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# Correlation between shock index and postoperative outcomes for patients undergoing on-pump coronary artery bypass graft surgery (an observational study)

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**ABSTRACT**

**Introduction:** Shock index (SI) is defined as a ratio of heart rate and systolic blood pressure. It was originally employed to evaluate hemorrhage and acute circulatory failure. Recently, SI has been used as a morbidity and mortality predictor in various fields. An elevated SI was associated with higher morbidity.

**Objective:** To detect the sensitivity and specificity of SI in predicting major cardiac events.

**Methods:** We randomly enrolled 100 patients who were set to undergo on-pump coronary artery bypass graft (CABG) surgery in the study. The primary outcome was to detect the sensitivity and specificity of SI to predict the occurrence of major adverse cardiac events, occurrence of acute kidney injury (AKI) and the need for ventilator support for >48 h. The secondary outcome was to correlate between SI and need of inotropic support, length of hospital stay and in-hospital mortality.

**Results:** The main findings of our study were the presence of a good correlation between SI and occurrence of postoperative cardiovascular (CV) collapse, AKI and prolonged postoperative mechanical ventilation after on-pump CABG as primary outcomes as well as the presence of a significant correlation between the occurrence of in-hospital mortality and morbidities and high values of SI as secondary outcomes.

**Conclusions:** We believe that SI has a good prediction of postoperative CV collapse, AKI and prolonged postoperative mechanical ventilation >48 h.

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Shock index; on-pump CABG surgery

## 1. Introduction

Candidates for coronary artery bypass graft (CABG) surgery usually show multiple comorbidities, and this raises the concern to use a risk classification to predict perioperative morbidities and mortality.

A risk score was suggested during 1983 by Paiement and associates that included poor left ventricular function, congestive heart failure, unstable angina or recent myocardial infarction, age over 65 years, severe obesity, redo operation, emergency surgery and any significant or uncontrolled systemic disease [1]. During 1989, Parsonnet and colleagues stratified heart surgeries using 14 risk factors [2] to predict mortality.

The Society of Thoracic Surgeons developed a lot of risk modules, and, recently, there are three that are in use in general; these models are modified annually to be more predictive for postoperative mortality [3–5].

Nowadays, the most commonly used score is the European System for Cardiac Operative Risk Evaluation (EuroSCORE), the new version of which is the recently recommended risk index which can be automatically calculated with online calculator (EuroSCORE II) [6].

The complexities of theses scores made physicians search for a simple one; this raised the attention again to shock index (SI).

During 1967, SI was used by Allgöwer and Buri to diagnose hemorrhagic and septic shock states [7] calculated by dividing heart rate (HR) by systolic blood pressure (SBP) with a normal range between 0.5 and 0.7 in adults. The introduction of more complex and new scores made the SI lost its popularity.

SI is inversely proportionate to physiologic parameters, such as cardiac index, stroke volume (SV), left ventricular stroke work (LVSW) and mean arterial pressure (MAP). SI is a non-invasive parameter of left ventricular function and so predicting circulatory collapse. Values more than 1.0 are associated with poor prognosis in acutely hemodynamically unstable patients [8] with irreversible failure of left ventricular function after shock therapy in the ED [9].

SI showed great value for triage during high hospital admission rates, where vital signs as pulse or blood pressure solely [10] can be used, and SI was used as an indicator for severity of trauma [11,12], as a marker of active bleeding [13,14], as an indicator of septic shock [15] and strong association with unplanned intensive

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care unit (ICU) transfer being an indicator of illness severity, morbidity and in-hospital mortality [16].

## 2. Methodology

This study was a prospective observational study and was conducted in the Adult Cardiothoracic Unit, Kasr Al-Ainy Hospital, Cairo University, after approval from the ethical and research committee. The study was conducted from October 2018 until May 2019. All the patients consented to participate in the study after the nature and the scope of it had been explained in a form understandable to them.

The population included in this study was adult patients older than 18 years who underwent on-pump CABG surgery with cardiopulmonary bypass (CPB) and cardioplegic arrest.

The exclusion criteria were patients who were candidates for emergency CABG, morbidly obese patients, patients suffered from systolic dysfunction defined as having ejection fraction less than 50%, patients having associated valve lesion, previous cardiac surgery and patients suffering from chronic obstructive pulmonary disease or asthma, renal impairment and atrial fibrillation.

All patients were advised to continue their regular medications till surgery morning.

Patients received bromazepam 3 mg PO the night before the operation and 0.1 mg/kg morphine sulfate IM 1 h preoperatively. In the pre-induction room, ECG, NIBP and pulse oximeter were attached to patients, and oxygen was supplemented via a nasal cannula. After infiltration of local anesthesia (lidocaine 2%), a peripheral venous cannula (14 or 16 G) and a 20 G arterial cannula in the radial artery were inserted.

Anesthesia was induced with midazolam 0.05–0.1 mg/kg, fentanyl 3–5 µg/kg, thiopental 1–2 mg/kg, and pancuronium 0.1 mg/kg. Maintenance of anesthesia was accomplished with sevoflurane 1.5%–2%, fentanyl 2–5 µg/kg and incremental doses of pancuronium. After ETT placement, mechanical ventilation was adjusted with tidal volume of 6–8 mL/kg and a respiratory rate of 12–14 to achieve end-tidal $CO_2$ 30–35 mmHg; PEEP of 5 cm $H_2O$ was added and $FiO_2$ was adjusted to achieve $PaO_2$ between 200 and 300 mmHg. A triple lumen central venous catheter was inserted into the right internal jugular vein. A temperature probe was inserted into the nasopharynx. MAP was kept between 50 and 80 mmHg using vasopressors, inotropes or vasodilators.

Full bovine, heparin-induced anticoagulation was targeted to maintain an activated coagulation time greater than 400 s. After placement of an ascending aortic cannula and a two-stage right atrial cannula, CPB was instituted with a centrifugal roller pump. CPB was conducted with flow rate of 2.2–2.4 l/min/$m^2$ to keep MAP of 50–70 mmHg together with the use of vasopressors and vasodilators when needed and systemic cooling to 33°C. After aortic cross-clamping, warm oxygenated blood cardioplegic solution was delivered antegrade via aortic root.

All patients received an internal mammary artery graft to the left anterior descending artery and rewarming to 37°C.

During weaning from CPB, volume and pharmacological therapy with inotrope, vasopressors and vasodilators were used as needed to maintain MAP of 50–80 mmHg. Blood on the CPB machine was re-infused to the patient, and protamine was administered in a dose of 4 mg/kg to return ACT to baseline values.

After wound closure, patients were transferred to the ICU under GA and received the standard ICU management.

## 3. Data collection

Systolic, diastolic, MAPs and HR were recorded directly through the arterial catheter using Philips M1006B IBP Invasive Blood Pressure Monitoring Module.

SI calculated as HR/SBP before induction of anesthesia, after left internal mammary artery (LIMA) harvesting and after weaning from CPB machine.

Other data collected were age, sex, body mass index, smoking, hypercholesterolemia, peripheral vascular disease, renal dysfunction, EuroSCORE, left main disease, the use of angiotensin-converting enzyme inhibitors and/or angiotensin receptor blockers, use of B-blockers, number of grafted vessels, cross-clamp time, bypass time and surgery time, and doses of inotropes and vasopressors.

The primary outcome was to detect the sensitivity and specificity of SI to predict the occurrence of major adverse cardiac events (MACEs) including cardiovascular (CV) failure which is defined as SBP less than 90 mmHg, in conjunction with signs of tissue hypoperfusion (cold periphery, clammy skin, confusion, oliguria and elevated lactate level) in the absence of hypovolemia, occurrence of acute kidney injury (AKI) which is defined as 50% increase in the serum creatinine concentration relative to the base line creatinine and the need for ventilator support for >48 h.

The secondary outcome was to correlate between SI and need of inotropic support, length of hospital stay and in-hospital mortality.

## 4. Statistical analysis

### 4.1. Sample size

Based on a prevalence rate of MACE in patients undergoing CABG of 13% 17 a total sample size of 100 patients were required to detect sensitivity and specificity of 80% with a power level of 80% and two-sided α level of 0.05.

### 4.2. Statistical analysis

Data were expressed as mean + SD, median (range) or frequency as appropriate. Receiver operating characteristic (ROC) curve was used to determine the specificity and sensitivity of the SI. Pearson's or Spearman's correlation tests were used to detect correlation. A $P$ value <0.05 was considered statistically significant.

## 5. Results

In our study, here, we randomly enrolled 100 IHD patients who were set to undergo on-pump CABG surgery; after collection of data set preoperatively, intra-operatively and postoperatively, we lost complete contact with three patients during the follow-up postoperatively, and there were another four patients that we lost data of primary outcomes, so we omitted those seven patients from the study to have a total of 93 patients who are eligible for the inclusion criteria and their dataset were collected accurately and completely present.

Clinical characteristics, demographic, preoperative echo-cardiography, intraoperative parameters and primary outcome data are shown in Table 1.

**Table 1.** Clinical characteristics of the study population. Data are presented as mean (standard deviation) or number (percentage).

| | N | Mean | Std. deviation |
|---|---|---|---|
| **Age** | 93 | 56.67 | ±11.316 |
| EF % preop | 93 | 53.0108 | ±16.94 |
| Male | 70 | 75.2% | |
| Female | 23 | 24.7% | |
| DM | 42 | 45.2% | |
| HTN | 47 | 50.5% | |
| Smoking | 57 | 61.3% | |
| **Grafts** | | | |
| 1 vessel graft | 6 | 6.5% | |
| 2 vessel grafts | 22 | 23.6% | |
| 3 vessel grafts | 41 | 44% | |
| 4 vessel grafts | 20 | 21.5% | |
| 5 vessel grafts | 4 | 4.3% | |
| **Primary outcomes** | | | |
| Vasopressor | 70 | 75.3% | |
| CV collapse | 10 | 10.8% | |
| AKI | 6 | 6.5% | |
| Ventilation >48 h | 8 | 8.6% | |
| Morbidity | 15 | 16.1% | |
| Mortality | 9 | 9.7% | |
| SI 0 | 93 | .54 | ±0.11 |
| SI 0 | 93 | .64 | ±0.16 |
| SI 2 | 93 | .78 | ±0.26 |
| CC time (minutes) | 93 | 85.15 | ±30.2 |
| ByP time (minutes) | 93 | 116.86 | ±54.8 |
| Op. time (minutes) | 93 | 333.23 | ±105.8 |

EF = ejection fraction, DM = diabetes mellitus, HTN = hypertension, CV collapse = cardiovascular collapse, AKI = acute kidney injury, SI 0 = shock index pre-induction, SI 1 = shock index after LIMA harvest, SI 2 = shock index after weaning from cardiopulmonary bypass, CC time = cross-clamp time, ByP time = bypass time, Op. time = operation time.

## 6. Ability of hemodynamic variables to predict CV collapse

Regarding the ability of hemodynamic variables to predict CV collapse, ROC curves show best cutoff values for sensitivity and specificity (Figure 1) for each hemodynamic parameter to predict CV collapse as shown in Table 2.

Best variable results were for baseline SI (SI 0) and post-LIMA harvest HR (HR 1) with cutoff values (>0.46, >79 bpm, respectively), with sensitivity and specificity (90%, 31% and 80%, 60%, respectively).

We excluded SI after weaning from CPB (SI 2) as a predictor of CV collapse postoperatively as it increases during the event of collapse, so it loses its ability to provide the health-care giver enough time to predict CV collapse before happening as a risk indicator or a predictive parameter; nevertheless, it gives a good significant $P$ value ($P = 0.000$) (Figure 2).

## 7. Ability of hemodynamic variables to predict postoperative AKI

Patients who developed postoperative AKI had shown significantly high SI values in comparison with patients who did not develop postoperative AKI and that was during two occasions SI 1 (post-LIMA harvest) and SI 2 (after weaning from bypass), with highly significant $P$ values ($P = 0.02$ and 0.000), respectively (Figure 3).

Table 3 shows the hemodynamic parameters and their sensitivity and specificity to predict postoperative AKI.

Best variables were HR after weaning from bypass (HR 2) and SI after weaning from bypass (SI 2) with cutoff values (>105 bpm and >1.2, respectively), with sensitivity and specificity (100%, 91.95% and 83.33%, 98.85%, respectively).

## 8. Ability of hemodynamic variables to predict prolonged postoperative ventilation >48 h

Patients who showed prolonged postoperative mechanical ventilation >48 h had shown significantly high SI values in comparison with patients who extubated earlier than 48 h and that was during the three occasions SI 0 (T0) (pre-induction/baseline SI), SI 1 (T1) (post-LIMA harvest) and SI 2 (T2) (after weaning from bypass), with highly significant $P$ values ($P = 0.020$, 0.008 and 0.000, respectively) with better results of both SI 1 and SI 2 more than SI 0 (Figure 4).

In Figure 5, ROC curves show best cutoff values for sensitivity and specificity for each hemodynamic

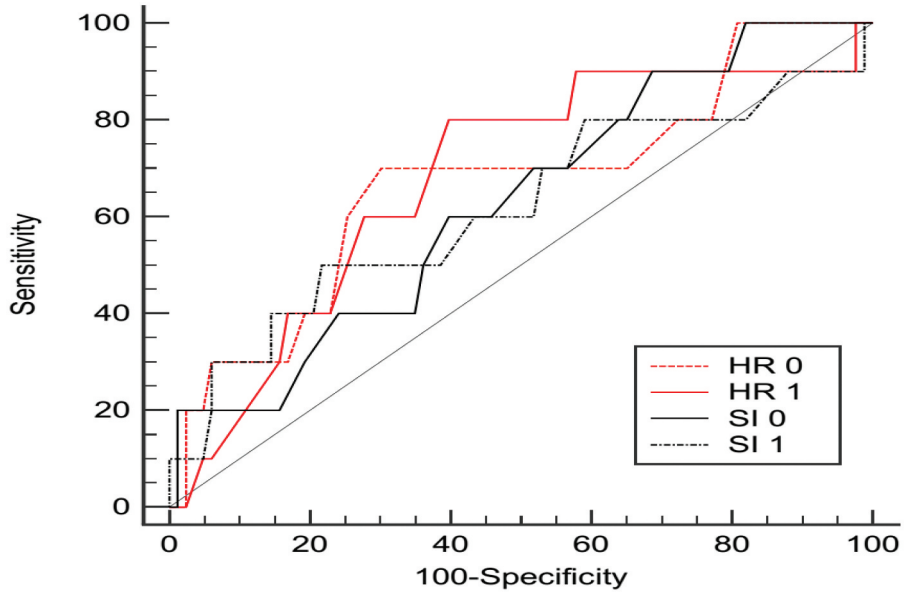


**Figure 1.** ROC curves for different hemodynamic variables as predictors of cardiovascular collapse.

**Table 2.** Hemodynamic variables as predictors of cardiovascular collapse.

| Variable | AUROC | Sensitivity | Specificity | *P* value | Cutoff value |
|---|---|---|---|---|---|
| Baseline heart rate (HR 0) | 0.669 | 70% | 70% | 0.09 | >84 bpm |
| Baseline shock index (SI 0) | 0.628 | 90% | 31% | 0.16 | >0.46 |
| Post-LIMA H heart rate (HR 1) | 0.678 | 80% | 60% | 0.057 | >79 bpm |
| Post-LIMA H shock index (SI 1) | 0.618 | 50% | 78% | 0.3 | >0.7 |

LIMA H = left internal mammary artery harvest.

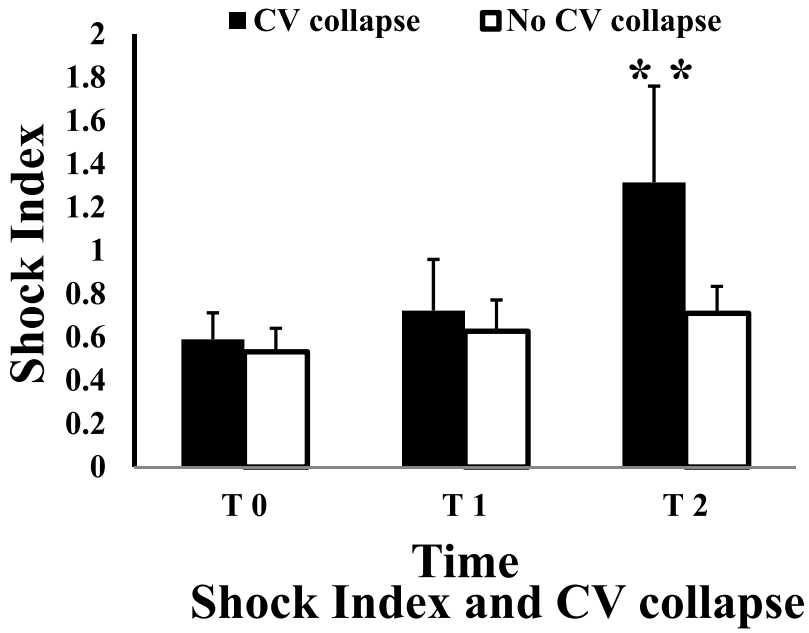


**Figure 2.** Shock index in patients with and without postoperative cardiovascular collapse. Data are presented as columns (mean) and error bars (standard deviation). CV = cardiovascular, *$p < 0.05$ and **$p < 0.01$. T 0 pre-induction, T 1 post-LIMA harvest and T 2 after weaning from cardiopulmonary bypass.

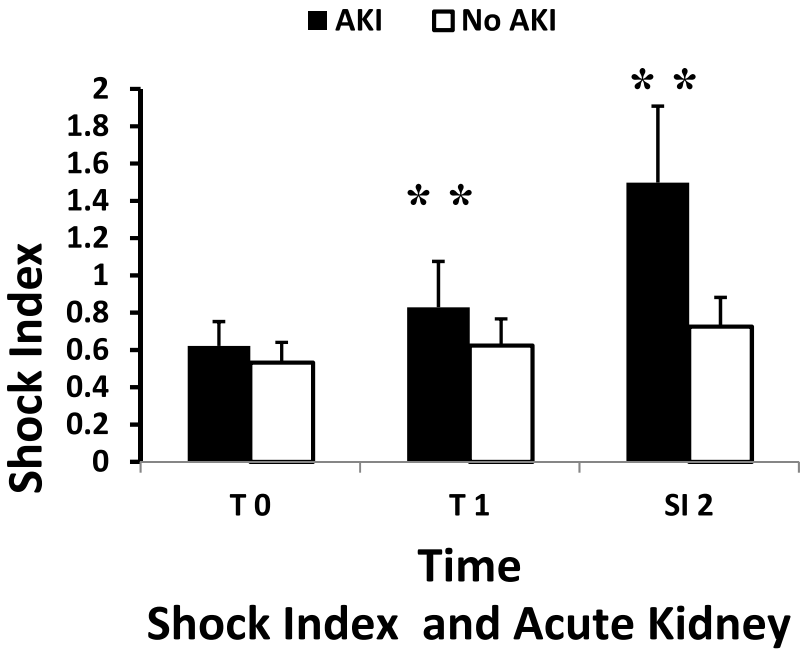


**Figure 3.** Shock index in patients with and without postoperative AKI. Data are presented as columns (mean) and error bars (standard deviation). AKI = acute kidney injury, *$p < 0.05$ and **$p < 0.01$.

**Table 3.** Hemodynamic parameters and their sensitivity and specificity to predict postoperative acute kidney injury.

| Variable | AUROC | Sensitivity | Specificity | *P* value | Cutoff value |
|---|---|---|---|---|---|
| Baseline heart rate (HR 0) | 0.752 | 83% | 69% | 0.01* | >84 bpm |
| Baseline shock index (SI 0) | 0.691 | 100% | 36.78% | 0.07 | >0.49 |
| Post-LIMAH heart rate (HR 1) | 0.759 | 83.33% | 58.62% | 0.0041** | >79 bpm |
| Post-LIMAH shock index (SI 1) | 0.784 | 83.33% | 79.31% | 0.0296* | >0.7 |
| Post-bypass heart rate (HR 2) | 0.919 | 100% | 91.95% | <0.0001** | >105 bpm |
| Post-bypass shock index (SI 2) | 0.929 | 83.33% | 98.85% | <0.0001** | >1.2 |

LIMA H = left internal mammary artery harvest.

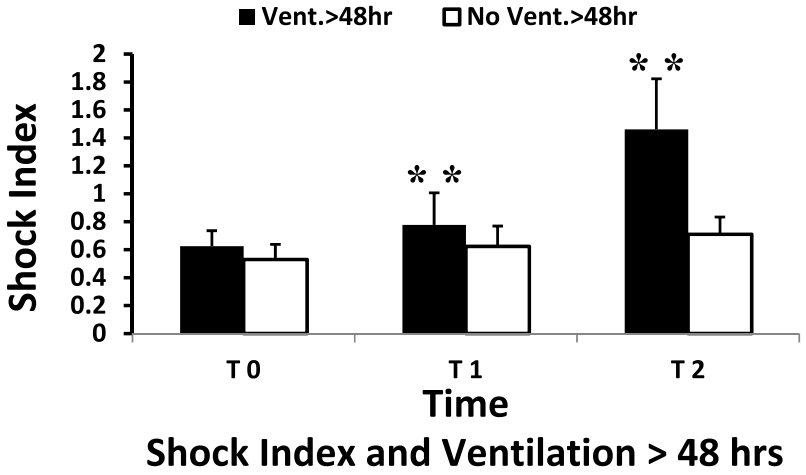


**Figure 4.** Shock index in patients with and without postoperative prolonged mechanical ventilation >48 h. Data are presented as columns (mean) and error bars (standard deviation). *$p < 0.05$ and **$p < 0.01$.

parameter to predict postoperative prolonged mechanical ventilation >48 h.

Best variables were SI after weaning from bypass (SI 2) then HR after weaning from bypass (HR 2) with cutoff values (>1.08, >105 bpm, respectively), with sensitivity and specificity (87.5%, 100% and 87.5%, 92.94%, respectively).

## 9. Ability of hemodynamic variables to predict postoperative in-hospital mortality

Postoperative in-hospital mortality had developed in cases who shown significantly high SI values in comparison with cases where in-hospital mortality did not happen and that was during two occasions SI 1 (post-

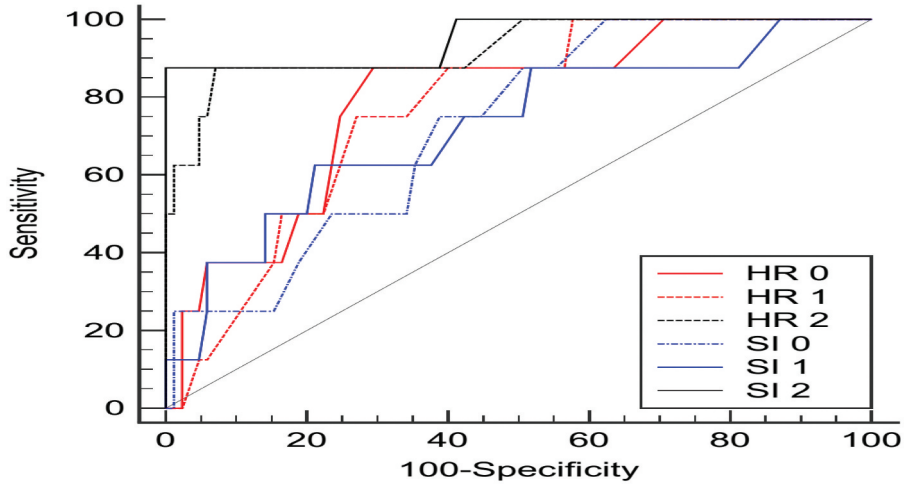


**Figure 5.** ROC curves for different variables as predictors of prolonged postoperative ventilation >48 h.

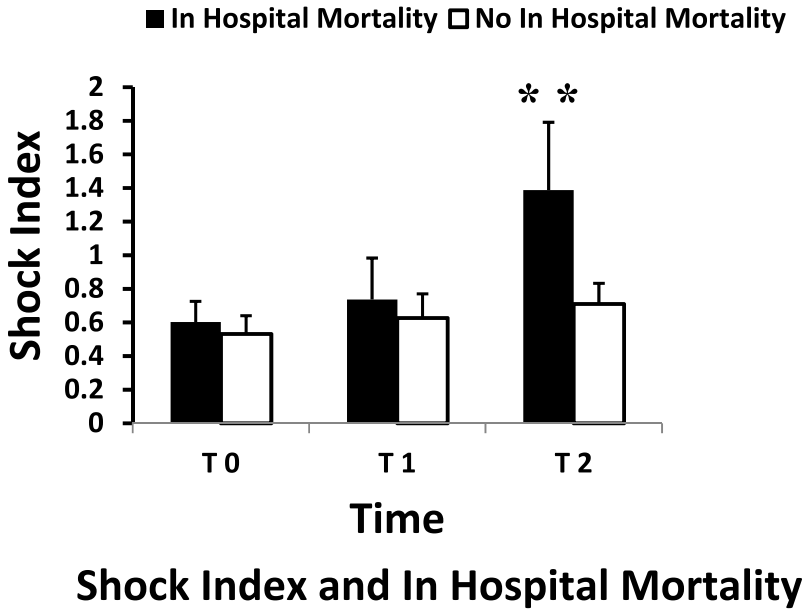


**Figure 6.** Shock index in cases of postoperative in-hospital mortality and in cases where there was no postoperative in-hospital mortality. Data are presented as columns (mean) and error bars (standard deviation). *$p < 0.05$ and **$p < 0.01$.

LIMA harvest) and SI 2 (after weaning from bypass), with highly significant *P* values ($P = 0.046$ and 0.000, respectively) with better results of SI after weaning (SI 2) (Figure 6).

## 10. Ability of hemodynamic variables to predict postoperative morbidity

SI after weaning (SI 2) had shown significantly high results in patients who developed postoperative morbidities than patients who did not develop morbidities, with *P* value ($P = 0.000$) (Figure 7).

## 11. Discussion

Our study showed that SI is a good predictor for postoperative CV collapse, AKI, prolonged postoperative mechanical ventilation >48 h, in-hospital mortality and postoperative morbidities, and the results obtained are comparable to those of other studies that describe SI as potentially useful for the identification of circulatory collapse, in-hospital mortality and morbidities.

The correlation between high SI and CV collapse and in-hospital morbidity and mortality was examined in many studies, in which their results were comparable to our results.

One of the earliest studies was done by Rady et al. in 1992, in which they induced an experimental hemorrhagic shock in 21 large white pigs, where hemodynamic and oxygen transport variables were measured and their relationships to SI were examined; they found that, in simple hemorrhage, the SI was inversely related to SV (i.e., cardiac output/HR) and mean arterial blood pressure, and, therefore,

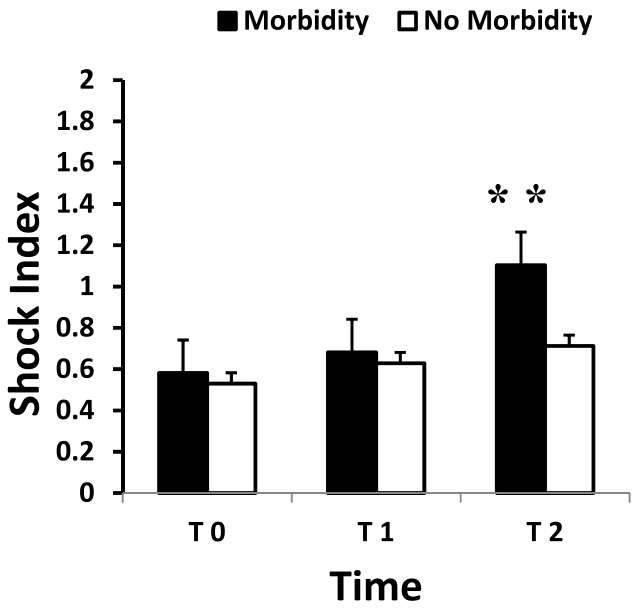


**Figure 7.** Shock index in patients with and without postoperative morbidity. Data are presented as columns (mean) and error bars (standard deviation). *$p < 0.05$ and **$p < 0.01$.

LVSW which is derived from both variables found that SI is a non-invasive means to monitor deterioration or recovery of LVSW during acute hypovolemic and normovolemic circulatory failure and its therapy [18].

In 1994, they published another study included 275 patients who came to the emergency department for urgent medical care. They found that, with apparently stable vital signs, an abnormal elevation of the SI to more than 0.9 was associated with an illness that was treated immediately, admission to the hospital and intensive therapy on admission with specificity for triage of patients to priority 1, admission to the hospital and transfer to the ICU (91%, 96% and 81%, respectively) and so SI may be useful to evaluate acute critical illness in the ED [19].

Birkhahn et al. enrolled 46 healthy blood donor volunteers to do a controlled blood loss of 450 ml as a simulation for early acute hypovolemia. They found that SI in early acute blood loss had increased above the normal range; meanwhile, there was no apparent increase above the accepted normal range in the HR nor decrease below the normal range in SBP, so SI was found to be superior in identifying patients with early acute hemorrhage than HR and sSBP [11].

Keller et al. in their study examined 50 general medical patients who had unplanned transfers to the ICU and 50 matched control patients (patients admitted to the general medical unit who did not require this high level of care, i.e., without ICU admission). They found that an SI of 0.85 and greater was strongly associated with unplanned ICU transfers, and patients who were transferred to the ICU had shown significantly higher or worst SI values than the control cases with significantly longer hospital stay and higher inpatient mortality rate [20].

Also, Terceros-Almanza et al. studied 287 patients in the trauma and emergency ICU of a tertiary hospital and found that SI is a good predictor of massive bleeding with an optimum cutoff point of 1.11, sensitivity 91.3% and specificity 79.69% [21].

To correlate SI with mortality, Sloan et al. studied data set of 219 traumatic hemorrhagic shock patients in different US and EU trauma centers and found that patients with an SI ≥1.0, 1.4 and 1.8 at any time points were 2.3, 2.7 and 3.1 times, respectively, more likely to die by 28 days than were patients with SI values below these cutoffs ($p < 0.001$). Similarly, after 120 min of resuscitation, patients with an SI ≥1.0 were 3.9 times more likely to die by 28 days (40 vs. 15%, $p < 0.001$). Therefore, the SI correlates with 28-day mortality, with higher SI values indicating greater mortality risk [22].

Waheed et al. in their study found that patients who were admitted to emergency department with SI >0.7 were more likely to be admitted to ICU and had a critical course in comparison to patients with SI of <0.7 who are 95% less likely to present with higher levels of sepsis markers like serum lactate [23].

In a recent study by Raza et al., they assessed the utility of SI in patients undergone both elective and emergency surgical procedures and recorded the outcome of these patients, and they found that patients with SI of 0.8 or more at admission indicate that they will experience intraoperative blood loss more than 1 L and required transfusions, and they were at high risk for

postoperative ventilation. Patients with SI more than 1.0 may be at a higher risk of reoperations and suffering from urinary tract infections. They documented an average value of SI for all morbidities, which was 0.81 at admission and 0.83 prior to induction of anesthesia [24].

In cardiac surgery, Hagel et al., in a study published in 2021, investigated the role of SI together with coronary perfusion pressure as predictors of adverse outcome after cardiac surgery in children and found that SI greater than 1.83 was significantly associated with the primary outcome which was the occurrence of any of the following adverse events in the first 7 days following cardiac ICU admission: cardiopulmonary resuscitation, extracorporeal cardiopulmonary resuscitation, mechanical circulatory support, unplanned surgery, heart transplant or death [25].

We excluded SI after weaning from CPB (SI 2) as a predictor of CV collapse postoperatively as it increases during the event of collapse, so it loses its ability to provide the health-care giver enough time to predict CV collapse before happening as a risk indicator or a predictive parameter; nevertheless, it gives a good significant *P* value ($P = 0.000$).

## 12. Limitations

The present study showed some limitations, and we used central venous pressure of 7–8 cm $H_2O$ as a cutoff point for satisfaction of good volume resuscitation after weaning from bypass before taking vital signs of that time interval and did not use the dynamic parameters in fluid resuscitation due to resource limitation.

## 13. Conclusion

We believe that SI has a good prediction of postoperative CV collapse, AKI, prolonged postoperative mechanical ventilation >48 h (as primary outcomes) and postoperative morbidities and in-hospital mortality (as secondary outcomes) in on-pump CABG surgery and that SI value after weaning from CPB is a good predictive one in comparison to other values taken in the other two occasions (baseline SI before induction of general anesthesia and SI after LIMA harvest) with cutoff values (>1.2 in AKI and >1.08 in prolonged postoperative mechanical ventilation >48 h).

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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