ORIGINAL ARTICLE

Oxygenation Index and Oxygen Saturation Index for Predicting Postoperative Outcome in Patients Undergoing Emergency Surgery: A Prospective Cohort Study

Ruma Thakuria[1], Emmanuel Easterson Ernest[2], Apala Roy Chowdhury[3], Neha Pangasa[4], Choro Athiphro Kayina[5], Sulagna Bhattacharjee[6], Puneet Khanna[7], Dalim K Baidya[8], Banupriya Ravichandrane[9], Souvik Maitra[10]

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Abstract

Background: The OI was originally evaluated as a prognostic tool for acute hypoxemic respiratory failure in children and was an independent predictor for mortality in adult patients with acute respiratory distress syndrome (ARDS).

Methods: Oxygenation index and OSI of 201 adult patients undergoing emergency surgery were evaluated at different time points. The primary objective of this study was to find the correlation between OI and OSI. The secondary objectives were to find the prognostic utility of OI and OSI for postoperative mechanical ventilation and mortality.

Results: Significant statistical correlation was found between OI and OSI both at the beginning ($r^2 = 0.61$; $p < 0.001$) and immediately after surgery ($r^2 = 0.47$; $p < 0.001$). Oxygen saturation index at the beginning [area under the receiver operating characteristics curve (AUROC) (95% CI) 0.76 (0.62–0.89); best cutoff 3.9, sensitivity 64% and specificity 45%] and immediately after surgery [AUROC (95% CI) 0.82 (0.72–0.92); best cutoff 3.57, sensitivity 79%, and specificity 62%] were reasonable predictors of the requirement of invasive ventilatory support. Exploratory analysis reported that older age ($p = 0.02$), higher total leukocyte count ($p = 0.002$), higher arterial lactate ($p = 0.02$), and higher driving pressure ($p < 0.001$) were independently associated with hospital mortality.

Conclusion: In adult patients undergoing emergency laparotomy under general anesthesia, OI and OSI were found to be correlated. Both metrics demonstrated reasonable accuracy in predicting the need for invasive ventilatory support beyond 24 hours and hospital mortality.

Keywords: Driving pressure, Emergency surgery, Mortality, Outcome, Oxygenation index, Oxygen saturation index.

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Highlights

Oxygenation index (OI) and oxygen saturation index (OSI) are correlated in adult patients undergoing emergency laparotomy under general anesthesia and both were able to predict postoperative mechanical ventilation and in-hospital mortality with reasonable accuracy.

Introduction

The oxygenation index (OI = mean airway pressure × inspired air oxygen fraction × 100/arterial oxygen tension) was initially explored as a prognostic marker for hypoxemic respiratory failure in children.[1] The OI was also established as an independent predictor for poor outcomes in adults with acute respiratory distress syndrome (ARDS).[2,3] A primary challenge with the OI and the P/F ratio (arterial oxygen tension to the fraction of oxygen in the inspiratory air) is that both require arterial blood gas analysis to determine arterial oxygen tension (PaO_2). Recently, a retrospective study reported that the oxygen saturation index (OSI = mean airway pressure x inspired air oxygen fraction × 100/oxyhemoglobin saturation) correlates strongly with OI in ARDS patients and also predicts mortality in these patients.[4] Non-invasive pulse oximetry-derived S/F ratio (oxyhemoglobin saturation to fraction of oxygen in the inspiratory air) has been used as a substitute for P/F ratio in several scoring systems, effectively predicting mortality in critically ill patients.

[1–10]Department of Anaesthesiology, Pain Medicine and Critical Care, All India Institute of Medical Sciences, New Delhi, India

Corresponding Author: Souvik Maitra, Department of Anaesthesiology, Pain Medicine and Critical Care, All India Institute of Medical Sciences, New Delhi, India, Phone: +91 8146727891, e-mail: souvikmaitra@aiims.edu

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Emergency or urgent surgery, especially abdominal surgery is considered to be a known risk factor for postoperative pulmonary complications (POPC). The incidence of POPC varies depending on the definition and type of surgery, but these complications are common following open abdominal and emergency surgeries and may contribute to increased postoperative morbidity and mortality.[5,6] General anesthesia reduces functional residual capacity in adults, regardless of the use of mechanical ventilation and muscle relaxants and contributes to atelectasis, which is considered the harbinger of postoperative pneumonia, which might ultimately cause respiratory failure.[7] However, several other mechanisms also contribute to POPC.

Although the OI was evaluated in patients with respiratory failure, it has not been evaluated in patients at risk of POPC. This study was designed to identify the statistical association between OI and OSI in adult patients undergoing emergency laparotomy, which could help detect those needing postoperative ventilatory support.

The primary objective was to identify correlations between OI and OSI. The secondary objectives included determining whether OI or OSI could predict the need for invasive ventilation for more than 24 hours in the postoperative period and hospital mortality. During the recruitment phase, we also evaluated the role of driving pressure (difference between plateau airway pressure and positive end-expiratory pressure), CO_2 gap (CO_2 gap = $PaCO_2$–$EtCO_2$), and baseline arterial lactate as metabolic parameters to predict outcomes in these patients.

Methods

This prospective cohort study was conducted at an apex teaching hospital in India. The study adhered to the Declarations of Helsinki and was approved by the institutional Ethics Committee (IEC-86/09.03.2018) prior to the recruitment. Written informed consents were received from all eligible participants/their legally acceptable representatives, and the study was registered in a publicly accessible registry, before enrolling the first case (CTRI/2019/04/018630, www.ctri.nic.in).

Adult patients of either sex (aged over 18 years) scheduled for emergency laparotomy were recruited in this research. Exclusion criteria included refusal of consent by the patient or their relatives, a history of abdominal surgery during the present admission, requirement of intensive within the last 6 months, significant comorbid illness, and intraoperative massive blood loss, defined as exceeding 1 L during surgery.

Sample Size Estimation

To the best of our knowledge at the time of designing this study, no prior research has evaluated the correlation between OI and OSI in the perioperative period. We conservatively hypothesized that a moderate correlation would exist between OI and OSI (Pearson's $R^2 = 0.2$). To refute this hypothesis with a beta of 80% and a both-sided alpha of 0.05, a minimum of 194 patients were required.

Study Protocol

A detailed history of the patient's current and co-morbid illness (including treatment and severity), previous surgical history, and allergies were recorded along with baseline vital signs. Preoperative laboratory investigations were performed according to the standard institutional protocol. A radial artery catheter was placed for intraoperative monitoring and arterial blood gas analysis.

Standard American Society of Anesthesiologists monitoring along with invasive blood pressure were used in all patients. Standard balanced anesthesia protocols, that included intravenous induction and maintenance by inhalation anesthetics, were followed in all patients. Muscle relaxation was achieved by intermittent boluses of non-depolarizing neuromuscular blocking agents.

The volume-controlled mode was used, with a tidal volume of 6–8 mL per kg of predicted body weight, PEEP of 0–5 cmH_2O, and a ratio of inspiratory-to-expiratory time of 1:2. Respiratory rate was set at 12 breaths per minute initially, and adjusted to maintain normocarbia. General anesthesia was maintained with volatile inhalation anesthetic in oxygen and air. In cases of arterial desaturation (peripheral oxygen saturation < 94%), FiO_2 and/or PEEP were adjusted to maintain SaO_2 > 97%.

The trachea was extubated in the operating room once the patients were awake, responsive to verbal commands, hemodynamically stable, and having acceptable oxygenation parameters. Supplemental oxygen therapy was used with a target oxyhemoglobin saturation > 94% when required. If extubation was not feasible in the operating room, patients were transferred to the intensive care unit (ICU) or high-dependency unit, and mechanical ventilation continued. Vasopressor support was provided as necessary. Clinical management of the patients was in accordance with the routine protocol of the institute.

Data Collection

Arterial blood gases (pH, pO_2, pCO_2, and serum bicarbonate) were analyzed immediately after the beginning of surgery (T1) and after surgery, just before the return of spontaneous ventilation (T2). At each time point, mean airway pressure, PEEP, FiO_2, and SpO_2 were recorded. The need for invasive ventilation beyond the initial 24 hours postoperatively, duration of ICU stay, duration of hospital stay, and death during the hospital stay were documented by an anesthesiologist who was blinded to the patient's intraoperative oxygenation data.

Data Analysis

Kolmogorov–Smirnov test for normality was used for the evaluation of data distribution. Mean and standard deviation (SD) were presented for the parametric data and skewed data were reported as median and interquartile range (IQR). Statistical correlation between OI and OSI was evaluated using Kendall's tau or Pearson's method, as appropriate. To determine the association between OI/OSI and the requirement of invasive ventilation and hospital mortality, a multivariable logistic regression model was employed, adjusting the baseline risk.

Results

In this study, $n = 201$ patients were recruited. The mean (SD) age of the patients was 40.8 (16) years and 52.7% (106 of 201 patients) were male. Demographic details and baseline laboratory parameters of the patients were reported in Table 1.

Patients underwent emergency laparotomy for several reasons, the most common being intestinal obstruction (42%) and clinically suspected or confirmed perforation peritonitis (39%). In this cohort, $n = 159$ patients (79%) were extubated within 24 hours of surgery and 173 (86%) patients survived hospital discharge. Median (IQR) length of ICU stay and hospital stay were 2 (0–4) days and 10 (6–16.8) days, respectively.

The correlation matrix of OI and OSI is presented in Figure 1. A significant correlation was noted between OI and OSI both at the beginning [r^2 (95% CI) = 0.61 (0.53–1.00); $p < 0.001$] and immediately after surgery [r^2 (95% CI) = 0.47 (0.35–0.57); $p < 0.001$].

Oxygen saturation index at the beginning [area under the receiver operating characteristics curve (AUROC) (95% CI) 0.76 (0.62–0.89)] and immediately after surgery [AUROC (95% CI) 0.82 (0.72–0.92)] were able to predict the requirement of invasive ventilatory support (Fig. 2). Best cutoff values were 3.9 (sensitivity and specificity were 64 and 45%, respectively) and 3.6 (sensitivity and specificity were 79 and 62%, respectively), respectively. Oxygen saturation index at both time points was also able to predict in-hospital mortality in this cohort (Table 2). The OI was also able to predict both invasive ventilation and hospital mortality (Table 2).

Table 1: Demographic and baseline laboratory parameters in survivors and non-survivors [data represented as median (IQR) or proportions as applicable]

Parameters	*All patients (n = 201)*	*Survivors (n = 173)*	*Non-survivors (n = 28)*	*Significance*
Age	41 (26–52)	41 (26–52)	45 (22–59)	$p = 0.72$
Sex (Male/Female)	108/95	92/81	14/14	$p = 0.76$
BMI	20.4 (19–22)	20.7	21.2	$p = 0.39$
Serum hemoglobin	10.7 (9–12.9)	11 (9.2–13)	9.85 (8.8–12)	$p = 0.09$
Total leukocyte count	8,000 (6,050–12,820)	7,620 (5,730–11,700)	14,810 (9,050–22,100)	$p < 0.001$
Platelet count ($\times 10^5$)	2.1 (1.5–3)	2.1 (1.6–3)	1.9 (1.2–2.6)	$p = 0.15$
INR	1.2 (1.08–1.4)	1.18 (1.05–1.34)	1.42 (1.3–1.6)	$p < 0.001$
Creatinine	0.70 (0.58–0.90)	0.70 (0.5–0.9)	0.98 (0.8–1.3)	$P < 0.001$
pH	7.38 (7.32–7.41)	7.38 (7.33–7.41)	7.35 (7.28–7.40)	$P = 0.07$
PaO_2	205 (169–247)	211 (173–249)	164 (126–225)	$p = 0.01$
$PaCO_2$	36.7 (33–40)	36.4 (32–42)	36.7 (33–39.5)	$p = 0.76$
Serum HCO_3	20.8 (19.1–22.7)	20.8 (19.4–22.7)	20.6 (16.3–22.6)	$p = 0.14$
Serum lactate	0.90 (0.70–1.40)	0.90 (0.7–1.3)	1.30 (0.9–2.6)	$p < 0.001$
PaO_2/FiO_2	430 (345–504)	438 (360–511)	342 (244–445)	$P < 0.001$
Driving pressure	12 (9–15)	11 (9–13)	17.5 (14.8–22)	$P < 0.001$
Oxygen index	1.7 (1.2–2.15)	1.59 (1.35–2)	2.48 (1.88–3.15)	$p < 0.001$
Oxygen saturation index	3.5 (3.16–4.04)	3.43 (3.15–3.8)	4.29 (3.67–4.82)	$p < 0.001$
Driving pressure index	2.76 (1.88–4.21)	2.55 (1.8–3.48)	5.04 (3.84–7.79)	$p < 0.001$
CO_2 gap	0.5 (–4.2–3.8)	0.3 (–4.4, 3.6)	0.65 (–2.6, 4.2)	$p = 0.67$

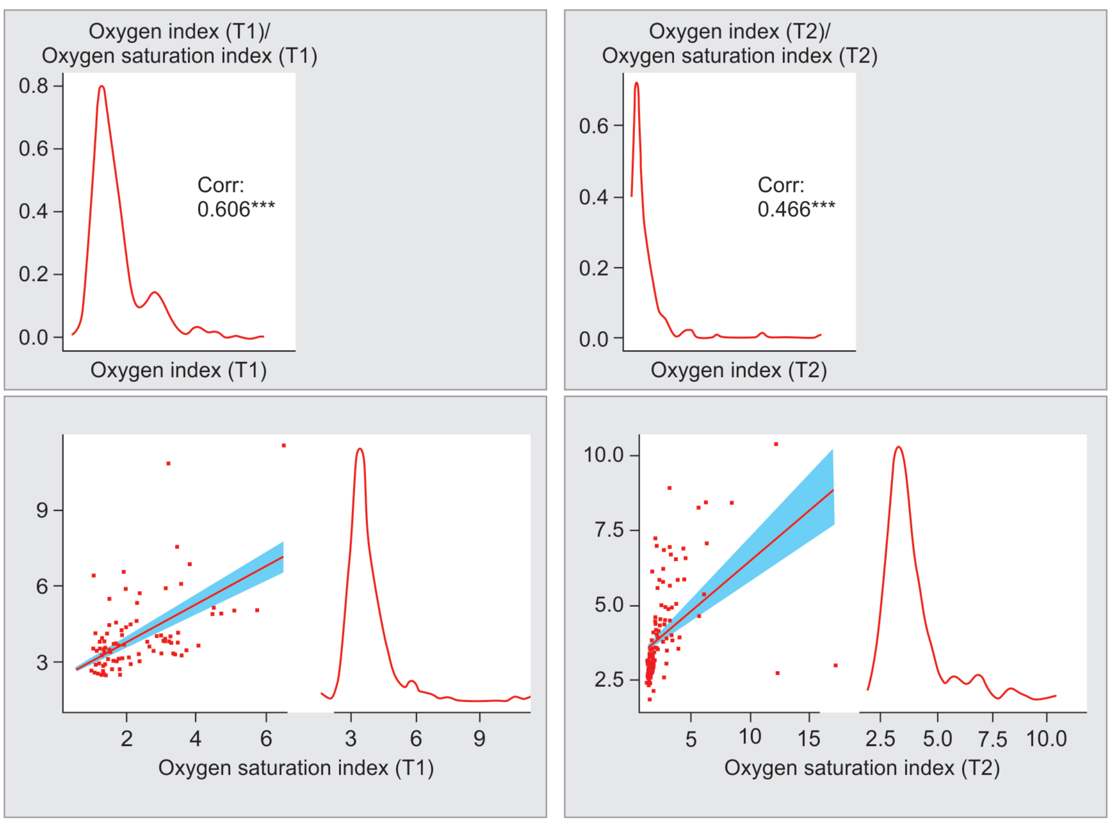

Fig. 1: Correlation matrix with 95% CI between oxygenation index (OI) and oxygen saturation index (OSI) and density of OI and OSI

The OI and OSI performed similarly to predict invasive ventilatory support ($p = 0.26$, DeLong's test) and mortality ($p = 0.68$, DeLongs' test).

As an exploratory analysis, risk prediction models were constructed with patients' demographic and baseline clinical parameters. Univariate statistics revealed a statistically significant association between hospital mortality with hemoglobin ($p = 0.09$), total leucocyte count ($p < 0.001$), international normalized ratio ($p < 0.001$), serum creatinine ($p < 0.001$), pH ($p = 0.07$), PaO_2 ($p = 0.01$), arterial lactate ($p < 0.001$), PaO_2/FiO_2 ratio ($p < 0.001$),

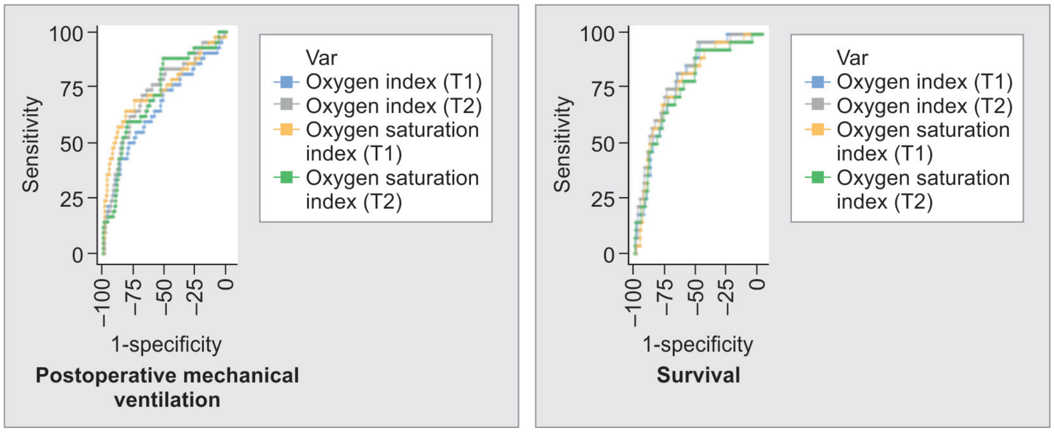

Fig. 2: Receiver-operating-characteristics curve of oxygen index (OI) and oxygen saturation index (OSI) to predict in-hospital mortality and postoperative mechanical ventilation

Table 2: Prognostic utility of oxygenation index and the oxygen saturation index to predict postoperative mechanical ventilation and in-hospital mortality

	AUROC (95% CI)	*Cutoff*	*Sensitivity (%)*	*Specificity (%)*
Postoperative mechanical ventilation				
Oxygenation index (T1)	0.73 (0.61–0.84)	2.4	43	86
Oxygen saturation index (T1)	0.76 (0.62–0.89)	3.9	64	82
Oxygenation index (T2)	0.83 (0.74–0.91)	2.2	62	79
Oxygen saturation index (T2)	0.72 (0.72–0.92)	4.0	60	81
In-hospital mortality				
Oxygenation index (T1)	0.79 (0.71–87)	1.86	82	67
Oxygen saturation index (T1)	0.78 (0.69–0.87)	3.8	71	75
Oxygenation index (T2)	0.81 (0.73–0.89)	1.89	82	66
Oxygen saturation index (T2)	0.77 (0.67–0.86)	3.5	93	51

AUROC, area under the receiver operating characteristics curve

Table 3: Binary logistic regression models to predict in-hospital mortality

	Adjusted OR (95% CI)	*p-value*	*Model characteristics*
Full model			
Driving pressure (T1)	1.21 (1.08, 1.35)	$p < 0.001$	AIC = 121
Age	1.04 (1.00, 1.07)	$p = 0.04$	AUROC = 0.89
Oxygenation index (T1)	1.47 (0.86, 2.50)	$p = 0.16$	$R^2_{McF} = 0.349$
INR	1.01 (0.57, 1.78)	$p = 0.98$	
Serum lactate	1.56 (1.03, 2.37)	$p = 0.04$	
Serum creatinine	0.97 (0.49, 1.94)	$p = 0.94$	
TLC	1.00 (1.00–1.0002)	$p = 0.002$	
Final model			
Driving pressure (T1)	1.25 (1.13, 1.39)	$p < 0.001$	AIC = 117
Serum lactate (T1)	1.52 (1.05, 2.16)	$p = 0.023$	AUROC = 0.89
Age	1.04 (1.00, 1.08)	$p = 0.024$	$R^2_{McF} = 0.337$
TLC count	1.00 (1.00–1.0002)	$p = 0.002$	

AIC, akaike information criteria; AUROC, area under the receiver operating characteristics curve; R^2, amount of variance explained

driving pressure ($p < 0.001$), OI ($p < 0.001$) and OSI ($p < 0.001$). The binary logistic regression model revealed that older age ($p = 0.02$), higher total leucocyte count ($p = 0.002$), higher arterial lactate ($p = 0.02$), and driving pressure ($p < 0.001$) were independently associated with hospital mortality (Table 3).

In univariate analysis, lower hemoglobin ($p = 0.04$), higher total leucocyte count ($p = 0.09$), lower platelet ($p < 0.001$), higher international normalized ratio ($p < 0.001$), higher serum urea ($p < 0.001$) and higher serum creatinine ($p = 0.018$), lower arterial pH ($p < 0.001$), lower serum bi-carbonate ($p = 0.003$), higher serum lactate ($p < 0.001$), higher OI ($p = 0.001$), OSI ($p < 0.001$) and driving pressure ($p < 0.001$) and lower P/F ratio ($p = 0.032$) were associated with postoperative mechanical ventilation beyond 24 hours. The logistic regression model found that lower hemoglobin level ($p = 0.02$), lower platelet count ($p = 0.001$), higher arterial lactate ($p < 0.001$), and higher driving pressure ($p < 0.001$) were independently associated with invasive ventilation (Table 4).

Discussion

This study found a statistically significant correlation between OI and OSI both in the intraoperative and postoperative periods. Both metrics were reasonable predictors of invasive ventilation in the postoperative period and hospital mortality. In an exploratory analysis, we also found that driving pressure and serum lactate are an independent predictor of postoperative mechanical ventilation and hospital mortality.

Several oxygenation parameters are being used in clinical practice for the identification of high-risk patients in the perioperative and critical care settings. PaO_2/FiO_2 ratio is widely and probably most commonly used for this purpose. However, it has several limitations,

Table 4: Binary logistic regression models to predict postoperative mechanical ventilation beyond 24 hours

	Adjusted OR (95% CI)	*p-value*	*Model characteristics*
Full model			
Hemoglobin	0.78 (0.64, 0.94)	$p = 0.009$	AIC = 140
TLC	1.00 (0.99–1.00)	$p = 0.62$	AUROC = 0.89
Platelet	0.45 (0.27–0.72)	$p = 0.001$	$R^2_{McF} = 0.409$
INR	0.90 (0.65, 1.25)	$p = 0.55$	
Creatinine	1.33 (0.51, 3.48)	$p = 0.56$	
Serum bicarbonate	0.94 (0.81, 1.08)	$p = 0.36$	
Oxygenation index (T1)	1.22 (0.76, 1.96)	$p = 0.41$	
Driving pressure (T1)	1.15 (1.03, 1.29)	$p = 0.01$	
Serum lactate	3.00 (1.66, 5.47)	$p < 0.001$	
Final model			
Hemoglobin	0.81 (0.67, 0.97)	$p = 0.02$	AIC = 139
Platelet	0.46 (0.29, 0.73)	$p = 0.001$	AUROC = 0.88
Driving pressure (T1)	1.17 (1.07, 1.28)	$p < 0.001$	$R^2_{McF} = 0.373$
Serum lactate (T1)	2.95 (1.77, 4.93)	$p < 0.001$	

AIC, akaike information criteria; AUROC, area under the receiver operating characteristics curve; R^2, amount of variance explained

such as the requirement of arterial blood gas analysis, and it doesn't consider lung mechanics parameters. Both OI and OSI overcome this problem by including mean airway pressure, which reflects the mechanical characteristics of the lung. A large observational study[8] reported that on day 1 of ARDS, OI and OSI correlated strongly and OSI measured on day 1, predicted both mortality and a reduced ventilator-free day in those patients. Our findings are also in concordance with the previous studies.[8] Another retrospective study reported a significant correlation between OI and OSI in mechanically ventilated patients with SARS-CoV-2 infection-associated ARDS and both of these parameters had prognostic importance.[9]

This study also noted that only driving pressure and serum lactate were independently associated with mortality. Interestingly, neither OI nor OSI was able to predict mortality. Previous research has identified that driving pressure was an independent predictor of mortality in ARDS patients[10] but not in patients with respiratory failure without ARDS.[11] Our findings are clinically significant as both driving pressure and serum lactate are easily measurable in the perioperative setting and can be used for risk stratification. It is also worth mentioning that POPCs are not uncommon even in elective surgery patients making early identification crucial.[12]

Strengths and Limitations

Despite being a single-center study, we recruited a reasonable number of patients, who were at risk of POPC. The most important limitation of this study is the limited sample size for conducting logistic regression analysis and our exploratory findings need to be validated with a larger cohort.

Conclusion

The OI and OSI were correlated in adult patients undergoing emergency laparotomy under general anesthesia. Both metrics accurately predicted the need for postoperative mechanical ventilation beyond 24 hours and in-hospital mortality. In adjusted analyses, driving pressure and serum lactate emerged as independent predictors of postoperative mechanical ventilation and mortality. However, these exploratory findings need validation in a larger cohort.

Orcid

Ruma Thakuria https://orcid.org/0000-0001-5963-7549
Emmanuel Easterson Ernest https://orcid.org/0009-0001-6611-6300
Apala Roy Chowdhury https://orcid.org/0000-0001-9027-9794
Neha Pangasa https://orcid.org/0000-0003-1131-3478
Choro Athiphro Kayina https://orcid.org/0000-0003-3509-5508
Sulagna Bhattacharjee https://orcid.org/0000-0001-8671-6875
Puneet Khanna https://orcid.org/0000-0002-9243-9963
Dalim K Baidya https://orcid.org/0000-0001-7811-7039
Banupriya Ravichandrane https://orcid.org/0000-0002-7928-7280
Souvik Maitra https://orcid.org/0000-0002-2328-9201

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