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ABOUT COVER

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AIMS AND SCOPE

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ORIGINAL ARTICLE

Retrospective Cohort Study

Shock index and its variants as predictors of mortality in severe traumatic brain injury

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Abstract

BACKGROUND
The increase in severe traumatic brain injury (sTBI) incidence is a worldwide phenomenon, resulting in a heavy disease burden in the public health systems, specifically in emerging countries. The shock index (SI) is a physiological parameter that indicates cardiovascular status and has been used as a tool to assess the presence and severity of shock, which is increased in sTBI. Considering the high mortality of sTBI, scrutinizing the predictive potential of SI and its variants is vital.

AIM
To describe the predictive potential of SI and its variants in sTBI.

METHODS
This study included 71 patients (61 men and 10 women) divided into two groups: Survival (S; *n* = 49) and Non-survival (NS; *n* = 22). The responses of blood pressure and heart rate (HR) were collected at admission and 48 h after admission. The SI, reverse SI (rSI), rSI multiplied by the Glasgow Coma Score (rSIG), and Age multiplied SI (AgeSI) were calculated. Group comparisons

included Shapiro-Wilk tests, and independent samples *t*-tests. For predictive analysis, logistic regression, receiver operator curves (ROC) curves, and area under the curve (AUC) measurements were performed.

RESULTS

No significant differences between groups were identified for SI, rSI, or rSIG. The AgeSI was significantly higher in NS patients at 48 h following admission (S: 26.32 ± 14.2, and NS: 37.27 ± 17.8; *P* = 0.016). Both the logistic regression and the AUC following ROC curve analysis showed that only AgeSI at 48 h was capable of predicting sTBI outcomes.

CONCLUSION

Although an altered balance between HR and blood pressure can provide insights into the adequacy of oxygen delivery to tissues and the overall cardiac function, only the AgeSI was a viable outcome-predictive tool in sTBI, warranting future research in different cohorts.

Key Words: Head trauma; Critical patient; Neuro-cardio axis; Predictive tool; Clinical practice

Core Tip: Patients who suffer severe head trauma are also affected by altered balance between heart rate and blood pressure which influences oxygen delivery to tissues and the overall cardiac function. Although previous studies indicated that shock index (SI) and its variants could predict the outcomes following traumatic brain injury (TBI) the studies were conducted in patients with different severities of injury. Therefore, when evaluating patients who suffered a severe TBI (sTBI), the SI and its variants are not a viable outcome-predictive tool in sTBI, due to similar responses in both surviving and non-surviving patients. However, the Age multiplied SI was a viable outcome-predictive tool in sTBI, warranting future research in different cohorts.

INTRODUCTION

Presently recognized as a significant public health issue, traumatic brain injury (TBI) commonly results in persistent neurological dysfunction[1,2]. TBI is defined as an alteration in normal brain function resulting from biomechanical forces, caused by rapid acceleration or deceleration of the brain due to motorcycle or automobile accidents; impact resulting from the brain's collision due to falls, motorcycle and automobile accidents, or contact sports; changes in pressure and air displacement due to explosions; and also, by the penetration of projectiles or objects into the brain[2,3]. The initial pathophysiological changes resulting from primary mechanical damage can trigger deleterious secondary effects, including progressive neurodegeneration[3]. Additionally, cardiovascular complications are common after TBI, including disturbances in systemic blood pressure, cardiac arrhythmias, and left ventricular dysfunction[4]. Therefore, as these abnormalities are associated with increased morbidity and mortality in TBI, it is plausible that persistent cardiocirculatory dysfunction may underlie some of the pathological features of chronic TBI.

TBI is classified as mild, moderate, or severe, and it can lead to premature death, cognitive alterations, and neuropsychiatric impairments, often compromising the quality of life of surviving individuals[1,5]. This classification is a combination of various criteria, with the Glasgow Coma Scale (GCS) being the most commonly used tool[6]. The severity level holds prognostic value but does not necessarily predict the patient's final level of functioning. The pathophysiological mechanisms associated with TBI involve primary injury resulting from mechanical or inertial damage to both white and gray matter, causing membrane rupture, content release, and diffuse axonal injury[7,8]. Secondary damage refers to the progression of changes associated with the primary brain injury, such as the persistent activation of a series of neurotoxic events, leading to structural damage progression[7]. Thus, the extent and severity of secondary damage are proportional to the trauma intensity and the location of the primary insult, in addition to mechanisms influencing secondary damage, including cardiovascular impairment[9]. Importantly, a complex set of neural pathways, termed the "neuro-cardiac axis," explains cardiac rhythm and hemodynamic disturbances following head trauma[10]. This interaction between the brain and the heart is evident during both primary (due to sympathetic hypertonus, arrhythmias, and cerebral perfusion pressure) and secondary injury (due to catecholamine release, microvascular and myocardial disturbances), as evidenced by conditions such as subarachnoid hemorrhage[4]. In this context, the shock index (SI) is a physiological parameter that quantifies the relationship between heart rate (HR) and systolic blood pressure[11]. This index serves as an indicator of cardiovascular status and is widely used as a tool to assess the presence and severity of shock or circulatory disturbances in various medical conditions, including TBI[12,13].

Hence, to the best of our knowledge, there are no studies that assess the role of SI and its variants as a predictor tool of mortality in severe TBI (sTBI) patients without multiple central injuries. The findings of this study can guide future clinical procedures to ensure a positive impact on the prognosis and quality of life of this population. Therefore, this study aims to describe the predictive potential of SI and its variants as an outcome-predictive tool in sTBI patients.

MATERIALS AND METHODS

Study design

This was a prospective observational study by convenience sampling conducted between January 2019 and December of 2022 at the Pronto-Socorro Hospital, a trauma reference center at Porto Alegre, RS, Brazil.

This study followed the ethical precepts, guidelines, and norms established in Resolution No. 466 of 2012 of the National Health Council, and was carried out only after approval by the Health Research and Ethics Committee of the Municipal Health Secretariat Office of Porto Alegre (CEP SMSPA; registration number: 3.912.623). Patients were identified through registration numbers, which only serves to validate the individuality of the information. The sample was determined in a non-probabilistic way for convenience, selected through the inclusion and exclusion criteria described below, without any discrimination in the selection of individuals or exposure to unnecessary risks. Patients admitted to the adult trauma intensive care units (ICUs) aged 18 years or older who required enteral or parenteral nutritional therapy were included. The following were excluded from the study: Patients with a GCS score of 9 to 15; patients who were diagnosed with cervical, thoracic or abdominal trauma; patients who received only oral diet, and those with incomplete medical records or records due to lack of data. Of 342 patients admitted to the trauma ICU during the explored period, 71 patients were included in this study.

The study was carried out in the adult trauma ICU of the Hospital de Pronto Socorro de Porto Alegre, with retrospective data, covering the period from January 2019 to December 2022. Data collection was carried out using the institutional Hospital Information System, which includes the complete electronic medical record of the patient. The collected variables were: GCS score, injury description, age, sex, days of fasting, body mass, estimated height, blood pressure, and HR parameters. Body mass index (BMI = Body mass/Height^2) was calculated to classify the patients according to the criteria of the World Health Organization[14]. The SI, rSI, and rSIG were calculated as the ratio of HR to systolic blood pressure (SBP) (SI = HR/SBP), the ratio of SBP to HR (rSI = SBP/HR), the score of rSI × GCS, and age multiplied SI (AgeSI = Age × SI) respectively.

Statistical analysis

The general description of the selected data is available through simple and relative frequencies. The normality of distributions of all variables were evaluated using the Shapiro-Wilk test. Student's t test for independent or the Pearson's Chi-Square test was used to compare data between groups. Spearman's rho was used to evaluate the correlation between different variables. To evaluate the predictive potential of SI, rSI, rSIG, and AgeSI we used logistic regression, where regression coefficients (B) were obtained for each variable. When the Wald test values were significant, the odds ratio was calculated to indicate the percentage changes (Exp(B) – 100). Also, receiver operator curves (ROC) analysis was performed. Significant correlations and differences were considered where $P < 0.05$. All data were analyzed using the Statistical Package for Social Sciences 26.0 statistical program.

RESULTS

Table 1 provides the characteristics of the 72 patients included in this study, which were allocated in two distinct groups: Survival (S; *n* = 49) and non-survival (NS; *n* = 22). Analysis of the variables indicated that the groups were significantly different regarding mean age (S: 40.51 ± 17.4, and NS: 50.73 ± 14.6; $P = 0.013$), number of days in hospital (S: 28.76 ± 14.6, and NS: 14.36 ± 16.8; $P = 0.001$). No differences were observed for the other variables, except for the presence of COPD in the NS group ($P = 0.032$).

Table 2 presents the data regarding blood pressure, HR, and different SI. The HR and the SI at 48 h after admission significantly differed between S and NS patients ($P = 0.036$, and $P = 0.03$, respectively). No differences were observed for the other variables, including the different SI, except for the AgeSI. The AgeSI was significantly higher in NS patients at 48 h following admission (S: 26.32 ± 14.2, and NS: 37.27 ± 17.8; $P = 0.016$). The logistic regression and area under the receiver operating characteristic curve (AUROC) results are shown in Table 3. When evaluating the significance and the odds ratio to explore further the relationship of different SI with survival odds, no relationship was identified. In patients with sTBI (Figure 1), the AUROC analysis indicated that the predictive accuracy of SI and its variants were insignificant, except for AgeSI at 48 h, where the AUROC curve for predicting mortality was 0.727.

DISCUSSION

The present study evaluated the role of SI as a variable to predict the outcomes of sTBI patients coinfected patients. Notably, the different SI were not predictors of outcomes for severe head injury patients, despite the significantly different HR and SI responses at 48 h following admission between S and NS patients. However, the AgeSI could be a

Table 1 Characteristics of patients with severe head injury

	Survival (*n* = 49)		Non-survival (*n* = 22)		*P* value[1]
Age (years), mean ± SD	40.51	17.4	50.73	14.6	0.013
Days in MV, mean ± SD	28.76	14.6	14.36	16.8	0.001
Fasted days, mean ± SD	13.78	8.7	7.68	6.4	0.002
Days in hospital, mean ± SD	28.76	14.6	14.36	16.8	0.001
					P value[2]
Sex, *n* (%)					0.161
Male, *n* (%)	44	89.8%	17	77.3%	
Female, *n* (%)	5	10.2%	5	22.7%	
Injury type, *n* (%)					0.607
Closed	35	71.4%	17	77.3%	
Open	14	28.6%	5	22.7%	
Injury cause, *n* (%)					0.408
Fall	13	26.5%	10	45.5%	
Transit accident	18	36.7%	4	18.2%	
Assault	13	26.5%	6	27.3%	
Gunshot	4	8.2%	1	4.5%	
Other	1	2.0%	1	4.5%	
Associated injuries, *n* (%)					0.658
None	36	73.5%	19	86.4%	
Thoracic	4	8.2%	1	4.5%	
Arms	1	2.0%	0	0.0%	
Legs	5	10.2%	2	9.1%	
Spine	3	6.1%	0	0.0%	
Craniotomy procedure, *n* (%)					0.822
No	34	77.3%	15	68.2%	
Yes	14	31.8%	7	31.8%	
Body mass index (kg/cm²), *n* (%)					0.761
Underweight	4	8.2%	2	13.6%	
Eutrophic	25	51.0%	0	54.5%	
Overweight	14	28.6%	2	18.2%	
Grade I Obese	6	12.2%	2	13.6%	
Comorbidities, *n* (%)					
COPD	0	0	2	9.1%	0.032
Asma	1	0.02	0	0.0%	0.513
T2DM	1	0.02	2	9.1%	0.172
SAH	4	8.2%	2	9.1%	0.897
EVA	1	0.02	1	4.5%	0.555
AD	2	4.1%	1	4.5%	0.928

[1]Student's t test.

[2]Pearson's Chi-Square test.

MV: Mechanical ventilation; COPD: Chronic obstructive pulmonary disease; DM: Type 2 diabetes mellitus; SAH: Systemic arterial hypertension; EVA:

Encephalic vascular accident; AD: Alzheimer's disease.

Table 2 Blood pressure, heart rate and different shock indexes (mean ± SD)					
	Survival (*n* = 49)		Non-survival (*n* = 22)		*P* value
SBP-24 h (mmHg)	135.59	36.5	138.95	40.1	0.739
DBP-24 h (mmHg)	81.27	23.5	85.38	25.2	0.526
HR-24 h (bpm)	88.22	25.4	88.68	29.0	0.949
SBP-48 h (mmHg)	131.47	27.6	127.20	25.0	0.536
DBP-48 h (mmHg)	67.77	12.1	72.33	15.0	0.257
HR-48 h (bpm)	82.61	18.5	93.95	19.9	0.036
SI-adm	0.70	0.3	0.69	0.3	0.901
SI-48 h	0.65	0.2	0.79	0.3	0.03
rSI-adm	1.70	0.8	1.78	1.0	0.742
rSI-48 h	1.66	0.5	1.44	0.5	0.106
rSIG-adm	10.45	5.9	11.02	7.7	0.758
rSIG-48 h	10.26	4.8	9.29	4.8	0.452
AgeSIG-adm	28.02	16.8	34.40	17.1	0.152
AgeSIG-48 h	26.32	14.2	37.27	17.8	0.016

SBP: Systolic blood pressure; HR: Heart rate; DBP: Diastolic blood pressure; SI: Shock index; rSI: Reverse shock index; rSIG: rSI multiplied by the Glasgow Coma Score; AgeSIG: Age multiplied SI.

Table 3 Logistic regression and receiver operator curves analysis parameters							
	Sig.	Exp(B)	95%CI for EXP(B)		Odds ratio (%)	AUC	*P* value
			Inferior	Superior			
SI-adm	0.895	0.885	0.144	5.444	-11.5	0.487	0.864
SI-48 h	0.129	7.592	0.554	104.036	659.2	0.606	0.176
rSI-adm	0.727	1.107	0.626	1.956	10.7	0.517	0.832
rSI-48 h	0.194	0.436	0.125	1.527	-56.4	0.395	0.180
rSIG-adm	0.652	1.018	0.942	1.101	1.8	0.537	0.637
rSIG-48 h	0.641	0.973	0.867	1.092	-2.7	0.473	0.727
AgeSIG-adm	0.153	1.022	0.992	1.052	2.2	0.639	0.071
AgeSIG-48 h	0.015	1.044	1.008	1.082	4.4	0.727	0.003

SI: Shock index; rSI: Reverse SI; rSIG: rSI multiplied by the Glasgow Coma Score; AgeSIG: Age multiplied SI; AUC: Area under the curve.

useful tool to predict mortality, showing statistical difference among surviving and non-surviving sTBI patients, and significant predictive value.

The rationale behind the SI is rooted in the understanding that an altered balance between HR and blood pressure can provide insights into the adequacy of oxygen delivery to tissues and the overall cardiac function[15]. Therefore, these physiological responses are directly implicated in survival of TBI patients, due to the relationship with the extent of both primary and secondary damage mechanisms, including restriction of flow in the long pituitary portal vessels after injury [16]. The predictive value of the SI in determining mortality in critically ill patients (including TBI patients) has been a subject of investigation in recent studies. Notably, studies such as those conducted by Cannon *et al*[17] and McNab *et al* [18] have contributed to our understanding of the prognostic significance of the SI in this population. Cannon *et al*[17] conducted a retrospective analysis of TBI patients, elucidating the association between an elevated SI and increased mortality. Their findings underscored the utility of the SI as an early prognostic marker, with increased values indicative
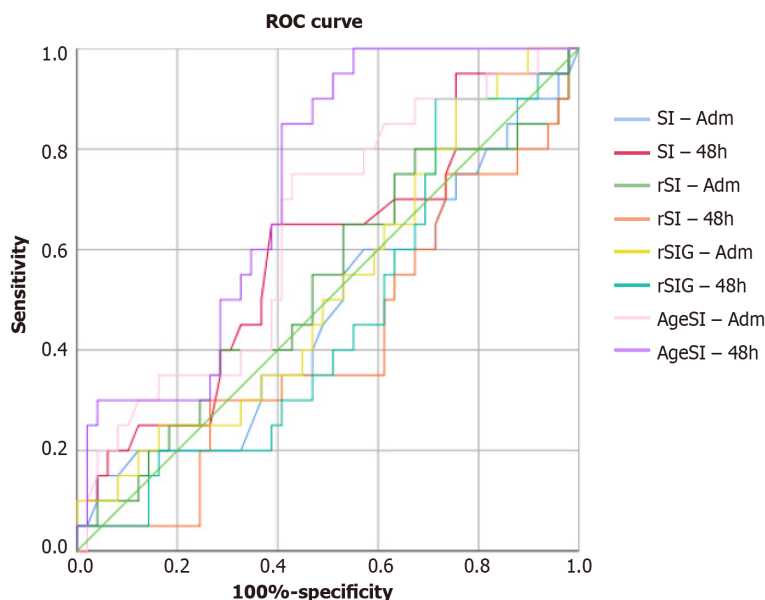
Figure 1 Area under the receiver operator curve analysis. ROC: Receiver operator curve; SI: Shock index; rSI: Reverse shock index; rSIG: rSI multiplied by the Glasgow Coma Score; AgeSIG: Age multiplied SI.

of higher mortality risk. The study highlighted the clinical relevance of SI assessment in identifying TBI patients at heightened risk of adverse outcomes[17].

Building upon this foundational work, McNab *et al*[18] conducted a prospective study to further investigate the predictive capabilities of the SI in severe TBI patients. Their results affirmed a significant association between an elevated SI on admission and increased mortality, emphasizing the potential utility of this simple yet informative metric in risk stratification and early intervention[18]. In an earlier investigation, Rady *et al*[19] explored the predictive value of the SI in a broader trauma population, including TBI cases. Their prospective study demonstrated the sensitivity of the SI in identifying patients at risk of adverse outcomes. Although not specific to TBI, the results provided insights into the potential applicability of the SI as a valuable tool for early prognostication[19].

Recently, Wu *et al*[12] contributed to the literature by conducting a retrospective analysis focusing on the SI and reverse SI (rSI) multiplied by GCS as a predictor of mortality in 2438 patients with isolated head injury. Like the present study, the patients who died were significantly older that those who survived. However, the analysis included patients with different levels of TBI, as indicated by significant differences in the GCS. The study affirmed the independent association between an elevated SI and mortality, indicating that the rSI is superior to SI as a predictor of mortality in TBI, with comparable predictive power to both the Trauma and Injury Severity Score and Revised Trauma Score, further supporting its potential role in risk stratification for TBI patients. Comparatively, in the present study we investigated sTBI patients, which are more prone to have a higher SI score due to the nature of the injury mechanisms. Thus, no differences were identified for SI and its variants among S and NS patients. Interpreting traditional vital signs and the SI proves challenging when applied to the elderly population. Advanced age is associated with lower HR responses and elevated systolic blood pressures, leading to an escalation in false-negative values and influencing SI outcomes with increasing age. To address this issue, previous research suggested that SI multiplied by age (AgeSI) is a better predictor of mortality following traumatic injury of an elderly patient, we also included this variant in the analysis[20,21]. In the present study, AgeSI showed tendency to significance at admission, and was significantly different at 48 h following admission, showing significant predictive value. Our findings those of Kim *et al*[22], showing that the predictive power of the AgeSI for in-hospital mortality was higher in geriatric trauma patients. Therefore, AgeSI is a viable predictive tool in sTBI which is supported by previous research validating AgeSI index[23,24].

This study is subject to several limitations. Firstly, it relied on a retrospective analysis. Secondly, the exact time profile from injury occurrence to mortality was not measured. While the SI proves effective in predicting short-term mortality, the lack of a precise timeline from injury to mortality, due to database constraints, limits the comprehensive predictive capacity of the SI assessment. Rather than presenting an exact time profile, our evaluation focused on the SI's predictive efficacy for mortality during the emergency department stay and the overall in-hospital period, respectively. Thirdly, the database did not furnish information regarding the use of anti-hypertensive medications (such as beta blockers), introducing a potential factor that may impact the validity of SI assessment. Also, the data regarding previous comorbidities rely on the information given by the patients or their caregivers and may present inconsistencies. As for strengths, we highlight the investigation in sTBI patients, the study's originality, and the importance of this study evaluating the SI and its variants, an important tool for prognosis in the clinical treatment of critical patients.

CONCLUSION

In conclusion, only AgeSI was a viable predictor of mortality following severe head injury. Therefore, future studies should continue to search for cost-effective clinical tools that can predict survival and other outcomes in sTBI patients, considering the cohort-specific characteristics.

ARTICLE HIGHLIGHTS

Research background

Patients who suffer severe head trauma are also affected by altered balance between heart rate (HR) and blood pressure which influences oxygen delivery to tissues and the overall cardiac function. Although previous studies indicated that shock index (SI) and its variants could predict the outcomes following traumatic brain injury (TBI) the studies were conducted in patients with different severities of injury.

Research motivation

To the best of our knowledge, there are no studies that assess the role of SI and its variants as a predictor tool of mortality in severe TBI (sTBI) patients without multiple central injuries. The findings of this study can guide future clinical procedures to ensure a positive impact on the prognosis and quality of life of this population.

Research objectives

This study aims to describe the predictive potential of SI and its variants as an outcome-predictive tool in sTBI patients.

Research methods

This was a prospective observational study conducted at the Pronto-Socorro Hospital, a trauma reference center at Porto Alegre, RS, Brazil, including 71 patients were included in this study. The study included retrospective data, covering the period from January 2019 to December 2022. The collected variables were: Glasgow Coma Scale (GCS) score, injury description, age, sex, days of fasting, body mass, estimated height, blood pressure, and HR parameters. Body mass index (BMI = body mass/Height^2) was calculated to classify the patients according to the criteria of the World Health Organization. The SI, reverse SI (rSI), and rSI multiplied by the Glasgow Coma Score (rSIG) were calculated as the ratio of HR to systolic blood pressure (SBP) (SI = HR/SBP), ratio of SBP to HR (rSI = SBP/HR), the score of rSI × GCS, and age multiplied SI (AgeSI = Age × SI) respectively. Group comparisons included Shapiro-Wilk tests and independent samples *t*-tests. For predictive analysis, logistic regression, receiver operator curves (ROC) curves, and area under the curve (AUC) measurements were performed.

Research results

No significant differences between groups were identified for SI, rSI, or rSIG. The AgeSI was significantly higher in non-survival (NS) patients at 48 h following admission (Survival: 26.32 ± 14.2, and NS: 37.27 ± 17.8; *P* = 0.016). Both the logistic regression and the AUC following ROC curve analysis showed that only AgeSI at 48 h was capable of predicting sTBI outcomes. For AgeSI at 48 h, the AUROC curve for predicting mortality was 0.727.

Research conclusions

Patients who suffer severe head trauma are also affected by altered balance between HR and blood pressure which influences oxygen delivery to tissues and the overall cardiac function. Although previous studies indicated that SI and its variants could predict the outcomes following TBI the studies were conducted in patients with different severities of injury. Therefore, when evaluating patients who suffered a sTBI, the SI and its variants are not a viable outcome-predictive tool in sTBI, due to similar responses in both surviving and non-surviving patients. However, the AgeSI was a viable outcome-predictive tool in sTBI, warranting future research in different cohorts.

Research perspectives

Future studies should evaluate the AgeSI as an outcome-predictive tool in sTBI.

FOOTNOTES

Conflict-of-interest statement: All authors declare that there are no conflicts of interest related to this article.

Data sharing statement: No additional data is available for sharing.

STROBE statement: The authors have read the STROBE Statement checklist of items, and the manuscript was prepared and revised according to the STROBE Statement checklist of items.

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