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Cohort Study

Shock index as a prognosticator for emergent surgical intervention and mortality in trauma patients in Johannesburg: A retrospective cohort study

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ABSTRACT

Introduction: Trauma is the leading cause of morbidity and mortality worldwide with exsanguination being the primary preventable cause through early surgical intervention. We assessed two popular trauma scoring systems, injury severity scores (ISS) and shock index (SI) to determine the optimal cut off values that may predict the need for emergent surgical intervention (ESI) and in-hospital mortality.
Methods: A retrospective analysis of patient records from a tertiary hospital's trauma unit for the year 2019 was done. Descriptive statistics, univariate and multivariate logistic regression analyses were performed. Receiver operator characteristic (ROC) curve analysis was conducted and area under the curve (AUC) reported for predicting the need for ESI in all study participants, as well as in patients with penetrating injuries alone, based on continuous variables of ISS, SI or a combination of ISS and SI. The Youdin Index was applied to determine the optimal ISS and SI cut off values.
Results: A total of 1964 patients' records were included, 89.0% were male and the median age (IQR) was 30 (26–37) years. Penetrating injuries accounted for 65.9% of all injuries. ISS and SI were higher in the ESI group with median (IQR) 11 (10–17) and 0.74 (0.60–0.95), respectively. The overall mortality rate was 4.5%. The optimal cut-off values for ESI and mortality by ISS (AUC) were 9 (0.74) and 12 (0.86) ($p = 0.0001$), with optimal values for SI (AUC) being 0.72 (0.60), and 0.91 (0.68) ($p = 0.0001$), respectively.
Conclusion: ISS and SI are significant, independent prognosticators for the need of ESI and in-hospital mortality.

1. Introduction

Everyday more than 14 000 lives are lost as a result of trauma, making it the leading cause of morbidity and mortality worldwide [1]. This number is expected to increase by 40% by the year 2030 resulting in nearly 8.2 million injuries per year. The brunt (>90%) of which is largely carried by lower and middle-income countries (LMIC) with nearly one-fifth in Africa alone [2].

The burden of injury is inversely proportional worldwide with mortality increasing as the economic level of the country decreases, an inequality that creates 2 million preventable deaths per year [3].

Trauma not only places a significant burden on the global economy, but also directly on a country's health care system, reportedly being the fifth leading cause of death within government hospitals [4]. Death from trauma has been shown to have a trimodal distribution with 45% occurring within the golden hour (first 60 min from time of injury) and a further 34% in the next 1–4 h [5–7]. Brain injury, exsanguination, and a combination of both account for the leading causes of death during these first two periods. Approximately one-fourth of these mortalities are potentially preventable, with exsanguination being the number one preventable cause through early surgical intervention [7].

The diagnosis of haemorrhagic shock from exsanguination however is not always a simple one to make. The traditional tachycardia and hypotension can be masked due to patient and external factors. Compensatory mechanisms, rate-controlled medications, pacemakers [8], as well as the advancement in trauma care worldwide which has led to the earlier initiation of resuscitation interventions in response to hypovolemia, has resulted in patients being normotensive on arrival to emergency departments. It has been shown that patients with pre-hospital hypotension but normal systolic blood pressures on arrival to hospital, where occult shock persists, have a greater likelihood of requiring emergent surgical intervention and higher mortality rates if

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undiagnosed [8–10].

It is for these reasons that vital signs alone are unreliable, and that trauma societies seek to create clinical scoring systems to aid in the early identification of shock.

One such scoring system first introduced by Allgöwer and Burri in 1976 described the Shock Index (SI) by the ratio of Heart Rate (HR) to Systolic Blood Pressure (SBP) as a means of measuring hypovolemia in haemorrhagic and infectious states [11]. A normal SI range of 0.5–0.7 is found in the general healthy population with values greater than 0.9 predicting higher triage priority and intensive therapy [11]. In predominantly high-income countries with differing traumatology to LMIC, studies over the years have shown that higher SI values have the ability to predict the need for massive transfusions, emergent surgical intervention, 28-day mortality and are superior to SBP and HR in triaging [12–17]. Noteworthy none of these studies demonstrated a uniformly determined SI cut off value. Moreover, with the burden of trauma largely born by LMIC, it is imperative to define the predictive role of SI within a large cohort of patients from our setting.

Another commonly cited scoring system is the Injury Severity Score (ISS). Described as the gold standard, ISS is an anatomically based score originally derived in 1974 as a means of uniformly describing patients with multiple injuries. It is calculated by taking the three most severely injured body regions and adding together the square of the single highest abbreviated injury scale (AIS) score for each, giving a score between 0 and 75 [18]. While some variation exists as to the accepted definition of severe trauma, an ISS of >15, which is theoretically predictive of 10% mortality, is universally accepted and such patients should be treated in a level one trauma center. Not only does morbidity and mortality increase with an increasing ISS but so does the need for surgical intervention and the length of hospital stay [19].

Making use of standardized scoring systems allows for the early identification and rapid triage of the severely injured requiring immediate medical and/or surgical care and predicting patient outcomes, while at the same time providing a universal outcome-based measure of hospital performance. However, these systems have been developed in high-income environments where the burden of trauma differs to that seen in LMICs and thus have been found to underpredict mortality in LMICs [20].

A recent study by Lammer et al. [21] evaluated the role of both ISS and SI in a relatively resource-limited combat trauma facility and found an ISS lower than 15 to be predictive of mortality and need for surgical intervention, with an SI cut-off of 0.94 and 0.81, respectively.

Our study therefore sought to evaluate the role of SI and ISS within a LMIC urban trauma centre in South Africa by evaluating the need for emergent surgical intervention (ESI) and mortality as the outcome parameters.

2. Methods

2.1. Patient selection

A retrospective cohort review of all trauma patients records at a single academic tertiary hospital trauma unit (modelled after Level 1 United States of America Guidelines for trauma centers) in Johannesburg, South Africa, during a 12-month period from 1st January 2019 to 31st December 2019 was performed on patient records over the age of 18 years old who were trauma team activations. The patient records excluded from the study cohort are shown in Fig. 1. The data set was then grouped according to the need for ESI, as defined by the patients need for surgery following evaluation on arrival to hospital, by a

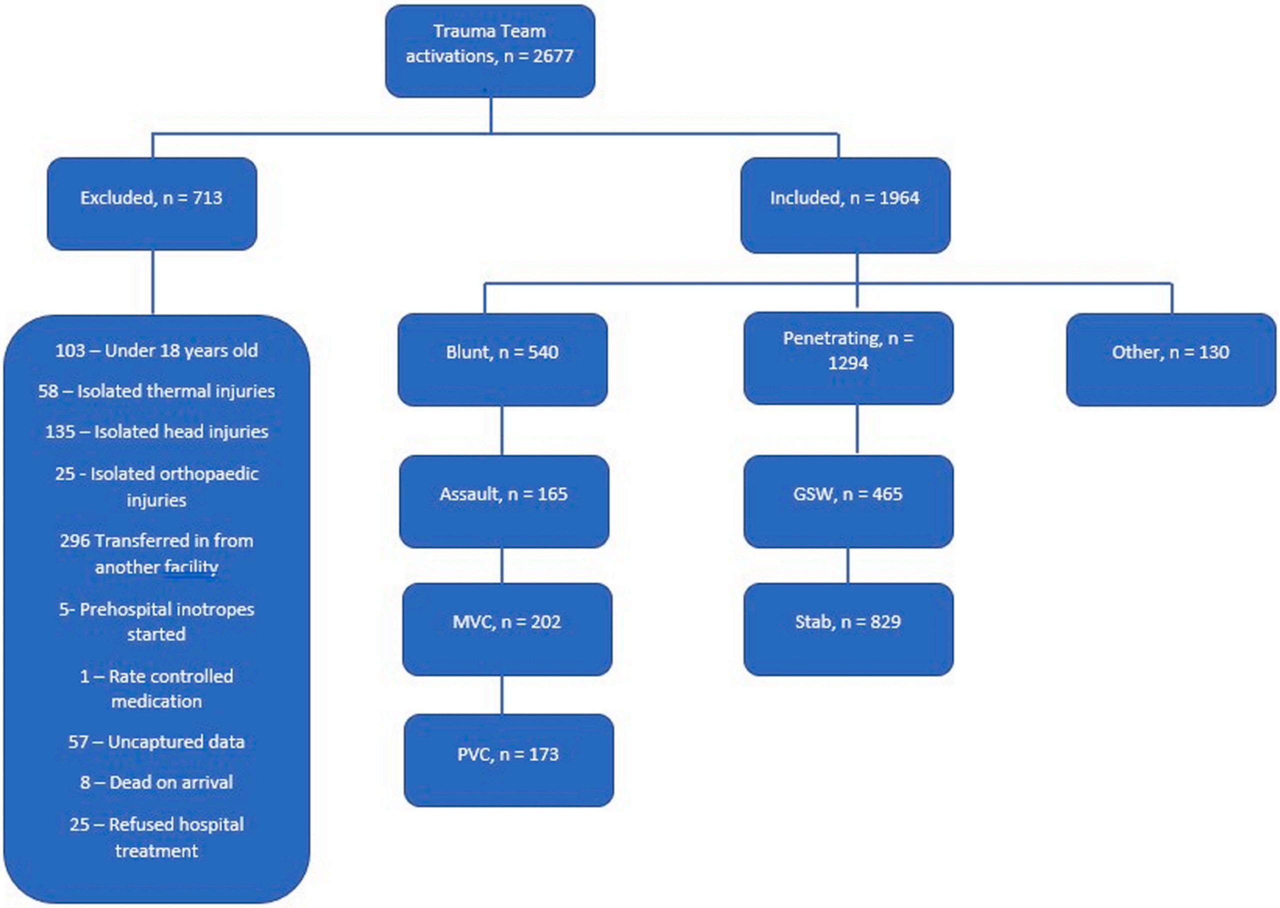


Fig. 1. Consort diagram of patient records included and excluded from the study.

qualified physician, whereby failure to operate will result in the potential or actual loss of limb or life. Statistical analysis was then based on those who underwent an ESI vs those not operated on. The operative notes of all ESI performed were grouped according to the need for hemorrhage control, sepsis control, a combination of both or other.

2.2. *Ethical approval*

Ethical approval was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical) (clearance number M190814) and from the office of the hospital's Chief Executive Officer (CEO). The study was been registered in accordance with the declaration of Helsinki with registration number ChiCTR2100044537 (http://www.chictr.org.cn/showprojen.aspx?proj=123685) issued by the Chinese Clinical Trial Registry.

2.3. *Data acquisition and reporting*

All data collected was de-identified with a unique study number within a Microsoft Excel spreadsheet, to which only the researchers had access. Data included age, gender, population group, ISS (as calculated by adding the squared values of the three most injured regions as determined by their respective AIS) and mechanism of injury (MOI). MOI was categorised as Penetrating (including stab and gunshot wounds), Blunt (including assault, motor vehicle collisions and pedestrian vehicle collisions) or Other injuries. The latter group included injury types that did not distinctly conform to penetrating or blunt injuries, such as falls, crushes, dog bites or hangings. Physiological parameters included the first recorded HR and SBP on arrival, taken within in 10 min of arrival to the trauma unit, with the corresponding cross-sectional SI being calculated (HR divided by SBP), type of surgical intervention performed, and cavity operated on, day of mortality from injury and identifiable factors associated with the mortality were recorded. The study has been reported in line with the Strengthening The Report Of Cohort Studies in Surgery (STROCSS) Criteria [22].

2.4. *Statistical analyses*

The full dataset was imported, and all statistical analyses were conducted using the STATA Version 14.2 suite of analytics software. The Shapiro-Wilk W test was performed to determine the normality of data distribution. Descriptive statistics were performed for all study participants and reported as median values with interquartile ranges (IQRs) or frequencies, as appropriate. Dichotomized grouping of patients for the outcome variables of need for ESI (ESI vs non-operated), mode of injury (blunt vs penetrating) and in-hospital mortality (dead vs alive) were assessed using the non-parametric Mann-Whitney U tests and the Pearson's Chi-squared with Fishers' exact test, as appropriate. A 5% level of significance was considered statistically significant.

Univariate and multivariate logistic regression analyses were conducted for risk analysis and model building. Receiver Operator Characteristic (ROC) curve analysis was conducted and area under the curve (AUC) reported for predicting the need for ESI in all study participants, as well as in patients with penetrating injuries alone, based on continuous variables of ISS, SI or a combination of ISS and SI. The Youdin Index was applied to determine the optimal ISS and SI cut off values and sensitivity and specificities are reported for these values.

3. Results

During the 12-month study period, a total of 1964 out of 2677 (73.4%) patient records met the inclusion criteria (Fig. 1). From Table 1, significantly more patients (89.0%, p-value = 0.02) were male, and the median (IQR) age was 30 (26–37) years, with no significant difference in age between the ESI and non-operated groups. Male patients also accounted for most patients requiring an ESI (92.1%, n = 406/441).

Table 1
Patient demographics, mechanism of injury, vital parameters and calculated indices by need for emergent surgical intervention (ESI) and in-hospital mortality.

Variable	All patients	Non-Operated	ESI	P value
Total, n (%)	1964 (100%)	1523 (77.6)	441 (22.5)	–
Age (years), median (IQR)	30 (26–37)	31 (26–37)	30 (25–36)	0.10[a]
Gender, n (%)				0.02[b]
Female	217 (11.1)	182 (83.9)	35 (16.1)	
Male	1747 (89.0)	1341 (76.8)	406 (23.2)	
MOI, n (%)				<0.0001[b]
Blunt	540 (27.5)	486 (90.0)	54 (10.0)	
Assault	165 (8.4)	*155 (93.9)*	*10 (6.1)*	
MVC	202 (10.3)	*186 (92.1)*	*16 (7.9)*	
PVC	173 (8.8)	*145 (83.8)*	*28 (16.2)*	
Penetrating	1294 (65.9)	919 (71.0)	375 (29.0)	
GSW	465 (23.7)	*280 (60.2)*	*185 (39.8)*	
Stab	829 (42.2)	*639 (77.1)*	*190 (22.9)*	
Other	130 (6.6)	118 (90.8)	12 (9.2)	
ISS, median (IQR)	9 (1–10)	4 (1–10)	11 (10–17)	<0.0001[a]
Blunt	5 (1–12)	5 (1–10)	17 (10–26)	<0.0001[a]
Penetrating	10 (1–10)	2 (1–10)	10 (10–17)	<0.0001[a]
Other	9 (2–16)	6 (1–14)	16 (12.5–27)	0.002[a]
HR (bpm), median (IQR)	89 (77–101)	88 (76–99)	90 (79–107)	0.001[a]
SBP (mmHg), median (IQR)	133 (116–149)	135 (120–152)	123 (102–140)	<0.0001[a]
SI, median (IQR)	0.67 (0.55–0.80)	0.65 (0.54–0.78)	0.74 (0.60–0.95)	<0.0001[a]
Blunt	0.67 (0.55–0.81)	0.66 (0.54–0.79)	0.95 (0.65–1.33)	<0.0001[a]
Penetrating	0.67 (0.55–0.80)	0.65 (0.54–0.78)	0.73 (0.60–0.90)	<0.0001[a]
Other	0.65 (0.53–0.81)	0.62 (0.51–0.78)	0.82 (0.68–0.98)	0.008[a]
Mortality, n (%)	83 (4.5)	34 (38.2)	55 (61.8)	<0.001[b]
Age (years), median (IQR)	31 (27–35)	32 (27–35)	31 (26–35)	0.90[a]
Day, median (IQR)	1 (1–4)	1 (1–2)	1 (1–6)	0.36[a]

Abbreviations: bpm, beats per minute; G*SW, Gunshot Wound; HR, Heart Rate; ISS, Injury Severity Score; IQR, Interquartile Range; mmHg, millimeters of mercury; MOI, Mechanism of Injury; MVC, Motor Vehicle Collision; n, Number; PVC, Pedestrian Vehicle Collision; SI, Shock Index.*

[a] Mann-Whitney U test.

[b] *Chi-squared test.*

Penetrating injuries (65.9%, n = 1294) were the most common mechanism of injury sustained and the most likely injury type requiring an ESI, with 29.0% of all penetrating injury patients needing an ESI compared to only 10.0% of blunt injury patients (p < 0.0001).

When comparing vital parameters recorded on arrival in the ESI vs non-operated group of patients, a significantly higher median (IQR) HR of 90 (79–107) vs 88 (76–99) bpm, respectively (p = 0.001), and a significantly lower median (IQR) SBP of 123 (102–140) vs 135 (120–152) mmHg, respectively (p < 0.0001) were found (Table 1). In addition, the calculated indices of ISS and SI were also significantly higher in the ESI group with median (IQR) values of 11 [10–17] and 0.74 (0.60–0.95), respectively (both p-values <0.0001). When these indices were further analyzed according to MOI, both ISS and SI had significantly higher medians for those who underwent an ESI to those who did not (both p-values <0.0001). Notably however, blunt injuries that underwent an ESI had higher median (IQR) ISS and SI to that of penetrating injuries [17 [10–26] vs 10 [10–17] and 0.95 (0.65–1.33) vs 0.73 (0.60–0.90), respectively].

The overall mortality rate for the study cohort was 4.5%, of which the majority were in the ESI group (61.8%; p < 0.001), with no significant differences for age or day of mortality between the two groups.

Table 2 shows univariate logistic regression analysis of ISS and SI across the study cohort, as well as in the subgroup of penetrating MOI patients alone, an independent predictor of ESI in our study. For ISS, the effect of the odds of a 1-unit increase in ISS is 1.13, meaning the odds of requiring an ESI are on average 13% higher for every unit increase of ISS ($p < 0.0001$) with a specificity of 95.3%, albeit at a low sensitivity of 17.2%. The Youdin index was used to determine the optimal cut-off value for ISS in our study of 9. Based on this value, a patient is 10.87 (95% confidence interval, CI: 8.05–14.69) times more likely to require an ESI if their ISS is ≥ 9, compared to those patients with an ISS below this cut-off ($p < 0.0001$). Similarly, in the penetrating injury group alone, with an optimal ISS cut-off value of 4, a patient is 25.45 (95% CI: 14.95–43.35) times more likely to require an ESI if their ISS is above or equal to 4 ($p < 0.0001$).

For SI, the effect of the odds of a 1-unit increase in SI is 6.79, meaning the odds of requiring an ESI are approximately 6.79 times more likely for every unit increase of SI ($p < 0.0001$) with a specificity of 99.2% and low sensitivity of 7.6%. As a 1-unit increase in SI is clinically highly unlikely, this translates to the equivalent of a 21% increase in the odds of requiring an ESI for a 0.1 unit increase in SI as shown in Fig. 2, with a regression constant of 0.069. Based on our optimal SI cut-off for ESI of 0.72 in our study, a patient is 2.22 (95% confidence interval, CI: 1.79–2.75) times more likely to require an ESI if their SI is ≥ 0.72, compared to those patients with a SI below this cut-off ($p < 0.0001$). In the penetrating injury group alone, a patient is 2.03 (95% CI: 1.59–2.60) times more likely to require an ESI if their SI is above or equal to 0.72 ($p < 0.0001$).

In comparison, optimal cut off values reported in the recent study by Lammer et al. [21] were an ISS$\geq$12.5 (specificity of 75.1% and sensitivity of 86.9%) and SI $\geq$ 0.81 (specificity of 86.8% and sensitivity of 53.4%), hence we also included these cut off values in our analyses as well as the internationally recognized ISS cut-off value for defining major trauma of >15, as shown in Table 2.

Notably, the area under the curve (AUC) was much higher for ISS with sensitivity 17.2% and specificity 95.3% than SI and in the multivariate analysis SI did not contribute to increasing the AUC beyond that of ISS alone although there was a 4.74% increase in sensitivity (Table 2 and Fig. 3A). ISS alone is therefore the stronger predictor for ESI. Within the penetrating MOI subgroup there was significant improvement to the sensitivity of the model with ISS alone increasing to 40.80% and the sensitivity of the combined ISS and SI model to 42.74% (Table 2 and Fig. 3B).

In Table 3, a sub-analysis of in-hospital mortality showed that patients who later succumbed to their injuries had a significantly higher median (IQR) HR of 103 (78–118) bpm ($p = 0.001$) and a significantly lower median (IQR) SBP of 110 (78–134) mmHg ($p < 0.0001$), upon arrival to hospital. This equated to higher SI values for those who demised in hospital [0.91 (0.63–1.28) vs 0.67 (0.55–0.80), $p < 0.0001$] and significantly higher ISS values [26 [17–28] vs 5 [1–10], $p < 0.0001$]. Regarding the MOI, 6.1% of blunt injuries and 6.9% of 'other' injuries demised in hospital, compared to only 3.6% of penetrating injuries ($p = 0.023$). Of the penetrating injuries that demised, 85.1% (n = 40/47) underwent an ESI compared to 42.4% (n = 14/33) of blunt injuries and 11.1% (n = 1/9) of 'other' injuries (p=<0.0001; data not shown).

Control of hemorrhage was the most common surgical intervention performed during the ESI (n = 234/441) and was cited in 75% ($p = 0.001$) of patients who underwent an ESI and who later demised. A total of 17 emergency room thoracotomies were performed with only 2 survivors ($p < 0.001$). The most cited factors contributing to the mortality of patients were exsanguination in 41.7% (n = 35/84), 25% (n = 21/84) severe head injury and 17.9% (n = 15/84) sepsis, with the remaining including blunt cardiac injuries and renal failure (data not shown).

Table 4 shows univariate logistic regression analysis of ISS and SI in relation to in-hospital mortality in this study cohort and within the subgroup of penetrating MOI patients, also an independent predictor of in-hospital mortality. For ISS, the effect of the odds of a 1-unit increase in ISS is 1.20, meaning the odds of demise in hospital are on average 20% higher for every unit increase of ISS ($p < 0.0001$) with a specificity of 99.3%, albeit at a low sensitivity of 20.5%. The optimal ISS cut off value in our cohort as determined by the Youdin index was 12 and we also analyzed our data according to the internationally recognized ISS cut-off value for defining major trauma of >15 and that reported by Lammers' group of $\geq$12.5. All three these cut off values showed similar results with a patient 45 (95% CI: 22–94) times more likely to demise in hospital if their ISS is $\geq$ 12, compared to those patients with an ISS below this cut-off ($p < 0.0001$). Similar results are seen in the penetrating injury group alone (Table 4).

For SI, the effect of the odds of a 1-unit increase in SI is 8.8, meaning the odds of demise are approximately 8.8 times more likely for every

Table 2

Univariate and multivariate analysis of ISS and SI to distinguish patients needing an emergent surgical intervention (ESI) across the entire cohort and in penetrating MOI patients alone.

Variable	AUC	Sensitivity (%)	Specificity (%)	OR	OR 95% CI	P-Value
Entire Cohort						
ISS Continuous	0.81	17.2	95.3	1.13	1.11–1.14	<0.0001
ISS $\geq$9	0.74	0.0	100.0	10.87	8.05–14.69	<0.0001
ISS$\geq$12.5	0.68	49.7	86.8	6.48	5.11–8.23	<0.0001
ISS>15, internationally	0.68	44.4	91.0	8.09	6.26–10.47	<0.0001
SI Continuous	0.63	7.6	99.2	6.79	4.49–10.26	<0.0001
SI $\geq$ 0.72	0.60	0.0	100.0	2.22	1.79–2.75	<0.0001
SI $\geq$ 0.81	0.59	0.0	100.0	2.45	1.95–3.09	<0.0001
Multivariate ISS and SI	0.81	22.0	95.5			<0.0001
ISS				1.12	1.10–1.13	<0.0001
SI				3.29	2.14–5.06	<0.0001
Penetrating MOI only						
ISS Continuous	0.82	40.8	94.5	1.18	1.16–1.21	<0.0001
ISS $\geq$4	0.74	0.0	100.0	25.45	14.95–43.35	<0.0001
ISS $\geq$12.5	0.69	46.1	92.4	10.39	7.56–14.26	<0.0001
ISS>15, internationally	0.68	40.8	95.5	11.73	8.27–16.64	<0.0001
SI Continuous	0.61	7.8	99.0	5.80	3.48–9.66	<0.0001
SI $\geq$ 0.72	0.59	0.0	100.0	2.03	1.59–2.60	<0.0001
SI $\geq$ 0.81	0.58	0.0	100.0	2.27	1.73–2.97	<0.0001
Multivariate ISS and SI	0.83	42.7	93.6			<0.0001
ISS				1.18	1.15–1.21	<0.0001
SI				2.48	1.45–4.25	0.001

Abbreviations: *AUC, Area Under the Curve; CI, Confidence Interval; ISS, Injury Severity Score; OR, Odds Ratio; SI, Shock Index.*

Estimate probability of ESI $= \dfrac{e^{\ln(0.069)+[\ln(6.79)*\mathrm{SI}]}}{1 + e^{\ln(0.069)+[\ln(6.79)*\mathrm{SI}]}}$

p-hat $= \dfrac{e^{-2.668+[1.916*\mathrm{SI}]}}{1 + e^{-2.668+[1.916*\mathrm{SI}]}}$

For SI of 0.8:

p-hat $= \dfrac{e^{-2.668+[1.916*0.8]}}{1 + e^{-2.668+[1.916*0.8]}}$

p-hat $= \dfrac{4.630}{5.630}$

p-hat $= 0.822$

Odds ratio $= \dfrac{0.822}{1-0.822}$

$=$ **4.63**

For SI of 0.9 (0.1 unit increase):

p-hat $= \dfrac{e^{-2.668+[1.916*0.9]}}{1 + e^{-2.668+[1.916*0.9]}}$

p-hat $= \dfrac{5.607}{6.607}$

p-hat $= 0.849$

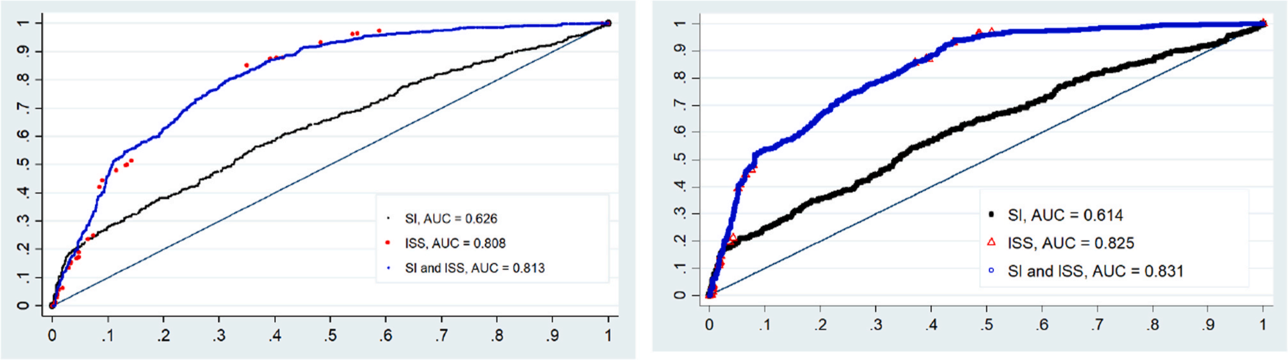
Odds ratio $= \dfrac{0.849}{1-0.849}$

$=$ **5.61**

Odds ratio for a **0.1 unit increase in SI** $= \dfrac{5.61}{4.63}$

$=$ **1.21**

Fig. 2. Logistic regression equations for a 0.1 unit increase in SI predicting the odds of requiring an emergency surgical intervention (ESI).



A. ROC for SI and ISS on need for emergency surgical procedure

B. ROC for SI and ISS on need for emergency surgical procedure in penetrating trauma

For each graph, the x axis represents 1 - Specificity and the Y axis represents Sensitivity.

Fig. 3. ROC showing the relationship of SI and ISS for emergent surgical procedure in all study patients (A) and in penetrating injury patients alone (B).

Table 3
Sub-analysis of factors associated with in-hospital mortality.

Variable	Survivors (n = 1875)	In-Hospital Mortality (n = 89)	P Value
ISS, median (IQR)	5 (1–10)	26 (17–28)	<0.0001
HR (bpm), median (IQR)	88 (76–100)	103 (78–118)	<0.001
SBP (mmHg), median mmHg (IQR)	133 (118–149)	110 (78–134)	<0.0001
SI, median (IQR)	0.67 (0.55–0.80)	0.91 (0.63–1.28)	<0.0001
MOI, n (%)			0.023
Blunt	507 (93.9)	33 (6.1)	
Penetrating	1247 (96.4)	47 (3.6)	
Other	121 (93.1)	9 (6.9)	
Emergency Thoracotomy, n (%)	2 (0.1)	15 (16.9)	<0.001
Surgery for Hemorrhage, n (%)	194 (49.9)	42 (75.0)	0.001

Abbreviations: *ESI, Emergent Surgical Intervention HR, Heart Rate; ISS, Injury Severity Score; MOI, Mechanism of Injury; SBP, Systolic Blood Pressure; IQR, Interquartile Range; SI, Shock Index.*

unit increase of SI ($p < 0.0001$) with a specificity of 99.8% and low sensitivity of 3.5%. As explained above for SI and ESI, based on the equation shown in Fig. 2, this translates to the equivalent of a 24% increase in the odds of in-hospital mortality for a 0.1 unit increase in SI with a regression constant of 0.008.

Our optimal cut-off for SI was ≥0.91 for both groups, which were lower than the optimal cut off values reported by Lammer et al. [21] with an SI ≥ 0.94 and ISS≥12.5 (Table 4). All our cut-off values carried a sensitivity 0% and specificity 100% and demonstrated they significantly discriminated patients who demised in hospital from those who survived to discharge (all p-values <0.0001). Based on our optimal SI cut-off for in-hospital mortality of 0.91, a patient is 6.65 times more likely to demise if their SI is ≥ 0.91, compared to those patients with a SI below this cut-off. Similarly, in the penetrating MOI group, a patient is 7.43 times more likely to demise if their SI is above or equal to 0.91.

ISS again proved to be the greater predictor with an AUC of 0.93 for in-hospital mortality across the entire cohort with SI not increasing the AUC in the multivariate model with only a marginal 5% improvement in sensitivity (Table 4 and Fig. 4A). Similar findings were found in the subgroup analysis of penetrating MOI alone (Table 4, Fig. 4B).

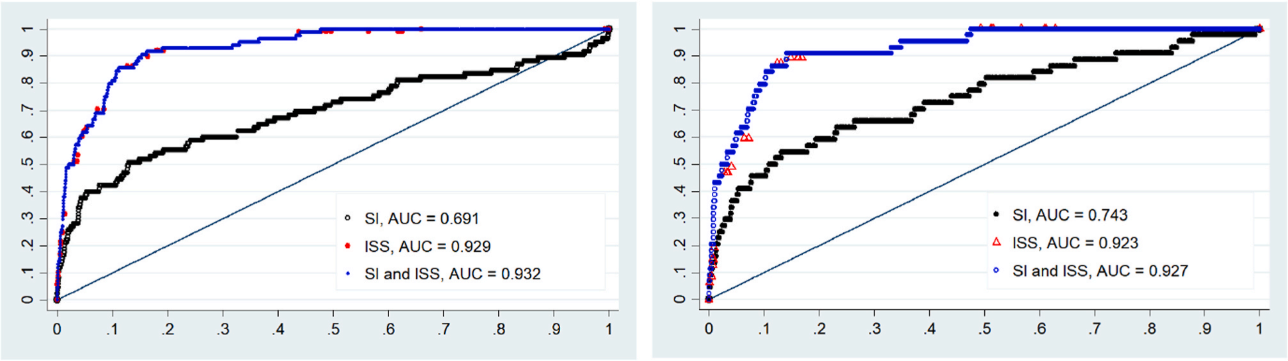
4. Discussion

South Africa is a middle-income country and, like other LMICs, has a high burden of traumatic injuries in the young 15–29 year old, predominantly male population [1], as is seen in our study. Globally injuries have significant variance depending on the geographical region and socio-economic background. Unintentional injuries, such as suicide

Table 4
Univariate and multivariate analysis of ISS and SI to distinguish in-hospital mortality across the entire cohort and in penetrating MOI patients alone.

Variable	AUC	Sensitivity (%)	Specificity (%)	OR	OR 95% CI	P-Value
Entire cohort						
ISS Continuous	0.93	20.5	99.3	1.20	1.17–1.23	<0.0001
≥12	0.86	0.0	100.0	45.06	21.59–94.04	<0.0001
≥12.5	0.87	0.0	100.0	52.43	24.01–114.49	<0.0001
>15, internationally	0.86	0.0	100.0	36.81	20.14–67.25	<0.0001
SI Continuous	0.69	3.5	99.8	8.80	5.11–15.15	<0.0001
≥0.91	0.68	0.0	100.0	6.65	4.26–10.39	<0.0001
≥0.94	0.66	0.0	100.0	6.28	3.99–9.87	<0.0001
Multivariate ISS and SI	0.93	25	99.2			<0.0001
ISS				1.19	1.15–1.22	<0.0001
SI				3.56	2.07–6.10	<0.0001
Penetrating Injuries only						
ISS Continuous	0.92	12.8	99.4	1.19	1.15–1.24	<0.0001
≥12.5	0.87	0.0	100.0	43.71	17.09–111.84	<0.0001
>15, internationally	0.87	0.0	100.0	45.44	18.99–108.72	<0.0001
SI Continuous	0.74	4.6	99.8	8.38	4.07–17.26	<0.0001
≥0.91	0.70	0.0	100.0	7.43	4.02–13.74	<0.0001
≥0.94	0.69	0.0	100.0	7.64	4.12–14.18	<0.0001
Multivariate	0.93	18.2	99.5			<0.0001
ISS				1.18	1.13–1.23	<0.0001
SI				4.24	2.13–8.44	<0.0001

Abbreviations: *AUC, Area Under the Curve; CI, Confidence Interval; ISS, Injury Severity Score; OR, Odds Ratio; SI, Shock Index.*



A. ROC for SI and ISS on in-hospital mortality

B. ROC for SI and ISS on in-hospital mortality in penetrating trauma

Fig. 4. ROC showing the relationship of SI and ISS for in-hospital mortality over the entire cohort (A) and in penetrating injuries alone (B).

and road traffic accidents, predominate in high-income countries. South Africa, on the other hand, is one of the only countries worldwide where the rate of intentional injury (blunt assault and penetrating injuries) is higher than that of unintentional injuries, most likely as a result of social anomie and broader social economic factors [1,23]. This is also reflected in our findings and in keeping with a surveillance study from Cape Town [24] reporting that road traffic accidents accounted for 19.1% and interpersonal violence for 74.5% of all injuries sustained.

Penetrating injuries accounted for the majority of our study patients and in those who demised. These statistics reflect the fact that South Africa's intentional homicide rate at 35.8 per 100 000 is over six times that of the world average [25]. Our study findings support those from a recent study by Lammers' group reporting on combat trauma [21] where penetrating injuries predominated unlike the usual blunt trauma of civilian trauma and showed ISS and SI to be predictive of mortality. Furthermore and in keeping with other international studies [13–15,18,19], we too found that mortality increases as both ISS and SI increase and thus ISS and SI are predictive factors within our setting.

We report that a lower ISS cut off, than international standards, of ≥9 across our study cohort, and an even lower ISS of ≥4 within the sub analysis of penetrating MOI patients alone, are on average 10.9 and 25.5 times more likely to require emergency surgery, respectively. These findings are in keeping with that of Lammers' group [21] who reported that a ISS>12.5 (below the internationally recognized ISS of 15) was predictive of ESI and mortality across their study population. Noteworthy within our study, an optimal ISS cut off for blunt injuries alone requiring ESI remained 15, in keeping with the international definition of severe trauma. This highlights the downfall of the discriminative ability of ISS to identify severe trauma in penetrating injuries alone as it only considers the single highest AIS per cavity and negates the full extent of injury caused. It is for this reason that, due to the predominance of penetrating injuries within our study cohort, we suspect that our ISS values demonstrating severe injury and requiring ESI are lower than the globally recognized ISS of 15.

The clinical bedside value of ISS is limited though, not only within resource-constrained environments lacking access to adequate radiological evaluation, but also due to the extensive time-consuming coding based on AIS that is required. Its value however is in trauma quality improvements and appropriate allocation of resources through evaluating the services and resources needed, such as dedicated theaters and intensive care capacity [20]. Results from our study demonstrate that the globally accepted ISS cut-off of 15 for severe trauma may in fact underestimate the severity of trauma within our population and thus the resources required to manage it. However, a larger, prospective study across multiple institutions is needed to validate the optimal ISS cut off level for our trauma patients in South Africa and subsequently inform resource allocation.

SI, a physiological based score, has the advantage of being easily calculated at the bedside with the first set of vital signs recorded in hospital, or even before hospital admission. While the clinical utility of SI is well known in predicting in-hospital mortality, blood transfusion and ICU admissions, there is still conflicting evidence to its use in predicting the need for surgical intervention in the trauma patient and large heterogeneity in optimal cut off values are reported [10,12–17,26,27]. Our study reports an optimal SI cut off value of ≥0.72 for ESI, a level at which the likelihood of requiring an ESI doubled. In addition, at an optimal SI cut off of ≥0.91 for in-hospital mortality, the odd of demise were 6.7 times higher. Again, our findings are in keeping with those reported by Lammers' group of cut off values of 0.81 and 0.94, respectively, showing that SI is an independent predictor of both ESI and in-hospital mortality.

Moreover, theoretically ISS was a stronger predictor than SI of both ESI and in-hospital mortality but, as discussed above, the clinical bedside value of ISS is limited.

The ever-growing burden of trauma globally cannot be highlighted enough as the effects are far-reaching. With approximately 50% of patients with haemorrhagic shock in the emergency department being taken directly to theatre [28], and hemorrhage being one of the leading causes and the leading preventable cause of early mortality, it is crucial that prompt and continuous assessment of the patient on arrival to hospital occurs such that occult shock and hemorrhage are detected early.

While no optimal scoring system can currently accurately identify the need for surgery alone, we found that for every 0.1 unit increase in SI there is a 21% increase in the odds of requiring an ESI and 24% increase in mortality. We believe that the use of SI at the bedside to alert clinicians to patients, who on initial presentation present with stable vitals but in fact have a greater likelihood of requiring an ESI or of demising, can be invaluable in a low resourced setting.

4.1. Limitations of the study

We acknowledge that the retrospective nature of the study allows for possible selection bias, with a significant number of patients excluded. Furthermore, our study was conducted at an urban trauma centre within the economic hub of South Africa and so may not be representative of the rest of the general population.

5. Conclusion

We report that the ISS and SI values are significantly higher in patients requiring an ESI, as well as in those who demised in hospital. Moreover, from logistic regression analysis we have demonstrated that ISS and SI are significant, independent predictors of the need for ESI as well as in-hospital mortality, especially in patients with penetrating injuries, in a retrospective cohort of trauma patients from a single trauma centre in Johannesburg, South Africa. A future prospective, multicentre study is required to validate these findings in the larger South African trauma population.

Declarations

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Not commissioned, externally peer-reviewed.

Ethical approval

Yes, ethical approval was obtained from the University of the Witwatersrand Human Research Ethics Committee (Medical) (clearance number M190814).

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Author contribution

Richard Crawford: conceived and contributed to study design, data collection, data interpretation, drafted the manuscript and approved the final version.

Deirdré Kruger: contributed to the study design, data analysis, data interpretation, critically revised the manuscript, and approved the final version.

Maeyane Moeng: conceived the study design, critically revised the manuscript and approved the final version.

Research registration Unique Identifying number (UIN)

Name of the registry: Chinese Clinical Trial Registry.

Unique Identifying number or registration ID: ChiCTR2100044537.

Hyperlink to your specific registration (must be publicly accessible and will be checked): http://www.chictr.org.cn/showprojen.aspx?proj=123685.

Guarantor

All three the authors (RC, DK, MM) accept full responsibility for this study and manuscript.

Declaration of competing interest

The authors report no conflict of interest nor proprietary or commercial interest in any product mentioned or concept discussed in this article.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2021.102710.

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