pleural effusion.

It has been suggested that anastomotic leakage is associated with ischemia and hypoxia occurring in anastomotic areas during surgery, and this can be reflected by our eSAS-based nomogram (including EBL, lowest MAP, and lowest HR) (5,25). Postoperative meticulous fluid management can control blood pressure and protect the postoperative blood supply to the anastomotic site. Additionally, close monitoring of gastric distension using bedside ultrasound in the ICU can better control tension at the anastomotic site, preventing anastomotic leakage. Unexpectedly, we did not find a significant difference in the incidence of anastomotic leakage between the two groups (P=0.12). During the period of this study, the probability of developing anastomotic leakage in our center was 5.9%, which is lower than that reported elsewhere (5,11,26). This could be attributed to differences in prehospitalization and preoperative surgery screening and surgical technique. Compared with the surgical data in our previous study (9), the surgical data in this study indicated that OE was performed less frequently, with MIE being the most common surgical approach. Therefore, we suspect that the observed difference in anastomotic leakage may become

more significant with a larger sample size.

A significant difference was observed in the occurrence of anastomotic leakage or pneumonia (counting the occurrence of either one) between the two groups, with a P value of 0.02. This could be attributed to the diverse management of high-risk patients after surgery having a comprehensive impact on improving the occurrence of anastomotic leakage and pneumonia. Previous studies have suggested that pneumonia and anastomotic leakage are closely linked (27). Anastomotic leakage can contribute to the spread of local inflammation, leading to pleural or mediastinal effusion and promoting pneumonia occurrence. Meanwhile, postoperative pneumonia can trigger systemic reactions, creating an inflammatory environment around the anastomotic site, which can affect blood supply and nutrition, ultimately leading to the development of anastomotic leakage.

No significant difference was found in other major complications. The occurrence of recurrent laryngeal nerve paralysis, arrhythmia, and chylothorax may be influenced by additional factors not considered in our study, which could explain these results. For example, eSAS does not directly predict recurrent laryngeal nerve palsy because this mainly depends on how strictly cervical lymph nodes are dissected (28).

We further performed multivariate analysis to account for potential confounding factors, including the different surgical approaches, as randomization was not stratified by surgical methods. Our results demonstrated that the eSAS-based nomogram remained an independent positive factor for postoperative morbidity. Furthermore, the MIE approach also emerged as an independent positive factor, consistent with prior research (29).

Our risk-prediction model can substantially benefit patients without increasing hospital costs. Since our findings demonstrated a positive relationship between its use and reduced postoperative complications and hospital length of stay, it is reasonable to deduce that hospital costs would also be reduced. However, in our study, the hospital costs between the two groups were not discernibly different. We believe that the NG included more patients who required ICU stay, where the medical expenses per day are higher, whereas the CG experienced more postoperative complications, which led to a longer hospital stay. A higher proportion of ICU admissions negated the economic benefits derived from a lower number of complications in the NG, keeping the costs comparatively equal between the two groups.

Our study found that the nomogram system did not improve postoperative QOL. However, previous research has shown that complications after surgery are associated with poor health-related QOL outcomes (30). The ineffectiveness of the nomogram system in improving QOL may be attributable to different postoperative treatments and interventions for tumor recurrence within 6 months, including chemotherapy (oral or intravenous), immunotherapy, and radiotherapy. Additionally, the short follow-up period may not fully reflect the negative impact of complications on QOL. Other studies also suggest that the occurrence of postoperative anastomotic leakage does not affect long-term prognosis (28,31). In line with this, considering the influence of postoperative QOL influencing on prognosis after esophagectomy (11), our findings suggest that although anastomotic leakage may lead to worse perioperative outcomes (32), its impact on short-term QOL appears to be minimal.

We enrolled patients with esophageal cancer with a mix of ages, gender, and clinical stages, including those who received neoadjuvant therapy, illustrating the versatility of our predictive nomogram model for a broad spectrum of esophageal cancer resection candidates. However, our study still has some limitations that should be mentioned. First, this trial was conducted at a single center, with a predominantly Asian patient population. In order to confirm our findings, a multicenter study is needed. Furthermore, the implementation of neoadjuvant therapy in our study was constrained by certain contextual factors mentioned earlier. Hence, future investigations are warranted to evaluate the efficacy of our system within a more comprehensive clinical context that encompasses a broader spectrum of patients who have undergone neoadjuvant therapy. Additionally, the follow-up period was relatively short in this study. Thus, extended follow-up data and further accumulation of cases are necessary to collect more valid evidence regarding the effect of our nomogram in terms of QOL and prognosis after esophageal cancer surgery.

Conclusions

This study demonstrated that the eSAS-based nomogram as a triage tool can reduce the overall occurrence of postoperative complications and shorten the postoperative hospital length of stay without increasing hospital costs. Risk-based triage and postoperative care modification based on our nomogram can improve the perioperative outcome and is clinically practicable.

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Footnote

Reporting Checklist: The authors have completed the CONSORT reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-451/rc

Trial Protocol: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-451/tp

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-451/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-24-451/coif). J.Y.K. serves as an unpaid editorial board member of *Journal of Thoracic Disease* from April 2024 to June 2026. J.O.W. receives grants or contracts from Intuitive and receives consulting fees from Meditronic. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was approved by the Ethics Committee of Ningbo Medical Center, Lihuili Hospital (No. DYLL2018075). Written informed consent was required from each patient. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

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