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Integrated Pulmonary Index as a Predictor of Respiratory Compromise in Critically Ill Patients: A Prospective, Observational Study

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Abstract

Background: Recent developments in detecting ARDS focus on using multiple physiological parameters, integrating them into a single index to improve accuracy while reducing false alarms and alarm fatigue. The Integrated Pulmonary Index (IPITM) is one such multi-parameter tool, combining oxygen saturation, respiratory rate, $ETCO_2$, and pulse rate into a 1-10 scale. Scores ≥8 indicate normal conditions, while ≤4 suggest intervention is needed.

Aim of Study: In this study, we prospectively investigated the effectiveness and usefulness of integrated pulmonary index as a predictor of respiratory compromise in critically ill patients.

Patients and Methods: This prospective observational study was conducted at Ain Shams University Hospitals from June 2023 to December 2023, involving 70 critically ill patients aged 18 or older, admitted to the ICU. IPI measurements were recorded for all patients at (2, 6, 12, 18, and 24 hours). Patients were then categorized into respiratory compromise (RC) defined as development of hypoxemia, hypercapnia, bronchospasm, tachypnea, and any other events that required intervention, and non-respiratory compromise (NRC). The values were then correlated with the need for oxygen support, onset of mechanical ventilation, duration of mechanical ventilation, length of ICU, duration of hospital stay and 28-day mortality rate.

Results: Among the 70 patients included in the study 41 patients (58.6%) developed respiratory compromise (RC), while 29 patients (41.4%) did not develop any respiratory compromise (NRC). Analysis of the Integrated Pulmonary Index (IPI) showed significant differences between patients with respiratory compromise (RC) and those without. At all-time intervals (2, 6, 12, 18, and 24 hours), median and interquartile ranges for IPI values were lower in the RC group (p<0.001), highlighting IPI's reliability in predicting respiratory status. The RC group required longer duration of mechanical ventilation, had longer ICU and hospital stays and exhibited a higher mortality rate (19.5%) compared to 0% in the non-compromised group (p=0.011). Correlation analysis showed strong negative associations between IPI and various clinical parameters, such as respiratory compromise (r=–0.812), the need for oxygen support (r=–0.812), and the need for mechanical ventilation (r=–0.542), as well as ICU stay (r=–0.814) and hospital stay (r=–0.809), as well as 28-day mortality rate (r=–0.477). These correlations emphasize IPI's value in predicting adverse clinical outcomes. ROC curve analysis demonstrated that IPI, with a cut-off value of <6, had excellent predictive accuracy for oxygen support (AUC=0.906, sensitivity 90%, PPV 98.7%). SpO_2 also showed good predictive performance (AUC=0.839, sensitivity 86.7%, PPV 94.3%). Overall, IPI was the superior predictor, emphasizing its clinical utility in identifying patients at risk for respiratory deterioration.

Conclusion: The findings of this study highlight the Integrated Pulmonary Index (IPI) as a reliable and dynamic predictor of respiratory compromise and oxygen support requirements in critically ill patients, outperforming SpO_2 in overall accuracy. The IPI demonstrated strong correlations with adverse clinical outcomes, including the duration of mechanical ventilation, length of ICU, length of hospital stay, and mortality rate. Its high sensitivity and predictive values emphasize its utility in early detection of respiratory compromise, aiding timely interventions to improve patient outcomes. These results underscore the importance of incorporating IPI into routine monitoring protocols in intensive care settings to enhance patient care and prognosis.

Key Words: *Integrated – Pulmonary – Respiratory – Critically – Prospective – Observational.*

Introduction

RECENT developments aim to use multiple parameters to detect ARDS (acute respiratory distress syndrome). Application of smart algorithms that

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combine individual physiological variables into one index may increase the ability to detect a true adverse respiratory event while avoiding false alarms and limiting alarm fatigue **[1]**.

An example of such a multi-parameter index is the Integrated Pulmonary Index or IPITM, which integrates oxygen saturation (SpO_2), respiratory rate (RR), end-tidal CO_2 ($ETCO_2$) and pulse rate (PR) into a single integrated value of 1–10 that represents adequacy of respiratory condition of the patient using a fuzzy logic inference mathematical model **[2]**. The IPI (Integrated Pulmonary Index) algorithm summarizes the state of ventilation and oxygenation at a point in time. Scores ≥8 points are within normal range and those ≤4 points suggest requirement of interventions **[3]**.

Aim of the work:

In this study, we investigated the effectiveness and usefulness of integrated pulmonary index as a predictor of respiratory compromise in critically ill patients.

Patients and Methods

Type of study: Prospective Observational Study.

Study setting: Ain Shams University Hospitals.

Study period: From June 2023 to December 2023.

Study population: Critically ill patients aged 18 years or older of both genders admitted to the intensive care unit.

Inclusion criteria: Patients aged 18 years or older from critical ill patients who were admitted to ICU.

Exclusion criteria: Age <18 years old, morbid obesity, mechanical ventilation on admission, patients with hemodynamic instability, post-thoracotomy and cardiac surgery.

Sampling method:

Sample size: Using PASS 15 program for sample size calculation, setting power error at 80% and alpha error 0.05, the expected area under ROC curve for IPI for prediction of respiratory compromise=0.80, assuming 20% rate of RC, a sample size of 70 patients will be needed to detect predictive ability of IPI.

Study tools: Expiratory gas sampling lines were attached to the patients upon admission to the ICU and the $ETCO_2$, RR, SpO_2, pulse rate, and IPI values were recorded using (CapnostreamTM Medtronic). The sampling line of this device features oral and nasal sampling as well as a supplemental oxygen delivery system. The device measures the $ETCO_2$ and RR by sampling exhaled gas and the SpO_2 and HR (heart rate) by pulse oximetry. Furthermore, the IPI (Integrated Pulmonary Index) is calculated automatically from four parameters and all values are displayed on a screen. The calculation methods use fuzzy logic inference model. After the provisional IPI is assigned according to the matrix table of RR and $ETCO_2$, the definite IPI is decided finally adding evaluation of SpO_2 and HR. The IPI values range from 1 to 10, where "10" indicates a normal respiratory status, and "1" indicates that patient requires immediate intervention **[5]**.

Study procedure: This is a prospective observational study in which all cases were collected from ICUs (Intensive Care Units) of Ain Shams University Hospitals during the period between June 2023 and December 2023. Included patients received the standard care, according to the usual standard clinical practice at the institution. After admission to the ICU, patients were continuously monitored with ICU standard monitoring in addition to IPI using (CapnostreamTM Medtronic). IPI measurements were recorded upon admission to the ICU, as well as at 2, 6, 12, 18 and 24 hours. Any respiratory, hemodynamic events or interventions were recorded by the ICU nurses.

Laboratory and radiological investigations:

Demographic (age, gender, body mass index, comorbidities), clinical, laboratory, and outcomes data were recorded. Routine laboratory tests were done for all patients, including CBC, C-reactive protein, renal profile, coagulation profile, liver profile and chest X-ray.

Study outcomes:

Primary outcome:

The primary outcome of the present study was defined as the occurrence of respiratory compromise (RC) on ICU admission. We defined RC such as bronchospasm, hypoxemia (SpO_2 <94%), hypercapnia ($PaCO_2$ >45mmHg), tachypnea (respiratory rate >20/minute), hypopnea (respiratory rate <8/minute), apnea, requiring any form of respiratory support (such as oxygen supplementation via nasal cannula, venturi mask, nebulizer, NRM (Non-rebreathing mask), high flow nasal cannula, NIV (Non-invasive ventilation), endotracheal intubation and mechanical ventilation.

Patients were divided accordingly into two groups:

- Group I: Respiratory compromise (RC) group.
- Group II: Non respiratory compromise (RC) group.

Secondary outcomes:

Secondary outcomes included the need for oxygen support, the onset and duration of mechanical ventilation, length of ICU stay, length of hospital stay and 28-day mortality rate. Mechanical ventilation was defined as both invasive (requiring endotracheal intubation) and non-invasive (requiring CPAP mask).

Ethical considerations:

This study was performed after approval of the research ethical committee of faculty of medicine. All patients provided a written informed consent prior to inclusion in the study.

Statistical analysis:

Recorded data were analyzed using the statistical package for social sciences, version 23.0 (SPSS Inc., Chicago, Illinois, USA). Quantitative data were presented as mean ± SD (standard deviation) and ranges when their distribution was parametric (normal), while non-parametric data were presented as median with interquartile range (IQR). Also qualitative data were presented as number and percentages. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk Test. Independent-samples *t*-test of significance was used when comparing two means. Chi-square test was used for comparison between groups with qualitative data. The confidence interval was set to 95% and the margin of error accepted was set to 5%. *p*-value for significance was considered significant ≤ 0.05, *p*-value ≤ 0.01 was considered as highly significant, *p*-value >0.05 was considered non-significant. Spearman correlation coefficient (*r*) was used to measure the strength and direction of the relationship between two ranked ordinal variables, ranging from -1 (perfect negative correlation) to +1 (perfect positive correlation). ROC curve analysis was used to evaluate the integrated pulmonary index and SpO_2 in predicting adverse respiratory events.

Results

Table (1) presents the demographic characteristics of studied patients in relation to respiratory compromise. No statistically significant differences were observed between patients with and without respiratory compromise regarding gender (*p*=0.798), age (*p*=0.648), and BMI (*p*=0.392). In terms of gender distribution, 51.2% males and 48.8% females had respiratory compromise, while 48.3% males and 51.7% females did not, showing a nearly equal distribution. The mean age was slightly higher in the respiratory compromise group (63.8±11.48 years) compared to the non-compromise group (60.4±9.76 years), but the difference was not statistically significant. Similarly, the BMI was slightly higher in the respiratory compromise group (26.1±3.48kg/m^2) compared to the non-compromise group (25.3±2.76kg/m^2), but without significance.

Table (2) compares the Integrated Pulmonary Index (IPI) at 2, 6, 12, 18, and 24 hours in patients with (n=41) versus without (n=29) respiratory compromise. Across all time points, the compromised group consistently showed significantly lower median IPI scores (ranging from 4 to 5) compared to the non-compromised group (ranging from 8 to 9), with *p*-values <0.001 for each comparison. The lower interquartile ranges in the compromised group suggest more uniform respiratory impairment, while the non-compromised group maintained higher and more stable IPI values.

Table (1): Comparison of demographic characteristics of the studied patients.

	Respiratory Compromise				Test value	*p*-value
	Yes (n=41)		No (n=29)			
Gender:						
Male	21	51.2%	14	48.3%	0.138	0.798
Female	20	48.8%	15	51.7%		
Age (years):						
Mean ± SD	63.8±11.48		60.4±9.76		0.447	0.648
Range	26-93		24-88			
BMI (Kg/m^2):						
Mean ± SD	26.1±3.48		25.3±2.76		0.642	0.392
Range	22-30		23-28			

Table (2): Comparison of Integrated Pulmonary Index (IPI) values of the studied patients over time.

	Respiratory Compromise		Test value	*p*-value
	Yes (n=41)	No (n=29)		
Integrated Pulmonary Index 2hr:				
Median (IQR)	4 (3 – 6)	8 (7 – 9)	10.228	<0.001**
Range	2 – 7	7 – 10		
Integrated Pulmonary Index 6hr:				
Median (IQR)	5 (3 – 6)	9 (8 – 10)	12.131	<0.001**
Range	2 – 7	6 – 10		
Integrated Pulmonary Index 12hr:				
Median (IQR)	5 (3 – 6)	9 (8 – 9)	13.204	<0.001**
Range	2 – 7	7 – 10		
Integrated Pulmonary Index 18hr:				
Median (IQR)	5 (4 – 6)	8 (8 – 9)	12.711	<0.001**
Range	2 – 7	7 – 10		
Integrated Pulmonary Index 24hr:				
Median (IQR)	5 (4 – 6)	9 (8 – 9)	13.979	<0.001**
Range	2 – 7	7 – 10		

Table (3) presents the primary outcomes for the 70 studied patients, focusing on respiratory and non-respiratory compromise. 41 patients (58.6%) experienced respiratory compromise, while 29 patients (41.4%) did not experience any adverse respiratory events. Among those with respiratory compromise, various combinations of symptoms were observed. The most common were hypoxemia, hypercapnia, and bronchospasm (20%), followed by hypoxemia, tachypnea, and bronchospasm (10%). Other combinations included hypoxemia with bronchospasm (7.1%) and hypoxemia with tachypnea (7.1%). Less frequent combinations involved apnea, hypercapnia, or tachypnea.

Table (3): Incidence of adverse respiratory events in the studied patients.

	Respiratory Compromise			
	Yes (n=41)		No (n=29)	
	N	%	N	%
Hypoxemia, Hypercapnia, Bronchospasm	14	20.0	0	0
Hypoxemia, Tachypnea, Bronchospasm	7	10.0	0	0
Hypoxemia, Bronchospasm	5	7.1	0	0
Hypoxemia, Tachypnea	5	7.1	0	0
Hypoxemia, Apnea, Bronchospasm	5	7.1	0	0
Hypoxemia, Hypercapnia	3	4.3	0	0
Hypercapnia, Tachypnea, Bronchospasm	1	1.4	0	0
Hypoxemia, Hypercapnia and Tachypnea, Bronchospasm	1	1.4	0	0

Comparison between patients with respiratory compromise (n=41) and those without (n=29) reveals significant differences in clinical outcomes. Although the onset of mechanical ventilation approached significance (*p*=0.056), the duration of mechanical ventilation was significantly longer in the compromised group (IQR 0–5; *p*=0.007).

Additionally, patients with respiratory compromise experienced significantly longer ICU stays (median 10 vs. 3 days; *p*<0.001) and extended hospital stays (median 14 vs. 5 days; *p*<0.001). 28-day mortality rate was also higher among the compromised patients, with 19.5% deceased compared to 0% in the non-compromised group (*p*=0.011).

Among the 70 patients included in the study 41 patients (58.6%) required oxygen support while 29 (41.4%) did not require oxygen support (*p*=0.151). *p*-value exceeds the significance threshold indicating that the observed difference was not statistically significant.

Table (4): Comparison of secondary outcomes in the studied patients.

	Respiratory Compromise				Test value	*p*-value
	Yes (n=41)		No (n=29)			
	N	%	N	%		
Onset of MV:						
1st day	2	4.9	0	0	9.231	0.056
2nd day	6	14.6	0	0		
3rd day	2	4.9	0	0		
4th day	0	0	0	0		
5th day	1	2.4	0	0		
Duration of MV (days):						
Median (IQR)	0 (0 – 5)		0 (0-0)		2.763	0.007**
Range	0 – 25		0 – 0			
Length of ICU stay (days):						
Median (IQR)	10 (7 – 14)		3 (2 – 4)		8.365	<0.001**
Range	4 – 27		2 – 7			
Length of Hospital stay (days):						
Median (IQR)	14 (10 – 17)		5 (4 – 6)		9.294	<0.001**
Range	6 – 27		3 – 10			
28-Day Mortality rate:						
Alive	33	80.5	29	100	6.389	0.011*
Dead	8	19.5	0	0		
Oxygen support	41	58.6	29	41.4	2.064	0.151

The data in Table (5) illustrates the strong negative correlations between the Integrated Pulmonary Index (IPI) at 2 hours after admission and various clinical outcomes, suggesting that a higher IPI score correlates with improved clinical metrics. Respiratory compromise, oxygen support, and length of ICU and hospital stay all show particularly high negative correlations (*r*=–0.81), indicating that patients with lower initial IPI scores tend to require more respiratory support and have prolonged ICU and hospital stays. Mechanical ventilation (MV) onset and duration also correlate negatively with IPI, although to a slightly lesser extent (*r*=–0.54), highlighting the potential of IPI as a predictor of ventilation needs. 28-day mortality rate displays a moderate but significant negative correlation (*r*=–0.477).

Table (5): Correlation between integrated pulmonary index and various clinical parameters.

	Integrated Pulmonary Index on Admission (2hr)
Respiratory Compromise:	
r	–0.812
p-value	<0.001**
Oxygen Support:	
r	–0.812
p-value	<0.001**
Onset of MV:	
r	–0.542
p-value	<0.001**
Duration of MV:	
r	–0.552
p-value	<0.001**
Length of ICU Stay:	
r	–0.814
p-value	<0.001**
Length of Hospital Stay:	
r	–0.809
p-value	<0.001**
28-Day Mortality Rate:	
r	–0.477
p-value	<0.001**

r = Spearman Correlation Coefficient.
p-value >0.05 is insignificant.
**p*-value <0.05 is significant.
***p*-value <0.01 is considered highly significant.

The ROC curve analysis detailed in Table (6) for both Integrated Pulmonary Index (IPI) and SpO_2 as predictors for oxygen support reveals that IPI, with an AUC of 0.906, and a cut-off value of <6 exhibits superior diagnostic accuracy compared to SpO_2, which has an AUC of 0.839.

IPI's high sensitivity (90.0%) indicates its efficacy in correctly identifying patients who need oxygen support, though its low specificity (17.5%) suggests a significant number of false positives, potentially leading to over-treatment.

Conversely, SpO_2, while slightly less sensitive, offers better specificity (30.0%), balancing the prediction accuracy with fewer false positives.

Both indicators demonstrate high positive predictive values (PPV), ensuring that when they indicate the need for support, it is likely required. However, the relatively lower negative predictive values (NPV), especially for SpO_2, hint at a cautious approach in ruling out oxygen support based solely on these metrics.

Table (6): Roc curve analysis for IPI and SpO_2 as a predictor for oxygen support.

	Cut off	AUC	Sensitivity	Specificity	PPV	NPV	*p*-value
Integrated Pulmonary Index (IPI)	<6	0.906	90.0%	17.5%	98.7%	82.5%	<0.001**
SpO_2	<90	0.839	86.7%	30.0%	94.3%	73.5%	<0.001**

Discussion

Respiratory compromise is a critical concern in the management of critically ill patients, as it often leads to significant morbidity, prolonged hospitalization, and increased mortality. Early detection and prompt intervention are paramount in limiting its impact *[6]*. Traditional monitoring methods, which rely on individual parameters such as oxygen saturation (SpO2), respiratory rate (RR), and arterial blood gas analysis, are often insufficient in providing a comprehensive assessment of respiratory function *[7]*. The Integrated Pulmonary Index (IPI) offers a novel, multi-parametric approach, combining SpO_2, RR, end-tidal carbon dioxide ($ETCO_2$), and pulse rate (PR) into a single numerical score. This index has shown promise in perioperative and sedation settings *[4,10,11]*, but its application in critically ill patients remains under-explored *[8]*.

The current study aimed to investigate the effectiveness and usefulness of integrated pulmonary index as a predictor of respiratory compromise in critically ill patients upon admission to ICU.

The demographic characteristics of the studied patients revealed no significant differences between both groups with regards to age, gender and BMI. Such demographics suggest a heterogenous population in terms of age and gender, offering a robust basis for evaluating the study outcomes across different patient profiles.

In the present study, the analysis of the Integrated Pulmonary Index (IPI) values over time highlights significant differences between patients with respiratory compromise and those without. At all-time intervals measured 2, 6, 12, 18, and 24 hours the median IPI values and interquartile ranges were consistently lower in the respiratory compromise group compared to the non-compromised group, with statistically significant differences (p<0.001 for all comparisons). For instance, at 2 hours, the median IPI in the respiratory compromise group was 4 (IQR: 3–6), markedly lower than 8 (IQR: 7–9) in the non-compromised group. Similar trends were observed across subsequent time points, with the respiratory compromise group maintaining a lower median IPI (range: 2–7) compared to the non-compromised group (range: 6–10). These findings underscore the utility of IPI as a dynamic and reliable predictor of respiratory status, with lower values being strongly associated with respiratory compromise.

Kuroe et al., [4] evaluated the Integrated Pulmonary Index (IPI) in a post-anesthesia care unit setting revealed that patients with lower IPI values upon admission were significantly more likely to experience respiratory compromise during their PACU stay. The predictive accuracy of the IPI was superior to that of traditional monitoring tools, as indicated by its higher sensitivity and specificity. These results align with the observed consistent differences in IPI values over time between respiratory compromised and non-compromised groups, emphasizing IPI's utility as a dynamic indicator of respiratory status.

Analysis of the primary outcome in the present study reveals that respiratory compromise in the studied patients was characterized by various combinations of clinical manifestations, with hypoxemia being a consistent feature in all cases. Among the 41 patients experiencing respiratory compromise, the most common presentations included hypoxemia combined with hypercapnia and bronchospasm (20.0%), followed by hypoxemia, tachypnea, and bronchospasm (10.0%). Less frequent combinations included hypoxemia with bronchospasm (7.1%), hypoxemia with tachypnea (7.1%), and hypoxemia with apnea and bronchospasm (7.1%). Other observed manifestations involved combinations such as hypoxemia and hypercapnia (4.3%) or rarer presentations like hypercapnia, tachypnea, and bronchospasm (1.4%). Notably, no respiratory compromise manifestations were reported in the non-compromised group 29 patients. These findings emphasize hypoxemia as a central common feature and its frequent coexistence with other respiratory adverse events like bronchospasm, hypercapnia, and tachypnea.

Kaur et al., [9] demonstrated that IPI is an effective predictor of extubation failure, frequently identifying critical conditions such as hypoxemia and hypercapnia early in the respiratory deterioration process. Similarly, Probst et al., [10], highlighted IPI's sensitivity in detecting impending adverse respiratory events, including hypoxemia and bronchospasm, within minutes prior to clinical manifestations in postoperative settings [10]. Both studies validate the role of IPI in recognizing diverse respiratory compromise presentations, including combinations like hypoxemia with hypercapnia and tachypnea, as observed in the current analysis, confirming IPI's clinical relevance for early intervention and management of respiratory conditions.

Contradictory to our results, was the study by Berkenstadt and colleagues [11] who evaluated the IPI on 51 adult patients undergoing sedation for colonoscopy. Patients were grouped according to respiratory adverse events as 'requiring attention' (at least 1 minute of SpO_2 ≤92% and/or RR ≤8 and/or 20% decrease in EtCO2), and 'requiring intervention' (at least 1 minute of SpO_2 ≤85% and/or RR ≤0). Their results revealed that low IPI (1-3), medium (4-6) and high (7-10) IPI groups did not differ in SpO_2, RR, or HR, but $EtCO_2$ was significantly higher among the high IPI group. Among the group requiring attention the IPI values were high (7-10) in 53.1%. Their study demonstrated limited agreement between respiratory physiological parameters and IPI.

The secondary outcomes in our study demonstrate significant differences between patients with and without respiratory compromise, particularly regarding mechanical ventilation (MV), ICU stay, hospital stays, and mortality. Among patients with respiratory compromise, mechanical ventilation was required, with the onset primarily occurring on the 2^{nd} day (14.6%). The duration of mechanical ventilation was significantly longer in this group, with a median of 0 days (IQR: 0–5) compared to 0 days (IQR: 0–0) in non-compromised patients (p=0.007). Additionally, the length of ICU stay was notably extended in patients with respiratory compromise, with a median of 10 days (IQR: 7–14) versus 3 days (IQR: 2–4) in those without compromise (p<0.001). Similarly, hospital stays were prolonged, with a median of 14 days (IQR: 10–17) compared to 5 days (IQR: 4–6) in non-compromised patients (p<0.001). 28-days mortality rates were also higher in the respiratory compromise group (19.5% vs. 0%, p=0.011), emphasizing the severe impact of respiratory compromise on patient outcomes. These findings highlight the critical importance of early identification and management of respiratory compromise to mitigate adverse outcomes.

Probst et al., [10] demonstrated the utility of the Integrated Pulmonary Index (IPI) in predicting respiratory events in the early postoperative period, with results highlighting the sensitivity of IPI for early detection of respiratory compromise, potentially reducing the need for prolonged mechanical ventilation and ICU stays by enabling timely intervention. Similarly, Kuar et al., [9] showed that IPI effectively predicts extubation failure, which is closely linked to extended durations of mechanical ventilation and increased ICU and hospital stays. Their study emphasized that the integration of IPI into respiratory monitoring protocols improves outcomes by earlier identifying patients at risk for respiratory failure. These findings corroborate the importance of early identification and management strategies, as reflected in the secondary outcome data.

Correlation analysis in the present study reveals strong negative associations between the Integrated

Pulmonary Index (IPI) recorded upon ICU admission (2 hours) and various clinical parameters, highlighting its predictive value for adverse outcomes in critically ill patients. The IPI showed a strong negative correlation with respiratory compromise ($r=-0.812$, $p<0.001$) and the need for oxygen support ($r=-0.812$, $p<0.001$), indicating that lower IPI values are strongly associated with respiratory deterioration. Additionally, the onset ($r=-0.542$, $p<0.001$) and duration of invasive mechanical ventilation ($r=-0.552$, $p<0.001$) were negatively correlated with IPI, suggesting that patients with lower IPI values are more likely to require and spend longer durations on mechanical ventilation. Furthermore, the IPI strongly correlated with the length of ICU stay ($r=-0.814$, $p<0.001$) and hospital stay ($r=-0.809$, $p<0.001$), emphasizing its association with prolonged recovery periods. 28 days mortality rate also demonstrated a moderate negative correlation with IPI ($r=-0.477$, $p<0.001$), underscoring the relevance of the index in predicting survival. These findings validate the utility of IPI as a comprehensive and reliable indicator of respiratory and overall clinical outcomes in critically ill patients.

Kuroe et al., *[4]* demonstrated that lower Integrated Pulmonary Index (IPI) scores were associated with respiratory compromise in post-anesthesia care , highlighting IPI's sensitivity to detect deteriorating respiratory status, which often necessitates increased oxygen support. Fot and colleagues *[3]*, reinforced this by showing that a low IPI (≤9) was predictive of postoperative complications, including prolonged mechanical ventilation and ICU stays, emphasizing the link between respiratory compromise, oxygen need, and extended hospitalization further validating its role as a dynamic monitoring tool in patients following off-pump coronary artery grafting. Similarly, Kuar et al., *[9]* found that IPI effectively predicted extubation failure, aligning with the observed association between respiratory dysfunction and the necessity for oxygen supplementation and prolongation of mechanical ventilation in critical settings, Lastly, Probst and colleagues *[10]* validated the utility of IPI in predicting respiratory events within minutes, correlating with the need for interventions like oxygen support, thereby reinforcing its role in identifying respiratory compromise and associated outcomes. Together, these findings corroborate IPI's utility as a robust predictor of respiratory deterioration, mechanical ventilation needs, and prolonged hospital stays.

The ROC curve analysis in the present study demonstrates the predictive performance of the Integrated Pulmonary Index (IPI) and SpO_2 for determining the need for oxygen support in critically ill patients. The IPI, with a cut-off value of <6, exhibited excellent predictive accuracy with an Area Under the Curve (AUC) of 0.906 ($p<0.001$), a high sensitivity of 90.0%, and a specificity of 17.5%. It also had an impressive Positive Predictive Value (PPV) of 98.7%, indicating its strong ability to correctly identify patients requiring oxygen support, although its lower specificity suggests limited ability to exclude those who do not. Similarly, SpO2, with a cut-off value of <90, showed good predictive capability with an AUC of 0.839 ($p<0.001$), a sensitivity of 86.7%, and a specificity of 30.0%. Its PPV of 94.3% highlights its utility in identifying true positives, though it also shares limitations in specificity. Both measures provide valuable insights, with IPI showing slightly superior overall performance, emphasizing its robustness as a predictor in clinical settings.

Ronen and colleagues *[5]*, demonstrated high levels of sensitivity for IPI ranging from 0.83-1.00 and corresponding specificity ranging from 0.96 to 0.74 based on IPI values 3-6. Likewise, Kaur et al., *[9]* demonstrated that the Integrated Pulmonary Index (IPI) is a reliable tool for predicting respiratory outcomes, with its ability to integrate multiple respiratory parameters resulting in high sensitivity and specificity for detecting respiratory compromise, similar to the findings of the current study, an AUC of 0.906 and a sensitivity of 90.0%. The study by Probst et al., *[10]* further supports these results by showing the IPI's effectiveness in the early detection of respiratory events in postoperative patients. Their study revealed that IPI values ≤7 demonstrated a sensitivity of 75.6% for early detection of adverse respiratory events within 2–15 minutes. The above studies underscore IPI's strength in identifying respiratory deterioration, mirroring its high predictive accuracy and utility in clinical settings. Moreover, the studies highlight the IPI's superiority over traditional metrics like SpO_2, which exhibits lower specificity and slightly reduced predictive performance, reinforcing IPI's superiority as a predictive tool.

Similarly the study by Karaarslan and colleagues, *[8]* demonstrated the value of IPI as a predictive tool for exacerbations of COPD in the emergency department. Their results revealed that IPI had the highest diagnostic accuracy in identifying mild exacerbations of COPD with an AUC 0.893.

Fot et al. *[3]* strongly support the utility of the Integrated Pulmonary Index (IPI) as a predictive tool for respiratory compromise, aligning with the ROC analysis described. In their study, IPI demonstrated significant predictive capability in identifying postoperative respiratory complications in patients undergoing off-pump coronary artery bypass grafting (OPCAB). The study reported that an IPI value ≤9 at 6 hours post-extubation was moderately predictive of postoperative complications, with an AUC of 0.71 ($p=0.04$). Additionally, suboptimal IPI values were associated with adverse respiratory and hemodynamic parameters, including reduced oxygenation and increased pulse rate. These findings highlight the role of IPI in enhancing respiratory monitoring, providing early detection of respiratory compromise, and guiding timely clinical interventions, complementing its robust performance as demonstrated by ROC curve analysis.

The present study has several limitations. First our study was not blinded, consequently some degree of bias may have influenced the results. Secondly, a larger sample size may be required to validate the results. Additionally the respiratory and non-respiratory compromise groups were unequal. This disproportion could have impacted the diagnostic validity profile of our results. Lastly our study was a single-center study performed on Egyptian patients. There may be some limitation regarding generalization of our results to other ethnic groups.

Conclusion:

The findings of this study highlight the Integrated Pulmonary Index (IPI) as a reliable and dynamic predictor of respiratory compromise and oxygen support requirements in critically ill patients, outperforming SpO_2 in overall accuracy. The IPI demonstrated strong correlations with adverse clinical outcomes, including the duration of mechanical ventilation, length of ICU and hospital stay, and mortality. Its high sensitivity and predictive values emphasize its utility in early detection of respiratory compromise, aiding timely interventions to improve patient outcomes. These results underscore the importance of incorporating IPI into routine monitoring protocols in intensive care settings to enhance patient care and prognosis.

References

1- GUPTA K., NAGAPPA M., PRASAD A., ABRAHAMYAN L., WONG J., WEINGARTEN T.N. and CHUNG F.: Risk factors for opioid-induced respiratory depression in surgical patients: A systematic review and meta-analyses. British Medical Journal, 8 (12): e024086, 2018.

2- AYAD S., KHANNA A.K., IQBAL S.U. and SINGLA N.: Characterisation and monitoring of postoperative respiratory depression: Current approaches and future considerations. British Journal of Anaesthesia, 123 (3): 378-391, 2019.

3- FOT E.V., IZOTOVA N.N., YUDINA A.S., SMETKIN A.A., KUZKOV V.V. and KIROV M.Y.: The predictive value of Integrated Pulmonary Index after off-pump coronary artery bypass grafting: A prospective observational study. Frontiers in Medicine, 4: 132, 2017.

4- KUROE Y., MIHARA Y., OKAHARA S., ISHII K., KANAZAWA T. and MORIMATSU H.: Integrated pulmonary index can predict respiratory compromise in high-risk patients in the post-anesthesia care unit: a prospective, observational study. Biomedcentral Anesthesiology Journal, 21 (1): 1-7, 2021.

5- RONEN M., WEISSBROD R., OVERDYK F.J. and AJIZIAN S.: Smart respiratory monitoring: Clinical development and validation of the IPITM (Integrated Pulmonary Index) algorithm. Journal of Clinical Monitoring and Computing, 31: 435–442, 2017.

6- ARABI Y.M., FOWLER R. and HAYDEN F.G.: Critical care management of adults with community-acquired severe respiratory viral infection. Intensive Care Medicine, 46 (2): 315–328, 2020.

7- VITAZKOVA D., FOLTAN E., KOSNACOVA H., MICJAN M., DONOVAL M., KUZMA A., KOPANI M. and VAVRINSKY E. (2024). Advances in respiratory monitoring: A comprehensive review of wearable and remote technologies. Biosensors, 14 (2): 90, 2024.

8- KARAARSLAN F.N., ÖZTÜRK Z.S., IŞıK G.Ç. and ÇEVIK Y.: Value of integrated pulmonary index to predict exacerbation of chronic obstructive pulmonary Disease’s severity. The American Journal of Emergency Medicine, 71: 54–58, 2023.

9- KAUR R., VINES D.L., LIU L. and BALK R.A.: Role of integrated pulmonary index in identifying extubation failure. Respiratory Care, 62 (12): 1550-1556, 2017.

10- PROBST S., ROMEISER J., GAN T.J., HALPER D., SISTI A.R., MORIMATSU H., SUGIMOTO K. and BENNETT-GUERRERO E.: Ability of the integrated pulmonary index to predict impending respiratory events in the early postoperative period. Perioperative Medicine, 12 (1): 39, 2023.

11- BERKENSTADT H., BEN-MENACHEM E., HERMAN A. and DACH R.: An evaluation of the Integrated Pulmonary Index (IPI) for the detection of respiratory events in sedated patients undergoing colonoscopy. J. Clin. Monit Comput., 26 (3): 177-81, 2012.

الفهرس الرئوى المتكامل كمتنبئ لفشل الجهاز التنفسى فى المرضى المصابين بأمراض خطيرة: دراسة رصدية مستقبلية

الخلفيــة: تركـز التطـورات الحديثـة فـى الكشـف عـن متلازمـة الضائقـة التنفسـية الحـادة علـى اسـتخدام معاييـر فسـيولوجية متعـددة ودمجهـا فـي مؤشـر واحـد لتحسـين الدقـة مـع تقليـل الإنـذارات الكاذبـة وإجهـاد الإنـذار. يعـد مؤشـر الرئـة المتكامـل (IPI™) أحـد هـذه الأدوات متعـددة المعاييـر، حيـث يجمـع بـين تشـبع الأكسـجين ومعـدل التنفـس و PETCO2 ومعـدل ضربـات القلـب فـى مقيـاس مـن ١ إلـى ١٠. تشـير الدرجـات ≥8 إلـى الظـروف الطبيعيـة، بينمـا تشـير ≤4 إلـى الحاجـة إلـى التدخـل.

هـدف العمـل: فـي هـذه الدراسـة، سـنحقق بشـكل اسـتباقى فـى فعاليـة وفائـدة مؤشـر الرئـة المتكامـل كمؤشـر علـى ضعـف الجهـاز التنفسـى لـدى المرضـى المصابـين بأمـراض خطيـرة.

المرضـى والطـرق: أجريـت هـذه الدراسـة الرصديـة الاستشـرافية فـى مستشـفيات جامعـة عـين شـمس مـن يونيـو إلـى ديسـمبر ٢٠٢٣، وشـملت مرضـى مصابـين بأمـراض خطيـرة تبلـغ أعمارهـم ١٨ عامًـا أو أكثـر، تم إدخالهـم إلـى وحـدة العنايـة المركـزة. باسـتخدام برنامـج PASS 15، تم حسـاب حجـم العينـة ليكـون ٣٥ مريضًـا، بافتـراض قـوة ٨٠٪، وخطـأ ألفـا ٠,٠٥، ومسـاحة منحنـى ROC المتوقعـة ٠,٨٠ لمؤشـر الرئـة المتكامـل (IPI) فـى التنبـؤ بالضعـف التنفسـى.

النتائـج: فحصـت الدراسـة ٧٠ مريضًـا فـي وحـدة العنايـة المركـزة فـي حالـة حرجـة بمستشـفيات جامعـة عـين شـمس، بمتوسـط عمـر ٥٩,٩ عامًـا (المـدى: ٢٤–٩٣). كان توزيـع الجنـس متسـاويًا (٥٠٪ ذكـور، ٥٠٪ إنـاث)، وكان متوسـط مؤشـر كتلـة الجسـم (BMI) ٢٥,١ كجـم / م ٢، ممـا يشـير إلـى تنـوع السـكان. أظهـر تحليـل مؤشـر الرئـة المتكامـل (IPI) اختلافـات كبيـرة بـين المرضـى الذيـن يعانـون مـن ضعـف الجهـاز التنفسـى (RC) وأولئـك الذيـن لا يعانـون مـن ذلـك. فـى جميـع الفتـرات الزمنيـة (٢ و٦ و١٢ و١٨ و٢٤ سـاعة)، كانـت قيـم IPI المتوسـطة أقـل فـى مجموعـة RC (p<٠,٠٠١)، ممـا يسـلط الضـوء علـى موثوقيـة IPI فـى التنبـؤ بحالـة الجهـاز التنفسـى. تميـزت الحالـة التنفسـية بنقـص الأكسـجين، وغالبًـا مـع ميـزات إضافيـة مثـل فـرط ثانـى أكسـيد الكربـون وتشـنج القصبـات الهوائيـة. ومـن بـين ٤١ مريضًـا مصابًـا بـ RC، تضمنـت التركيبـات الشـائعة نقـص الأكسـجين مـع فـرط ثانـى أكسـيد الكربـون وتشـنج القصبـات الهوائيـة (٢٠٪)، ونقـص الأكسـجين مـع سـرعة التنفـس وتشـنج القصبـات الهوائيـة (١٠٪). كشـفت النتائـج الثانويـة عـن اختلافـات كبيـرة فـى الحاجـة إلـى التهويـة الميكانيكيـة الغازيـة (MV)، ووحـدة العنايـة المركـزة والإقامـة فـى المستشـفى، والوفيـات. أظهـرت مجموعـة RC إقامـات أطـول فـي وحـدة العنايـة المركـزة والمستشـفى، وتطلبـت المزيـد مـن التهويـة الميكانيكيـة، وأظهـرت معـدل وفيـات أعلـى (١٩,٥٪) مقارنـة بـ ٠٪ فـى المجموعـة غيـر المصابـة. أظهـر تحليـل الارتبـاط ارتباطـات سـلبية قويـة بـين IPI ومعلمـات سـريرية مختلفـة، مثـل ضعـف الجهـاز التنفسـى (r = –٠,٨١٢)، ودعـم الأكسـجين (r = –٠,٨١٢)، والحاجـة إلـى التهويـة الميكانيكيـة الغازيـة (r = –٠,٥٥٢)، بالإضافـة إلـى وحـدة العنايـة المركـزة (r = –٠,٨١٤) والإقامـة فـي المستشـفى (r = –٠,٨٠٩). تؤكـد هـذه الارتباطـات علـى قيمـة IPI فـى التنبـؤ بالنتائـج السـلبية. ارتبـط دعـم الأكسـجين أيضًـا بقـوة بضعـف الجهـاز التنفسـى (r = –٠,٨٥٧) و SpO2 (r = –٠,٥٨٤)، ممـا يشـير إلـى دوره فـى عكـس تدهـور الجهـاز التنفسـي. أظهـر تحليـل منحنـى ROC أن مؤشـر IPI، بقيمـة حديـة ‎<٦، كان لـه دقـة تنبؤيـة ممتـازة لدعـم الأكسـجين (AUC = ٠,٩٠٦، حساسـية ٩٠٪، PPV ٩٨,٧٪). أظهـر SpO2 أيضًـا أداءً تنبؤيًـا جيـدًا (AUC = ٠,٨٣٩، حساسـية ٨٦,٧٪، PPV ٩٤,٣٪). بشـكل عـام، كان مؤشـر IPI هـو المتنبـئ المتفـوق، ممـا يؤكـد فائدتـه السـريرية فـي تحديـد المرضـى المعرضـين لخطـر التدهـور التنفسـى.

الاسـتنتاج: تسـلط نتائـج هـذه الدراسـة الضـوء علـى مؤشـر الرئـة المتكامـل (IPI) كمؤشـر موثـوق وديناميكـى للضعـف التنفسـى ومتطلبـات دعـم الأكسـجين لـدى المرضـى المصابـين بأمـراض خطيـرة، متفوقًـا علـى SpO2 فـى الدقـة الإجماليـة. أظهـر مؤشـر IPI ارتباطـات قويـة بالنتائـج السـريرية السـلبية، بمـا فـى ذلـك مـدة التهويـة الميكانيكيـة وطـول فتـرة الإقامـة فـى وحـدة العنايـة المركـزة والمستشـفى والوفيـات. تؤكـد حساسـيته العاليـة وقيمـه التنبؤيـة علـى فائدتـه فـى الكشـف المبكـر عـن الضعـف التنفسـى، ممـا يسـاعد علـى التدخـلات فـى الوقـت المناسـب لتحسـين نتائـج المرضـى. تؤكـد هـذه النتائـج علـى أهميـة دمـج IPI فـى بروتوكـولات المراقبـة الروتينيـة فـى بيئـات العنايـة المركـزة لتحسـين رعايـة المرضـى وتوقعاتهـم.