

Preoperative shock index in major abdominal emergency surgery

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ABSTRACT

Introduction: Major abdominal emergency surgery (MAES) patients have a high risk of mortality and complications. The time-sensitive nature of MAES necessitates an easily calculable risk-scoring tool. Shock index (SI) is obtained by dividing heart rate (HR) by systolic blood pressure (SBP) and provides insight into a patient's haemodynamic status. We aimed to evaluate SI's usefulness in predicting postoperative mortality, acute kidney injury (AKI), requirements for intensive care unit (ICU) and high-dependency monitoring, and the ICU length of stay (LOS).

Method: We retrospectively reviewed 212,089 MAES patients from January 2013 to December 2020. The cohort was propensity matched, and 3960 patients were included. The first HR and SBP recorded in the anaesthesia chart were used to calculate SI. Regression models were used to investigate the association between SI and outcomes. The relationship between SI and survival was explored with Kaplan-Meier curves.

Results: There were significant associations between SI and mortality at 1 month (odds ratio [OR] 2.40 [1.67–3.39], $P<0.001$), 3 months (OR 2.13 [1.56–2.88], $P<0.001$), and at 2 years (OR 1.77 [1.38–2.25], $P<0.001$). Multivariate analysis revealed significant relationships between SI and mortality at 1 month (OR 3.51 [1.20–10.3], $P=0.021$) and at 3 months (OR 3.05 [1.07–8.54], $P=0.034$). Univariate and multivariate analysis also revealed significant relationships between SI and AKI ($P<0.001$), postoperative ICU admission ($P<0.005$) and ICU LOS ($P<0.001$). SI does not significantly affect 2-year mortality.

Conclusion: SI is useful in predicting postoperative mortality at 1 month, 3 months, AKI, postoperative ICU admission and ICU LOS.

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INTRODUCTION

Major abdominal emergency surgery (MAES) is a complex and high-risk procedure with a significantly greater risk of complications and mortality as compared to elective surgery.¹⁻³ Mortality rates in MAES can range from 14% to 20%,^{2,4} with current literature quoting rates as high as 45%.⁵

To objectively assess the perioperative surgical risk, several scoring and risk-stratification systems have been developed to guide the perioperative management, decision and risk of surgery, and postoperative disposition planning. They include the Physiological and Operative Severity Score for the Enumeration of Mortality and Morbidity,⁶ National Surgical Quality Improvement Programme,⁷ Lee's Revised Cardiac Risk Index and its variations^{8,9} as well as Combined Assessment of Risk Encountered in Surgery surgical risk calculator.^{10,11} Despite their usefulness, these scoring and risk-stratification systems have limited utility in emergency settings. Their complexity can lead to difficulties in calculations, inter-observer variation, and reliance on biochemical investigations,¹² which may delay treatment and negatively impact patient outcomes. Furthermore, in emergency situations, there is often insufficient time to calculate and apply these scores, and they may not reflect the unique challenges and risks associated with emergency surgery. Therefore, there is a need for simpler and more efficient tools to assess surgical risk and guide perioperative management in emergency settings.

The shock index (SI) is a simple and widely studied parameter that provides important information about a patient's haemodynamic status and tissue perfusion.¹³ It was first introduced in 1967 by Allgöwer and Burri as a means of measuring the severity of hypovolemia in haemorrhagic and septic shock. The ratio is calculated by dividing the heart rate (HR) by systolic blood pressure (SBP).¹⁴ Subsequently, the use of SI has been extended to patients with other causes of shock, including cardiogenic and obstructive shock.¹⁵ By providing information about the ratio of HR to SBP, the SI can help clinicians identify patients who are at risk of developing shock or other haemodynamic instability. Conventionally, an SI index of more than 0.9 is considered to be a marker

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CLINICAL IMPACT

What is New

- The role of shock index (SI) in predicting mortality in patients undergoing major abdominal surgery remains unclear. This study explores the relationship between SI and postoperative mortality, and other secondary outcomes like length of ICU stay, incidence of AKI, and admissions to the ICU and high-dependency wards postoperatively.

Clinical Implications

- The study highlights the important role of SI in predicting postoperative mortality, duration of ICU stay, and incidence of AKI.
- SI provides a quick and reliable tool for predicting postoperative mortality at 1 month, 3 months, the incidence of AKI, and the length of ICU stay. This simple parameter can help guide future resource allocation and interventions to reduce the risk of poor outcomes.

of increased risk of adverse outcomes.¹⁶ Higher values of SI have been associated with increased morbidity and mortality in various clinical settings, including trauma, sepsis and myocardial infarction. However, the role of SI in predicting mortality in patients undergoing major surgery remains unclear. Therefore, investigating the association between SI and mortality in this patient population could potentially provide a valuable tool for predicting outcomes and improving patient care.

In this study, we aim to investigate the role of SI in predicting the mortality of patients undergoing MAES at 1 month, 3 months, and 2 years postoperatively. Other secondary outcomes of interest include admissions to the ICU and high-dependency (HD) wards, postoperative acute kidney injury (AKI), and the length of ICU and hospital stay postoperatively.

METHOD

Ethics approval was obtained from the SingHealth Centralised Institutional Review Board (Reference number 2020/3063) prior to the start of the study. Written consent was waived. This was a retrospective study reviewing the electronic medical records of all the patients who had MAES between January 2013 and December 2020 in Singapore General Hospital (SGH). In this study, all MAES done were exploratory laparotomy with either an infected appendix or gallbladder, or perforated and soiled abdomen. To avoid complicating the analysis, all

vascular operations (e.g. aortic) were removed from the study. There were minimal numbers of traumatic abdominal salvage operations due to the low trauma patient load SGH sees yearly.

Patients were included if they were above 21 years old and had undergone emergency abdominal surgery labelled as moderate or high risk. The SI (HR/SBP) was calculated using the first HR and blood pressure recorded on the anaesthesia chart before induction of anaesthesia. Invasive blood pressure was taken preferentially where available. If invasive blood pressure was not present on the first reading, the non-invasive blood pressure was recorded.

Clinical records were sourced from our institution's clinical information system (Sunrise Clinical Manager [SCM], Allscripts, IL, US) and stored in an enterprise data repository and analytics system (SingHealth-IHIS Electronic Health Intelligence System). Information from SCM, including patient demographics; urgency of operation; and preoperative comorbidities, such as ischaemic heart disease, congestive heart disease, cerebrovascular disease and diabetes, were recorded. The most recent active preoperative medication lists were extracted. Preoperative blood tests, including haemoglobin, HbA1C and creatinine, were recorded. Operative details, including details of operation, site, duration of surgery, type of anaesthesia and duration of surgery, were also obtained.

The length of stays in the hospital, HD ward and ICU were calculated from the date of surgery to the end of the respective stays. Readmission data were obtained similarly from SCM. Data on mortality date in our clinical information system are synced with the data from the National Registry of Diseases Office, ensuring a near-complete all-cause mortality capture. The cause of death was not collected. This study is reported in line with the STROCSS criteria 2019.¹⁷

Categorisation of groups and adverse event definitions

The first HR and SBP, which were recorded in the anaesthesia chart, were extracted. This was taken to be the preoperative vitals before induction of anaesthesia, which is in keeping with the local practice of minimum standard American Society of Anesthesiologists (ASA) monitoring prior to the start of the anaesthesia. SI was calculated with the formula of HR/SBP.

Postoperative acute myocardial injury is defined by patients who had high-sensitivity troponin-T done with a value of >65 ng/L¹⁸ at any point of time up to 7 days postoperatively. Postoperative AKI is defined as KDIGO stage 2 with criteria of >2 times elevation of creatinine from baseline within 7 days in the postoperative period.

Statistical analysis

Missing values for ASA score account for 9.8% are imputed using the k-nearest neighbour¹⁹ method and mode. Other variables, which had >2% missing values, were also non-essential to the purpose of the study and were discarded from the analysis.

To investigate the association between SI and outcomes, both univariable and multivariable linear regression models were performed. Mean and standard deviation were presented for continuous variables, and the Mann-Whitney U test was used to compare mean differences between groups. For categorical variables, the proportions between groups were compared using the chi-square test. The effect size was reported as an odds ratio (OR) and its 95% confidence interval (CI). To account for multiple comparisons, the Bonferroni correction was used to adjust for *P* value in multivariable regression models. Propensity score matching (PSM) analysis in a 1:8 ratio was done, and the cohorts were matched for gender, operative risk and the presence of end-stage renal failure, as these variables were found to be significantly different between both groups on preliminary analysis ($P < 0.001$). To assess the impact of an SI of >0.9 on long-term survival, Kaplan-Meier (KM) curves were plotted for up to 2 years of survival stratified by SI groups.

By utilising a combination of regression models and survival analysis, this study aims to

comprehensively investigate the association between SI and outcomes in patients undergoing MAES.

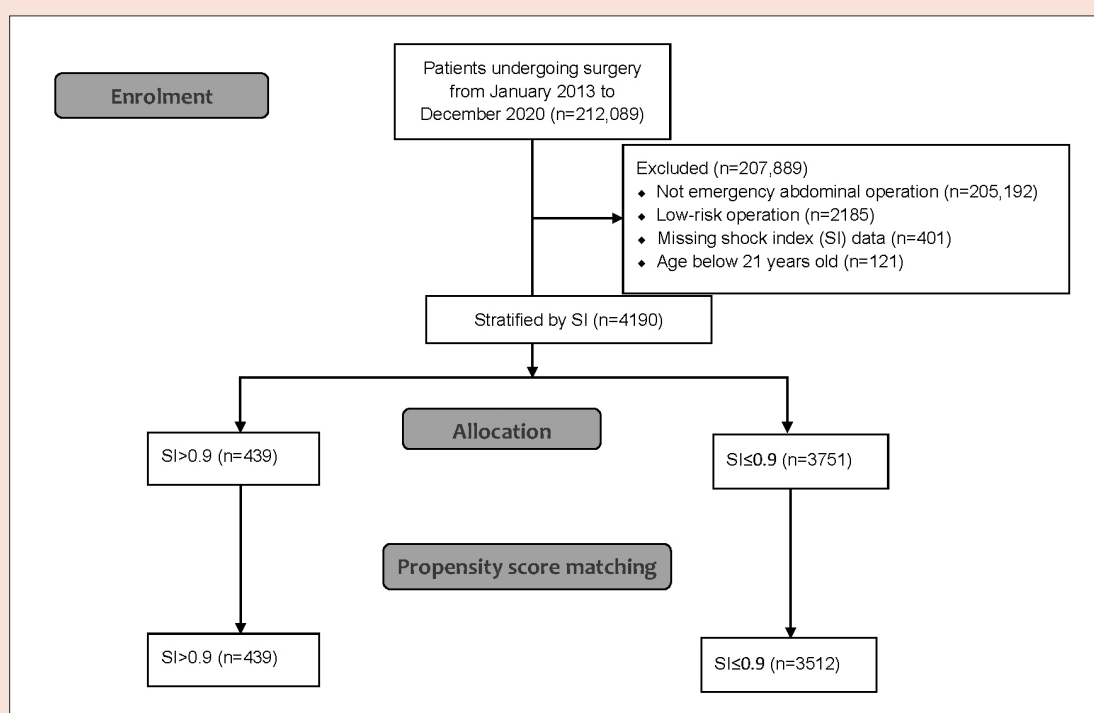
Analysis, statistical computing and visualisation were carried out with R environment version 4.0.5. The KM curve was plotted using scikit-survival package on Python 3.6.0.

RESULTS

Demographics and clinical characteristics

A total of 212,089 patients who underwent MAES between January 2013 and December 2020 were recruited. The exclusion criteria include the low-risk nature of the operation, non-emergent abdominal surgeries, and not satisfying the age criteria of being older than 21 years old. After applying the inclusion and exclusion criteria, the study was completed with 4190 patients with 205,192 patients excluded (Fig. 1). Patient demographics and clinical characteristics were stratified by their SI and compared (Table 1A). Of the included patients, 89.5% (3751) had an SI of ≤ 0.9 , whereas 10.5% (439) had an SI of > 0.9 . PSM was employed to ensure comparability between groups by matching patients based on gender, operative risk and renal disease. Following the matching process, the final cohort comprised 3960 patients, with 3521 patients exhibiting an SI of ≤ 0.9 , whereas 439 patients had an SI of > 0.9 . Patients with an SI of > 0.9 had a

Fig. 1. CONSORT diagram for patient recruitment.



mean SI of 1.09 as compared to patients with an SI of ≤ 0.9 who had a mean of 0.62. Patients with an SI of ≤ 0.9 had a higher mean age of 56.66 ± 18.23 years compared to those with an SI of >0.9 (52.80 ± 19.15 years). There were more males in the SI ≤ 0.9 group (51%) than in the SI >0.9 group (48%). Chinese patients constituted the majority of both groups, with 72% and 66% in the SI ≤ 0.9 and SI >0.9 groups, respectively.

Patients with a higher SI were found to have significantly elevated cardiac risk index ($P=0.002$) and ASA physical status ($P<0.001$); and a greater proportion of them have end-stage renal failure ($P=0.008$), indicating a greater comorbidity burden. Table 1A shows a summary of patient characteristics. Intraoperative parameters and postoperative complications can be found in Tables 1B and 1C, respectively.

The group with an SI of >0.9 had a greater proportion of patients on long-term steroids ($P<0.001$) and a smaller proportion of patients on angiotensin-converting enzyme inhibitors ($P=0.008$). However, there was no significant difference in the use of bisoprolol and statins between the two groups. Patients with an SI of >0.9 had long ICU and HD stays and were more likely to experience AKI compared to those with an SI of ≤ 0.9 (Table 1C).

Outcomes

Notably, patients in the SI >0.9 group were found to have significantly higher mortality at 1 month (OR 2.40, 95% CI 1.67–3.39, $P<0.001$), 3 months (OR 2.13, 95% CI 1.56–2.88, $P<0.001$), and at 2 years postoperatively (OR 1.77, 95% CI 1.38–2.25, $P<0.001$) (Table 2 and Fig. 2). After adjusting for variables, patients with an SI of >0.9 remained significantly associated with higher mortality at 1 month (OR 3.51, 95% CI 1.20–10.3, $P=0.021$) and 3 months postoperatively (OR 3.05, 95% CI 1.07–8.54, $P=0.034$) (Table 2). However, SI was not found to be significantly associated with 2-year mortality (Table 2). There was a significant difference in survival probability between the two groups ($P<0.001$) (Fig. 3). Overall, these findings suggest that the SI is a valuable predictor of short-term mortality and adverse outcomes in patients undergoing MAES. Fig. 4 depicts the violin plots of postoperative ICU admission between the two groups.

DISCUSSION

In this study, we analysed the relationship between SI in MAES and postoperative mortality and morbidity. SI, defined as the ratio of HR to SBP, is a simple and easily obtainable parameter that has been used as a marker of haemodynamic instability in various clinical settings. Conventionally, SI has

been used in the setting of emergency departments for patients who were admitted for trauma,^{20,21} haemorrhagic shock,²² and septic shock.^{23,24} More recently, SI has been used as an indicator of trauma severity,²⁵ early acute hypovolemia,²² early sepsis,^{23,24} and an outcome predictor of postpartum haemorrhage.²⁶ However, from our literature review, this is one of the few studies investigating the role of SI in predicting mortality outcomes in patients undergoing MAES.

Our results show that an SI of >0.9 is associated with increased postoperative mortality, HD requirements, AKI, and length of hospital and ICU stays. However, SI was not found to be significantly associated with 2-year mortality (Table 2). While the exact mechanisms underlying the association between elevated SI and postoperative mortality are not well understood, it is thought that increased SI may reflect a combination of decreased circulating blood volume²⁷ and reduced tissue perfusion, such as the central vena cava oxygen saturation and lactate concentration.^{28,29} SI is a valuable tool, as it is easily calculated and does not rely on any biochemical investigations. It allows clinicians to make quick judgements about a patient's disease severity and response to fluid resuscitation. SI also guides further management. Its utility extends to picking up early signs of haemodynamic instability, allowing appropriate escalation and interventions to be made.

In this study, the association between SI and postoperative ICU admission was found to be statistically significant ($P=0.043$) (Table 2). The decision to admit a patient to the ICU postoperatively usually depends on a multitude of different factors, including surgical success, intraoperative cardiopulmonary stability, the patient's past medical history, and the extent of the operation. Hence, SI would serve better as a predictor of mortality and morbidity than for postoperative ICU admission. SI was also found to be significantly associated with AKI in this study, which is consistent with other studies.^{30,31} Some studies had also extended this association to lactate concentration.^{28,32,33}

The study population included patients who underwent emergency exploratory laparotomies due to various conditions, such as an infected appendix, gallbladder, or perforated and soiled abdomen. Although the specific type of shock was not specified for all patients, it was observed that a majority of them experienced septic shock. It is important to note that patients with haemorrhagic shock constituted only a small proportion of the cohort, as vascular surgeries were excluded from the study. These findings suggest a potential correlation between SI and the severity of septic shock and these adverse outcomes.

Table 1A. Propensity-matched preoperative patient characteristics, stratified by shock index cut-off at 0.9.

	SI≤0.9 (n=3512)	SI>0.9 (n=439)	P value*
Preoperative parameters			
Age	57 ± 18	53 ± 19	<0.001
Gender			0.3
Female	1729 (49%)	229 (52%)	
Male	1783 (51%)	210 (48%)	
Race			0.12
Caucasian	47 (1.3%)	6 (1.4%)	
Chinese	2530 (72%)	290 (66%)	
Indian	301 (8.6%)	49 (11%)	
Malay	289 (8.2%)	42 (9.6%)	
Others	345 (9.8%)	52 (12%)	
Aspirin, warfarin or anti-platelets in the past 2 weeks			>0.9
No	2813 (88%)	334 (87%)	
Yes	400 (12%)	49 (13%)	
BMI (kg/m ²)	24.4 ± 5.2	23.7 ± 5.2	0.052
History of IHD			0.14
No	2994 (90%)	375 (93%)	
Yes	316 (9.5%)	29 (7.2%)	
History of CHF			0.7
No	3233 (98%)	393 (97%)	
Yes	74 (2.2%)	11 (2.7%)	
History of CVA			0.11
No	3207 (97%)	385 (95%)	
Yes	102 (3.1%)	19 (4.7%)	
DM on insulin			0.4
No	3169 (97%)	382 (96%)	
Yes	99 (3.0%)	16 (4.0%)	
Cardiac risk index			0.002
0	1312 (40%)	123 (31%)	
1	1522 (47%)	207 (52%)	
2	279 (8.6%)	46 (12%)	
3	86 (2.7%)	10 (2.5%)	
4	28 (0.9%)	8 (2.0%)	
5	13 (0.4%)	2 (0.5%)	
ASA score			<0.001
ASA 1-2	2359 (67%)	222 (51%)	
ASA 3-5	1144 (33%)	217 (49%)	
Preoperative haemoglobin (g/dL)	12.79 ± 2.35	12.17 ± 2.67	<0.001
Preoperative creatinine (mmol/L)	83.36 ± 78.18	104.58 ± 115.64	<0.001
Preoperative HbA1c (%)	7.18 ± 1.95	6.68 ± 1.74	0.088
Duration of operation (mins)	131 ± 81	152 ± 96	<0.001
Operative risk			<0.001
High	217 (6.2%)	50 (11%)	
Moderate	3295 (94%)	389 (89%)	
DM			0.4
Yes	608 (17%)	83 (19%)	
ESRF			0.008
Yes	116 (3.3%)	26 (5.9%)	
Use of steroids			<0.001
Yes	107 (3.1%)	32 (7.4%)	

Table 1A. Propensity-matched preoperative patient characteristics, stratified by shock index cut-off at 0.9. (Cont'd)

	SI≤0.9 (n=3512)	SI>0.9 (n=439)	P value*
Use of ACEIs			0.008
Yes	303 (8.7%)	21 (4.8%)	
Use of Bisoprolol			0.3
Yes	240 (6.9%)	36 (8.3%)	
Use of statins			0.3
Yes	836 (24%)	94 (22%)	

Values are presented as mean ± SD or numbers (%). ACEIs: angiotensin-converting enzyme inhibitors; ASA: American Society of Anesthesiologists; BMI: body mass index; CHF: congestive heart failure; CVA: cerebrovascular accident; DM: diabetes mellitus; ESRF: end-stage renal failure; IHD: ischaemic heart disease, SI: shock index. *Categorical variables were compared through chi-square test. Continuous variables were compared using Mann-Whitney. Bold values are significant at $P<0.05$.

Table 1B. Intraoperative patient characteristics, stratified by shock index cut-off at 0.9.

	SI≤0.9 (n=3512)	SI>0.9 (n=439)	P value*
First intraoperative parameters			
DBP (mmHg)	76 ± 15	66 ± 14	<0.001
SBP (mmHg)	136 ± 22	107 ± 18	<0.001
HR (bpm)	83 ± 16	115 ± 21	<0.001
SI (bpm/mmHg)	0.62 ± 0.13	1.09 ± 0.21	<0.001
PP (mmHg)	59 ± 20	41 ± 13	<0.001

Values are presented as mean ± SD. DBP: diastolic blood pressure; PP: pulse pressure; SBP: systolic blood pressure; SI: shock index. *Categorical variables were compared using chi-square test. Continuous variables were compared using Mann-Whitney. Bold values are significant at $P<0.05$.

Table 1C. Postoperative patient characteristics, stratified by shock index cut-off at 0.9.

	SI≤0.9 (n=3512)	SI>0.9 (n=439)	P value*
Postoperative complications			
Transfusion of red blood cells			0.6
Yes	276 ± 21	277 ± 20	
Length of hospital stay (days)	14 ± 23	23 ± 34	<0.001
HD and ICU stay	54 ± 151	124 ± 253	<0.001
Hospital readmission			
Yes	14 (100%)	2 (100%)	
HD admission postoperatively			<0.001
Yes	1571 (45%)	271 (62%)	

Values are presented as numbers (%) or mean ± SD. AKI: acute kidney injury; HD: high dependency; ICU: intensive care unit; SI: shock index. *Categorical variables were compared using chi-square test. Continuous variables were compared using Mann-Whitney. Bold values are significant at $P<0.05$.

In a clinical setting, SI can be useful for anaesthesiologists, as it provides a quick indication of the severity of an illness. This enables anaesthesiologists to make guided decisions regarding the preparation of resuscitation equipment and drugs, method of induction and intraoperative management. A high SI preoperatively

can also guide anaesthesiologists to adequately resuscitate the patient with fluids and vasopressors in the operating theatre prior to induction. Additionally, SI can aid anaesthesiologists in postoperative planning with regard to the need for an ICU bed for a patient. This will help facilitate getting an ICU bed early for a patient and avoid

Table 2. Univariable and multivariable regression analysis for 2-year mortality, 3-month mortality, 1-month mortality, ICU admission postoperatively, AKI postoperatively, and length of ICU stay (OR [95% CI]; *P* value).

	SI>0.9			
	Univariable		Multivariable	
	OR (95% CI)	<i>P</i> value*	OR (95% CI)	<i>P</i> value†
2-year mortality	1.77 (1.38–2.25)	<0.001	1.47 (0.96–2.23)	0.072
3-month mortality	2.13 (1.56–2.88)	<0.001	3.05 (1.07–8.54)	0.034
1-month mortality	2.40 (1.67–3.39)	<0.001	3.51 (1.20–10.3)	0.021
Postoperative ICU admission	4.36 (3.40–5.57)	<0.001	2.72 (1.03–7.25)	0.043
AKI	2.27 (1.80–2.88)	<0.001	3.39 (2.35–4.87)	<0.001
Length of ICU stay (days)	2.0 (1.6–2.5)	<0.001	1.2 (0.70–1.7)	<0.001

AKI: acute kidney injury; CI: confidence interval; ICU: intensive care unit; OR: odds ratio, SI: shock index. *A univariable binary logistic regression analysis was performed for each variable. †A multivariable binary logistic analysis regression analysis adjusted for shock index, age, use of aspirin, warfarin or antiplatelets over the past 2 weeks, cardiac risk index, diastolic blood pressure intraoperatively, cardiac risk index, pulse pressure intraoperatively, American Society of Anesthesiologists physical status, preoperative haemoglobin and creatinine, duration of operation, diabetes mellitus status, end-stage renal failure status, postoperative ICU admission, AKI, and length of ICU stay was performed. The multivariable analysis included variables with statistical significance ($P<0.05$). Bold values are significant at $P<0.05$. Variance inflation factor was used to ensure all factors were <5.0 to reduce multicollinearity.

Fig. 2. Violin plot of shock index against mortality at a) 1 month, b) 3 months and c) 2 years.



logistical delays. The benefits of SI can be extended to surgeons as well as patients with haemodynamic instability, and high SI could indicate a higher likelihood of bowel ischaemia. In such scenarios, SI can be one of the many considerations guiding surgeons, as these patients would have a higher likelihood of temporary abdominal closure. Future studies could explore the effect of optimising the preoperative SI with adequate resuscitation on postoperative outcomes. Other easily calculable parameters like the modified SI,³⁴ age SI,³⁵ and pulse pressure could also be studied for their associations with outcomes.

Despite promising results, there were also several limitations to this study. First, it was a single-centred, retrospective, observational study, which may increase the risk of selection bias. Second, the use of only a single time point for HR and SBP was used to calculate the SI. These parameters can change drastically with therapeutic interventions,

but information on these interventions was not included. The relationship between mortality and the average of SI measurements at various time points can be considered for future studies. Third, there is a lack of differentiation of SBP readings based on the measurement device (arterial lines, non-invasive blood pressure cuff) used. The cause of death was not collected, which may limit the interpretation of mortality data.

Opponents of risk-stratification tools may argue that their utility in emergency settings is limited, as there may not be ample time to optimise the high-risk emergency patient for MAES. However, we resonate with several other authors^{36,37} that a risk score for emergency surgery patients can be useful in preoperative counselling, identifying patients who require closer monitoring, and benchmarking the quality of the emergency surgery. It can also help guide providers to better

Fig. 3. Kaplan-Meier curve for postoperative mortality at 2 years. A significant difference in postoperative mortality at 2 years between the group with shock index (SI) >0.9 and SI<0.9 was observed ($P<0.005$). The confidence band represents the 95% CI.

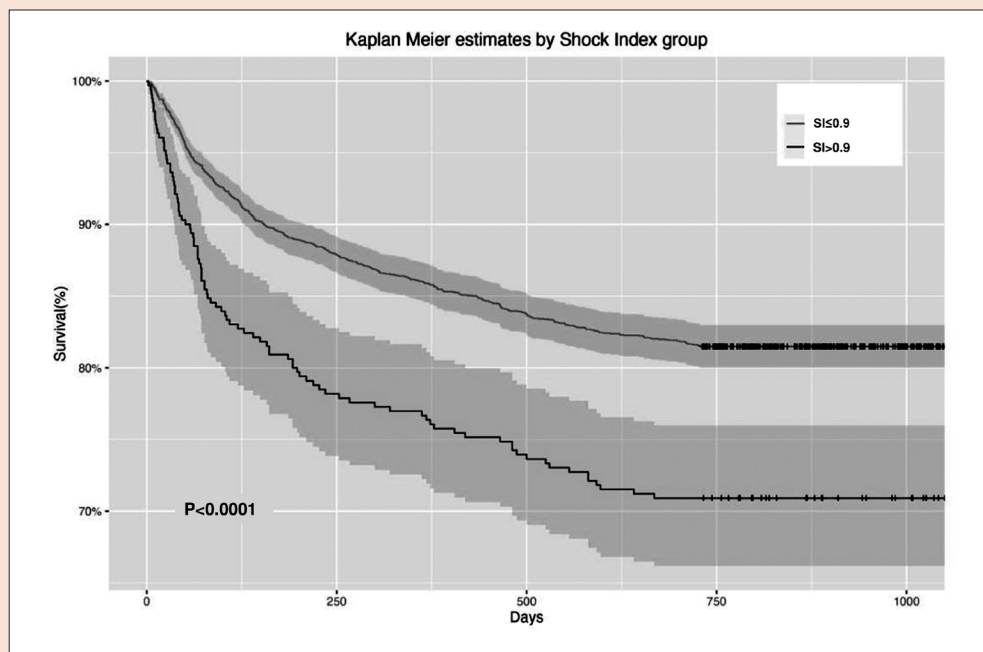
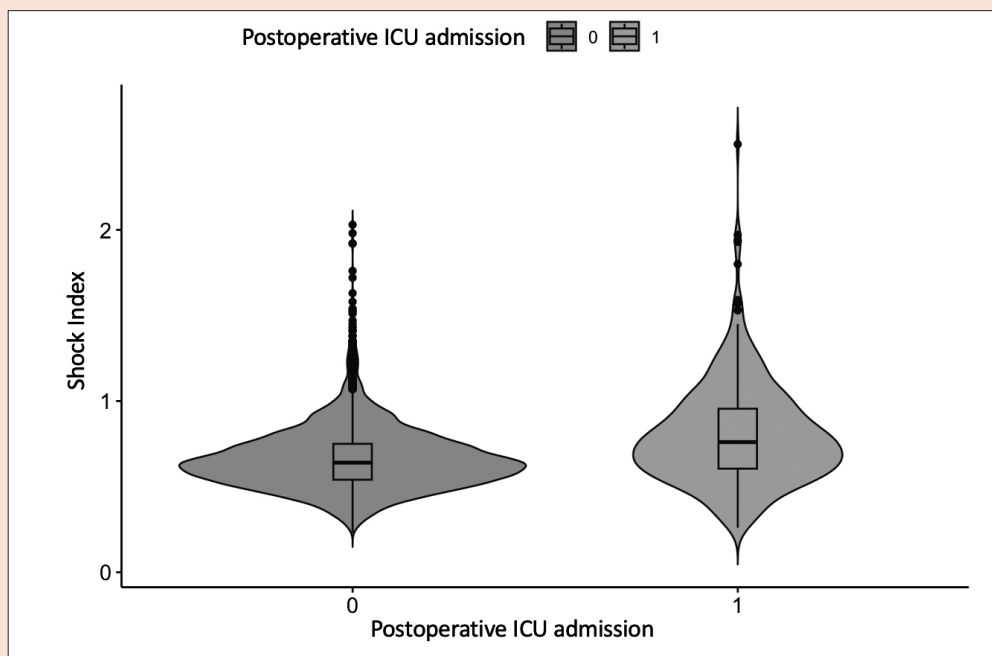


Fig. 4. Violin plot of shock index against postoperative ICU admission.



understand the patient at hand in comparison to other similar patients within the study population.

In conclusion, we found that SI is a valuable, convenient and reliable predictor of postoperative mortality, HD requirements, the incidence of AKI, postoperative ICU admission, and the length of hospital and ICU stays for patients undergoing

MAES. This can help guide future resource allocation and interventions to prevent poor outcomes.

Conflict of interest

There are no conflicts of interest.

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REFERENCES

- Ingraham AM, Cohen ME, Bilimoria KY, et al. Comparison of hospital performance in nonemergency versus emergency colorectal operations at 142 hospitals. *J Am Coll Surg* 2010; 210:155-65.
- Clarke A, Murdoch H, Thomas MJ, et al. Mortality and postoperative care after emergency laparotomy. *Eur J Anaesthesiol* 2011;28:16-9.
- Kassahun WT, Babel J, Mehdorn M. Assessing differences in surgical outcomes following emergency abdominal exploration for complications of elective surgery and high-risk primary emergencies. *Sci Rep* 2022;12:1349.
- Saunders DI, Murray D, Pichel AC, et al. Variations in mortality after emergency laparotomy: the first report of the UK Emergency Laparotomy Network. *Br J Anaesth* 2012;109:368-75.
- Vester-Andersen M, Lundstrøm LH, Møller MH, et al. Mortality and postoperative care pathways after emergency gastrointestinal surgery in 2904 patients: a population-based cohort study. *Br J Anaesth* 2014;112:860-70.
- Copeland GP, Jones D, Walters M. POSSUM: a scoring system for surgical audit. *Br J Surg* 1991;78:355-60.
- Khuri SF, Daley J, Henderson W, et al. The National Veterans Administration Surgical Risk Study: risk adjustment for the comparative assessment of the quality of surgical care. *J Am Coll Surg* 1995;180:519-31.
- Ke Y, Shannon NB, Abdullah HR. Improving the accuracy of revised cardiac risk index with HbA1C: Hemoglobin ratio (HH ratio) – A retrospective cohort study. *Front Med [Internet]* 2023;10:998477.
- Lee TH, Marcantonio ER, Mangione CM, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. *Circulation* 1999;100:1043-9.
- Chan DXH, Sim YE, Chan YH, et al. Development of the Combined Assessment of Risk Encountered in Surgery (CARES) surgical risk calculator for prediction of postsurgical mortality and need for intensive care unit admission risk: a single-center retrospective study. *BMJ Open* 2018;8:e019427.
- Chiew CJ, Liu N, Wong TH, et al. Utilizing Machine Learning Methods for Preoperative Prediction of Postsurgical Mortality and Intensive Care Unit Admission. *Ann Surg* 2020;272:1133-9.
- Singh K, Hariharan S. Detecting Major Complications and Death After Emergency Abdominal Surgery Using the Surgical Apgar Score: A Retrospective Analysis in a Caribbean Setting. *Turk J Anaesthesiol Reanim* 2019;47:128-33.
- Kurt E, Bahadiri S. The Usefulness of Shock Index and Modified Shock Index in Predicting the Outcome of COVID-19 Patients. *Disaster Med Public Health Prep* 2022;16:1558-63.
- Allgöwer M, Burri C. ["Shock index"]. *Dtsch Med Wochenschr* 1967;92:1947-50.
- Koch E, Lovett S, Nghiem T, et al. Shock index in the emergency department: utility and limitations. *Open Access Emerg Med* 2019;11:179-99.
- Rady MY, Smithline HA, Blake H, et al. A comparison of the shock index and conventional vital signs to identify acute, critical illness in the emergency department. *Ann Emerg Med* 1994; 24:685-90.
- Agha R, Abdall-Razak A, Crossley E, et al. STROCSS 2019 Guideline: Strengthening the reporting of cohort studies in surgery. *Int J Surg* 2019;72:156-65.
- Writing Committee for the VISION Study Investigators; Devereaux PJ, Biccari BM, Sigamani A, et al. Association of Postoperative High-Sensitivity Troponin Levels With Myocardial Injury and 30-Day Mortality Among Patients Undergoing Noncardiac Surgery. *JAMA* 2017;317:1642-51.
- Zhang Z. Introduction to machine learning: k-nearest neighbors. *Ann Transl Med* 2016;4:218.
- Sahu N, Yee S, Das M, et al. Shock Index as a Marker for Mortality Rates in Those Admitted to the Medical Intensive Care Unit from the Emergency Department. *Cureus* 2020; 12:e7903.
- Wikström L, Kander T, Gabbe BJ. The Utility of the Shock Index for Predicting Survival, Function and Health Status Outcomes in Major Trauma Patients: A Registry-Based Cohort Study. *Trauma Care* 2022;2:268-81.
- Birkhahn RH, Gaeta TJ, Terry D, et al. Shock index in diagnosing early acute hypovolemia. *Am J Emerg Med* 2005;23:323-6.
- Tseng J, Nugent K. Utility of the shock index in patients with sepsis. *Am J Med Sci* 2015;349:531-5.
- Berger T, Green J, Horeczko T, et al. Shock index and early recognition of sepsis in the emergency department: pilot study. *West J Emerg Med* 2013;14:168-74.
- King RW, Plewa MC, Buderer NM, et al. Shock index as a marker for significant injury in trauma patients. *Acad Emerg Med* 1996;3:1041-5.
- Nathan HL, El Ayadi A, Hezelgrave NL, et al. Shock index: an effective predictor of outcome in postpartum haemorrhage? *BJOG* 2015;122:268-75.
- Zarzaar BL, Croce MA, Fischer PE, et al. New vitals after injury: shock index for the young and age x shock index for the old. *J Surg Res* 2008;147:229-36.
- Cevik AA, Dolgun H, Oner S, et al. Elevated lactate level and shock index in nontraumatic hypotensive patients presenting to the emergency department. *Eur J Emerg Med* 2015;22:23-8.
- Cerović O, Golubović V, Spec-Marn A, et al. Relationship between injury severity and lactate levels in severely injured patients. *Intensive Care Med* 2003;29:1300-5.
- Rady MY, Edwards JD, Nightingale P. Early cardiorespiratory findings after severe blunt thoracic trauma and their relation to outcome. *Br J Surg* 1992;79:65-8.
- Heffner AC, Swords DS, Nussbaum ML, et al. Predictors of the complication of postintubation hypotension during emergency airway management. *J Crit Care* 2012;27:587-93.
- McNab A, Burns B, Bhullar I, et al. A prehospital shock index for trauma correlates with measures of hospital resource use and mortality. *Surgery* 2012;152:473-6.
- Choi JY, Lee WH, Yoo TK, et al. A new severity predicting index for hemorrhagic shock using lactate concentration and peripheral perfusion in a rat model. *Shock* 2012;38:635-41.
- Liu YC, Liu JH, Fang ZA, et al. Modified shock index and mortality rate of emergency patients. *World J Emerg Med* 2012;3:114-7.
- Bhandarkar P, Munivenkatappa A, Roy N, et al. Pattern and Distribution of Shock Index and Age Shock Index Score Among Trauma Patients in Towards Improved Trauma Care Outcomes (TITCO) Dataset. *Bull Emerg Trauma* 2018;6:313-7.
- Rozeboom PD, Bronsert MR, Henderson WG, et al. The preoperative risk tool SURPAS accurately predicts outcomes in emergency surgery. *Am J Surg* 2021;222:643-9.
- Sangji NF, Bohnen JD, Ramly EP, et al. Derivation and validation of a novel Emergency Surgery Acuity Score (ESAS). *J Trauma Acute Care Surg* 2016;81:213-20.