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Predictive value of admission SOFA scores for ICU mortality: A single-centre study from a South African tertiary hospital

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Background. The Sequential Organ Failure Assessment (SOFA) score was initially developed as a tool to quantify the degree of organ dysfunction in patients with sepsis. It is now a commonly used severity-of-illness score across a variety of settings. Although the SOFA score is versatile and simple, it has not been well evaluated in South African (SA) critical care populations.
Objective. To determine whether an association exists between admission SOFA score and patient outcomes in a heterogeneous population of critically ill patients in a tertiary intensive care unit (ICU) in SA.
Methods. This study was a single-centre, retrospective, observational study conducted at a level 3 ICU in Durban, SA. Data required to calculate SOFA scores were obtained from patient charts. The primary outcome of interest was ICU mortality.
Results. Complete data for SOFA score calculation were collected from 279 patient charts. Of the total cohort, 90 patients (32.3%) died, and 189 (67.7%) survived. The median SOFA scores of survivors and non-survivors were 7 and 10, respectively ($p<0.001$). Receiver operating characteristic curve analysis demonstrated an area under the curve of 0.739 (95% confidence interval (CI) 0.677 - 0.800; $p<0.001$) for SOFA score prediction and ICU mortality.
Conclusion. The SOFA score is a simple severity-of-illness tool derived from clinical variables routinely available on ICU admission. In this study, admission SOFA score was independently associated with ICU mortality in a multidisciplinary SA ICU and demonstrated fair discriminative ability for predicting ICU mortality.

Keywords. SOFA score; intensive care unit; critical care; South Africa; ICU mortality

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Contribution of study
This study evaluated the discriminative performance of a single admission SOFA score for predicting ICU mortality in a South African setting. A single admission SOFA score demonstrated fair discriminative ability for ICU mortality (AUC 0.739), performing notably better in trauma and non-communicable disease patients than in those with infection. Given its simplicity and reliance on data collected routinely on admission, the SOFA score may offer a practical, low-cost tool for risk stratification and communication of illness severity in resource-constrained South African ICUs, and provides a local baseline against which the newly released SOFA-2 score can be compare.

Intensive care unit (ICU) costs may amount to up to three times those of general ward patients;[1] therefore, the ability to identify critically ill patients and provide appropriate levels of care to the correct patients is paramount in the South African (SA) healthcare system. Illness severity scores may help identify patients most likely to benefit from critical care.[2] They are also important research and quality assurance tools. The Sequential Organ Failure Assessment (SOFA) score,[3] developed in 1994, is one such scoring system that evaluates the function of six important organ systems. Other commonly used scoring systems include the Acute Physiology and Chronic Health Evaluation (APACHE II) score and the Simplified Acute Physiology Score (SAPS).
The SOFA score was initially designed to describe the degree of organ dysfunction in patients with sepsis, but has subsequently been studied and utilised in a variety of contexts. Most current evidence derives from studies conducted in high-income countries, including the initial validation studies,[3,4] as well as subsequent studies among specific patient groups.[5-8] Although the SOFA score was initially intended for sequential use, a single SOFA score also has predictive value. In a study of 303 patients with cardiovascular disorders admitted to a medical ICU. The SOFA score was shown to be independently associated with outcome, with non-survivors having a higher day 1 SOFA score ($p<0.001$).[9] Furthermore, in a prospective study of patients presenting to an emergency department with sepsis and hypoperfusion, the admission SOFA score had a receiver operating characteristic (ROC)

curve area under the curve (AUC) of 0.75 for predicting in-hospital mortality.[10] These studies demonstrate the potential use of the SOFA score in the evaluation of critically ill patients.

Despite the importance of rational, evidence-based use of limited healthcare resources in SA, few studies have evaluated the use of severity-of-illness scoring systems in the SA context. Studies have evaluated serial SOFA scores,[11,12] the q-SOFA score,[13] the APACHE II score[14] and the SAPS III score,[15] but, to the authors' knowledge, no studies have evaluated admission SOFA scores in the SA ICU context. As the SOFA score is calculated using data routinely available for most ICU patients, further investigation in this setting was warranted.

The objective of this study was to determine whether an association exists between admission SOFA score and ICU outcome in a heterogeneous population of critically ill patients in a tertiary ICU in SA, and to evaluate the nature of this association.

Methods

This was a retrospective, observational study of patients admitted to a tertiary ICU in Durban, KwaZulu-Natal (KZN). The study ICU was a 12-bed, level 3 multidisciplinary adult ICU serving a population of 12.4 million people.[16]

Approval for the study was obtained from the University of KwaZulu-Natal Biomedical Research Ethics Committee (ref. no. BE318/19), Victoria Mxenge Hospital and the Health Research Committee of the KZN Department of Health.

Data collection involved review of all available patient charts for patients admitted to the ICU between 1 October 2019 and 30 June 2020.

All adult patients admitted to the ICU were eligible for inclusion. Exclusion criteria included patients aged <18 years and those with insufficient data from the first 24 hours after admission to calculate a SOFA score. Data were collected retrospectively from patient files stored in the ICU. Data collection proceeded sequentially in reverse chronological order from 30 June 2020 to 1 October 2019. Patients files were reviewed in one-month batches, and all patients admitted during each month were eligible for inclusion.

Data were extracted from patient files into an Excel spreadsheet (Microsoft, USA). Variables collected included demographic, clinical, biochemical and outcome data. Blood gas data were obtained from the GEM Premier 3000 analyser (Werfen, Spain), the point-of-care analyser used in the ICU.

The SOFA score evaluates the function of six major organ systems: respiratory, cardiovascular, renal, hepatic, central nervous system and circulation. (Table 1).

Individual SOFA scores were calculated for each of the six SOFA components, and the total SOFA score was derived as the sum of these component scores. The biochemical data used for SOFA score calculation were obtained from blood samples collected on ICU admission. As patients were expected to have received some form of sedation to facilitate safe transport or transfer to the ICU, the SOFA Glasgow Coma Scale (GCS) component was based on the best assumed unsedated GCS score, unless a pre-sedation GCS score had been documented, in which case that value was used for score calculation.

Using a baseline mortality rate of 35% (based on historical data from the study ICU), with a power of 80% and an alpha level of 0.05, a minimum sample size of 183 was calculated to demonstrate a 10% difference in mortality using a dichotomised SOFA score. Approximately 25% of admissions to the study ICU were anticipated to be trauma patients. To permit analysis with trauma patients both included and excluded, data for an additional 46 patients were targeted. The final minimum sample size was therefore determined to be 230 patients. Owing to *en bloc* data file storage and the data collection process, and to ensure that the minimum sample size was maintained after exclusions, data were collected for 283 patients. Four patients were subsequently excluded owing to incomplete data, yielding a final sample size of 279 patients.

Statistical analysis was performed using IBM SPSS Statistics for Windows, version 29.0 (IBM Corp., USA). Categorical variables were summarised as numbers and percentages and compared using the χ^2 test or Fisher's exact test, as appropriate. Continuous variables were described using medians and interquartile ranges (IQRs), as the data distributions were predominantly non-Gaussian according to the Kolmogorov–Smirnov test. Comparisons were performed using the Mann-Whitney *U*-test. ROC curve analysis was used to assess the discriminative ability of the SOFA score. Statistical significance was set at $p<0.05$.

The primary independent variable was the admission SOFA score. The SOFA score was evaluated as a continuous variable, and ROC curves

Table 1. SOFA score[3]

Organ dysfunction*	SOFA score				
	0	1	2	3	4
Respiratory system					
PaO_2/FiO_2 (mmHg)	≥400	<400	<300	<200 with respiratory support	<100 with respiratory support
Hepatic system					
Bilirubin (mg/dL)	<1.2	1.2 - 1.9	2.0 - 5.9	6.0 – 11.9	>12.0
Cardiovascular system					
Blood pressure and catecholamine pharmacotherapy	MAP ≥70mmHg	MAP <70mmHg	Dopamine <5† or Dobutamine (any dose)	Dopamine 5.1-15† or Epinephrine ≤0.1† or Norepinephrine ≤0.1†	Dopamine >15† or Epinephrine >0.1† or Norepinephrine >0.1†
Coagulation					
Platelets (10^3/uL)	≥150	<150	<100	<50	<20
Central nervous system					
Glasgow Coma Scale	15	13 - 14	10 - 12	6 - 9	<6
Renal system					
Creatinine (mg/dL)	<1.2	1.2 - 1.9	2.0 - 3.4	3.5 - 4.9	>5.0
Urine output (mL/day)				<500	<200

SOFA = Sequential Organ Failure Assessment; PaO_2 = partial pressure of oxygen; FiO_2 = fraction of inspired oxygen; MAP = mean arterial pressure.
*Organ dysfunction is identified as an increase in the SOFA score of ≥2 points.[3]
†All catecholamine doses are represented in µg/kg/min.

and the Youden Index were used to determine the optimal cut-off value. Prespecified SOFA categories were also evaluated and included scores >6, >8, >10 and >12. Prespecified subgroups included the primary diagnostic categories of infection, trauma and non-communicable disease.

Results

Baseline descriptive and demographic data are presented in Table 2. A total of 90 patients died in the ICU, resulting in an ICU mortality rate of 32.3%. The median (IQR) ICU length of stay was 5 (3 - 7) days.

The distribution of SOFA scores within the cohort is shown in Fig. 1.

SOFA data and their association with ICU mortality are presented in Table 3. ICU mortality rates according to different SOFA cut-off values are shown in the far-right column for ease of reference.

The median (IQR) admission SOFA score was significantly higher among non-survivors than survivors, at 10 (8 - 12) and 7 (4 - 9), respectively (p<0.001) (Table 3).

Fig. 2A shows the ROC curve for the SOFA score and ICU mortality for the entire cohort. The SOFA score demonstrated fair discriminative ability, with an AUC of 0.739 (95% confidence interval (CI) 0.677 - 0.800; p<0.001). According to the Youden Index, the optimal cut-off value was a SOFA score of 8. At this cut-off, sensitivity was 64.4% (95% CI 53.7 - 74.3), specificity was 74.1% (95% CI 67.2 - 80.2), positive predictive value was 54.2% (95% CI 47.1 - 61.2) and negative predictive value was 81.4% (95% CI 65.3 - 76.2).

ROC curves for SOFA score and ICU mortality according to the primary diagnostic categories are shown in Figs 2B – 2D. Performance data for the three subgroups were as follows: infection, AUC of 0.631 (95% CI 0.529 - 0.732; p=0.011); non-communicable disease, AUC of 0.800 (95% CI 0.709 - 0.890; p<0.001); and trauma, AUC of 0.891 (95% CI 0.783 - 0.998; p<0.001). Pairwise comparison of AUCs demonstrated significant differences between infection and trauma (AUC difference –0.260; 95% CI –0.408 - –0.112; p=0.001) and between infection and non-communicable disease (AUC difference –0.169; 95% CI –0.305 - –0.033; p=0.015), but no significant difference between trauma and non-communicable disease (AUC difference 0.091, 95% CI –0.50 - 0.232; p=0.205).

Discussion

The study cohort was relatively young, with a median age of 41 years. There was a high burden of infection (42.3% of patients), and a smaller but still sizeable proportion of trauma patients (15.1%). HIV prevalence was high (22.6% positive), although HIV status was unknown in 56.3% of patients. There was a low prevalence of other common comorbidities within the study population. This demographic and disease profile differs from that reported in most studies from high-income countries,

Table 2. Baseline demographic and disease data of the cohort

Characteristics	Total (median (IQR) or *n* (%))	Survived (median (IQR) or *n* (%))	Died (median (IQR) or *n* (%))	*p*-value
Age (years)	41 (28.0 - 56.0)	37 (26.0 - 54.0)	48 (34.0 - 57.0)	0.003
Sex				0.247
Female	138 (49.5)	98 (51.9)	40 (44.4)	
Male	141 (50.5)	91 (48.1)	50 (55.6)	
Admitting discipline				0.021
Internal medicine	98 (35.1)	60 (31.7)	38 (42.2)	
OBGYN	41 (14.7)	35 (18.5)	6 (6.7)	
Surgery	140 (50.2)	94 (49.7)	46 (51.1)	
Primary diagnostic category				0.061
Infection	118 (42.3)	71 (37.6)	47 (52.2)	
Non-communicable disease	119 (42.7)	86 (45.5)	33 (36.7)	
Trauma	42 (15.1)	32 (16.9)	10 (11.1)	
Source of infection				0.516
Abdominal	34 (28.8)	20 (28.2)	14 (29.8)	
CAP	39 (33.1)	20 (28.2)	19 (40.4)	
CNS	2 (1.7)	1 (1.4)	1 (2.1)	
HAP	13 (11.0)	7 (9.9)	6 (12.8)	
Skin or soft tissue	21 (17.8)	15 (21.1)	6 (12.8)	
Systemic/haematological	4 (3.4)	3 (4.2)	1 (2.1)	
Unknown	1 (0.8)	1 (1.4)	0 (0.0)	
Urinary tract	4 (3.4)	4 (5.6)	0 (0.0)	
Comorbidities				
Cardiovascular	68 (24.4)	44 (23.3)	24 (26.7)	0.538
Respiratory	31 (11.1)	21 (11.1)	10 (11.1)	1
Renal	15 (5.4)	9 (4.8)	6 (6.7)	0.573
Malignancy	4 (1.4)	3 (1.6)	1 (1.1)	1
Metabolic	38 (13.6)	21 (11.1)	17 (18.9)	0.077
HIV status				0.468
Negative	59 (21.1)	37 (19.6)	22 (24.4)	
Positive	63 (22.6)	41 (21.7)	22 (24.4)	
Unknown	157 (56.3)	111 (58.7)	46 (51.1)	

IQR = interquartile range; OBGYN = obstetrics and gynaecology; CAP = community-acquired pneumonia; CNS = central nervous system; HAP = hospital-acquired pneumonia.

Table 3. SOFA data and ICU mortality

SOFA score	Total (median (IQR) or *n* (%))	Survived (median (IQR) or *n* (%))	Died (median (IQR) or *n* (%))	*p*-value	ICU mortality rate (%)
SOFA total score	8 (5 - 10)	7 (4 - 9)	10 (8 - 12)	<0.001	
SOFA cut-off of 6				<0.001	
≤6	108 (38.7)	92 (48.7)	16 (17.8)		14.8
>6	171 (61.3)	97 (51.3)	74 (82.2)		43.3
SOFA cut-off of 8				<0.001	
≤8	172 (61.6)	140 (74.1)	32 (35.6)		18.6
>8	107 (38.4)	49 (25.9)	58 (64.4)		54.2
SOFA cut-off of 10				<0.001	
≤10	238 (85.3)	174 (92.1)	64 (71.1)		26.9
>10	41 (14.7)	15 (7.9)	26 (28.9)		63.4
SOFA cut-off of 12				0.009	
≤12	256 (91.8)	179 (94.7)	77 (85.6)		30.1
>12	23 (8.2)	10 (5.3)	13 (14.4)		56.5

SOFA = Sequential Organ Failure Assessment; IQR = interquartile range; ICU = intensive care unit.

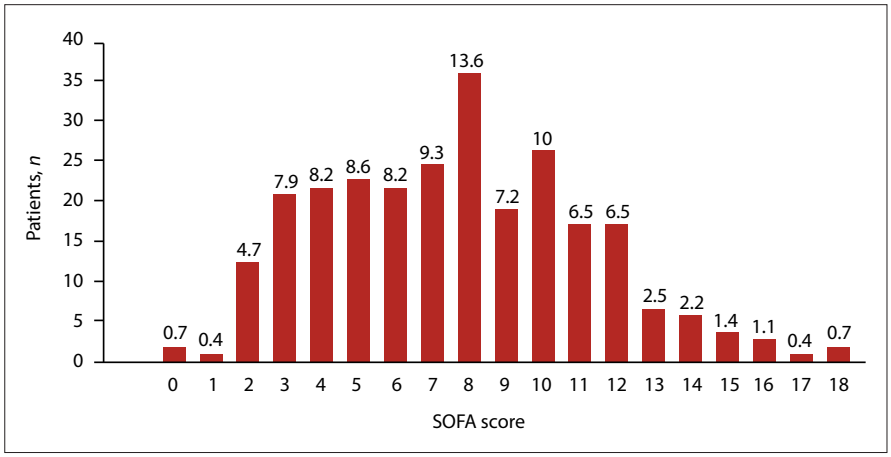


Fig. 1. Frequency distribution of SOFA scores for the entire cohort. (SOFA = Sequential Organ Failure Assessment).

where ICU populations tend to be older and have a higher burden of non-communicable disease.[4-6]

To the authors' knowledge, this is the first study specifically evaluating the performance of admission SOFA scores in a mixed ICU population in the SA setting, although other severity-of-illness scoring systems have previously been investigated.[13-15] The main study objective was to determine whether an association exists between admission SOFA score and ICU mortality. The findings demonstrated a significant association between higher admission SOFA scores and ICU mortality, with median admission SOFA scores being higher among non-survivors than survivors (10 points v. 7 points; $p<0.001$). These findings are consistent with those of other studies.[4-10]

One of the first large prospective studies evaluating the predictive performance of SOFA scores in ICU patients was conducted by Moreno *et al.*[4] This multicentre study included 1 449 patients and found that the mean maximum SOFA score was significantly higher among non-survivors (13.6 points v. 6.7 points; $p<0.001$). ROC curve results were also similar to those of the present study (AUC 0.772 v. 0.739, respectively).

When the data were stratified according to the three primary diagnostic categories in the study (infection, non-communicable disease and trauma), the SOFA score performed better in patients with non-communicable disease than in those with infection. This was unexpected, as the SOFA score was initially designed to objectively describe the degree of organ dysfunction in patients with sepsis.[3] One possible explanation is a type 1 error resulting from the relatively small sample size of the study. Another potential explanation is that, as demonstrated by Voysilius *et al.*,[7] the prognostic performance of SOFA scores in sepsis may improve over time. Their prospective study enrolled 117 patients with severe sepsis and recorded SOFA scores daily. Scores from day 1 and day 3 were used to assess prognosis. Day 3 SOFA scores demonstrated better predictive performance than day 1 scores (AUC 0.86 v. 0.68, respectively). This may suggest that, in the context of sepsis, SOFA scores are more predictive of outcome following ICU admission and initiation of critical care therapy. Alternatively, sepsis may follow a less predictable course, with the potential for early and rapid deterioration in patients with initially low SOFA scores.

In the non-communicable disease subgroup, admission SOFA score demonstrated fair discriminative ability for predicting ICU mortality (AUC 0.800; $p<0.001$). This finding is consistent with studies conducted in cardiac surgical patients,[5] critically ill burn patients[6] and patients with acute renal failure.[8]

The SOFA score has demonstrated limited reliability in trauma patients in previous studies; however, in the present study, admission SOFA score performed best in trauma patients (AUC 0.891; $p<0.001$). This performance was significantly better than that observed in patients with infection, but was not statistically significant when compared with patients with non-communicable disease. As only 42 trauma patients were enrolled in this study, this finding may reflect a type 1 error; nonetheless, some published data support this observation. Antonelli *et al.*[17] investigated the performance of the SOFA score in trauma patients in a multicentre trial examining the evolution of organ dysfunction over time in ICU trauma patients. Among the 181 enrolled patients, non-survivors had higher admission SOFA scores than survivors (8 points v. 4

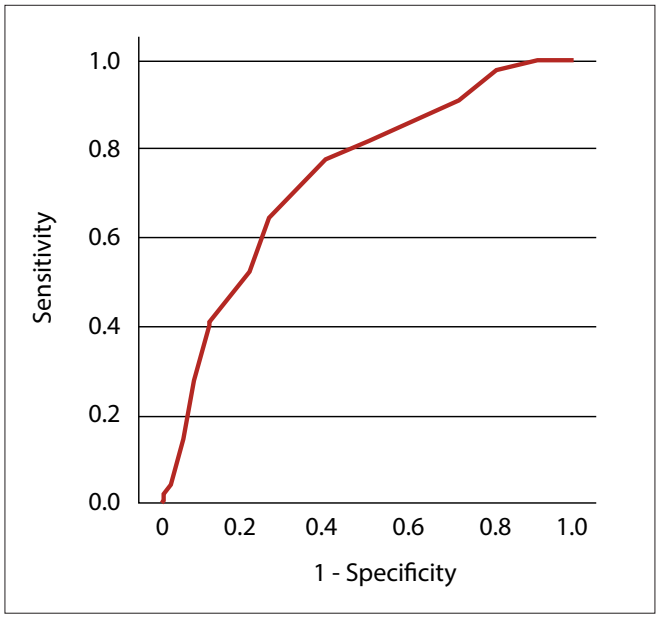


Fig. 2A. ROC curve for SOFA and ICU mortality for the entire cohort (AUC of 0.739) (ROC = receiver operating curve; SOFA = Sequential Organ Failure Assessment; ICU = intensive care unit; AUC = area under the curve).

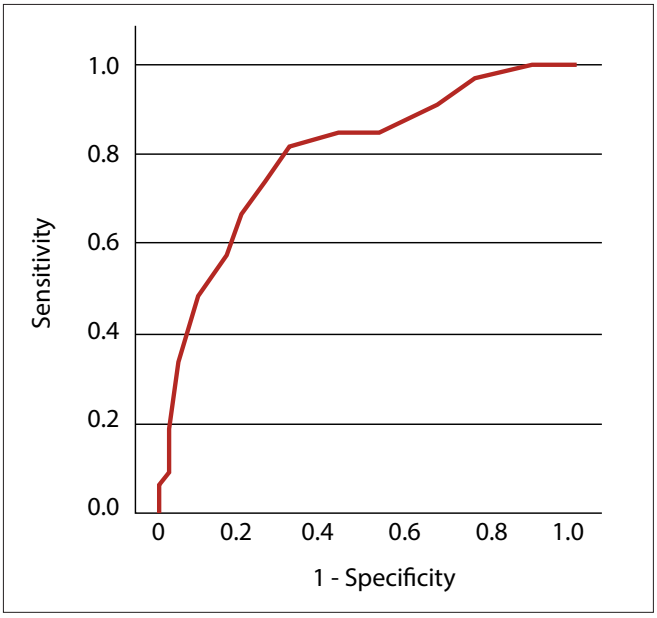


Fig. 2C. ROC curve for SOFA and ICU mortality in patients with non-communicable disease). (ROC = receiver operating curve; SOFA = Sequential Organ Failure Assessment; ICU = intensive care unit).

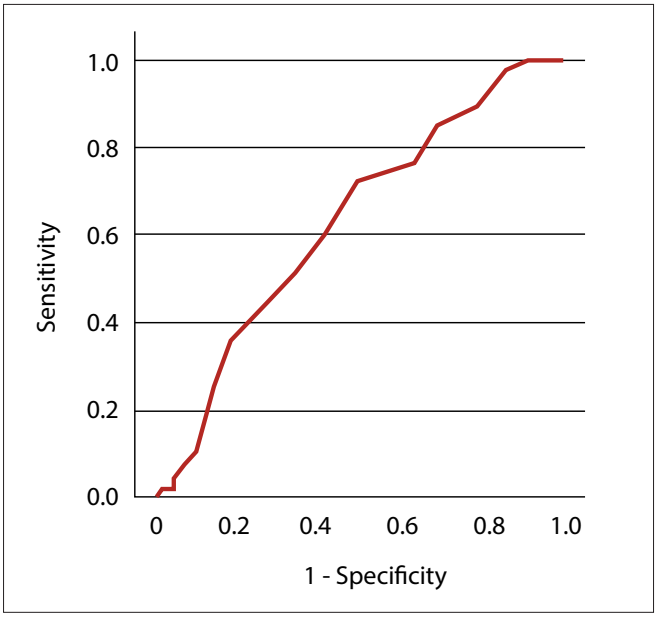


Fig. 2B. ROC curve for SOFA and ICU mortality in patients with infection. (ROC = receiver operating curve; SOFA = Sequential Organ Failure Assessment; ICU = intensive care unit).

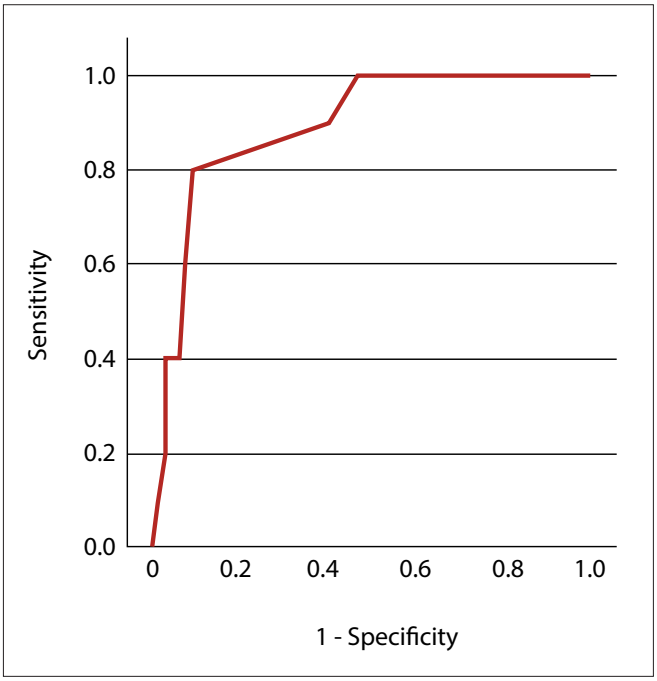


Fig. 2D. ROC curve for SOFA and ICU mortality in trauma patients. (ROC = receiver operating curve; SOFA = Sequential Organ Failure Assessment; ICU = intensive care unit).

points; $p<0.05$). Given previous concerns regarding the ability of standard trauma scoring systems to predict outcomes in the SA context,[18] further studies comparing the performance of SOFA with established trauma scoring systems in critically ill trauma patients may be warranted.

Based on the findings of this study, admission SOFA score demonstrated fair performance in the SA context. Given its simplicity and reliance on data routinely available in most critically ill patients, it may assist clinicians with risk stratification, communication of illness severity and risk among clinicians, patients and surrogate decision-makers, and the conduct of research and quality improvement programmes. These findings may also provide a useful baseline for future comparisons with the recently released SOFA-2 score.[19]

Study limitations

This study was a retrospective chart review and was therefore dependent on the quality and completeness of data contained in patient records. As a single-centre study, its external validity may be limited. However, the study ICU is a large provincial referral centre and is likely representative of critical care in similar SA healthcare settings. Although the study sample size was statistically adequate, it was relatively small and was not specifically powered for subgroup analysis. This may have contributed to false-positive and false-negative results, and subgroup analyses should therefore be treated as exploratory.

Although the study period overlapped with the COVID-19 pandemic in 2020, the study ICU was not designated as a COVID ICU, making direct pathophysiological effects on the study findings unlikely. However, COVID-19-related restrictions in place at the time may have altered patient and disease factors, potentially introducing bias.

The use of ICU mortality as the primary outcome represents another limitation, as patients may have been discharged to the ward and subsequently died outside the ICU setting. This may have resulted in an underestimation of mortality rates compared with other commonly used outcomes, such as hospital mortality and 30-day mortality. Longer-term outcomes were, however, unavailable for this study.

The SOFA score differs from other scoring systems such as APACHE II and SAPS 3 in that it was not designed to generate predicted mortality estimates. Consequently, calibration could not be assessed and a standardised mortality ratio could not be determined.

Conclusion

The SOFA score is a simple severity-of-illness tool derived from clinical variables routinely available at ICU admission. In this study of a multidisciplinary SA ICU, admission SOFA score was independently associated with ICU mortality and demonstrated fair discriminative ability for predicting ICU mortality. These findings support the potential role of the SOFA score in benchmarking, audit and administrative applications within the SA critical care setting. Exploratory subgroup analyses further indicate that additional research in larger, multicentre SA cohorts is warranted to better define patient subgroups in which the SOFA score may demonstrate stronger or weaker discriminative performance.

Data availability statement. The data used in this study are available from the authors upon reasonable request.

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Author contributions. Both authors meet the Southern African Journal of Critical Care (SAJCC) criteria for authorship. Both contributed to the conception, design, analysis and interpretation of the data, drafted and critically revised the manuscript, approved the final version for publication, and agree to be accountable for all aspects of the work.

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Conflicts of interest. None.

Data availability. The data set supporting the findings of this study is available from the corresponding author on reasonable request, with gatekeeper and ethics committee approval.

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