ORIGINAL ARTICLE

https://doi.org/10.1590/1806-9282.20221324

The new prognostic factor in pre-intubation follow-up of critically ill patients: integrated pulmonary index monitoring

Dilay Satılmış[1*], Ramazan Güven[2]

SUMMARY

OBJECTIVE: The objective of this study was to identify the integrated pulmonary index in the follow-up of non-intubated critically ill patients in the emergency department and its efficacy in deciding on advanced airway application in comparison with the Glasgow Coma Scale.

METHODS: This is a prospective, single-center, methodological study. In our study, we recorded the demographic characteristics, Glasgow Coma Scale, and the integrated pulmonary index of 90 patients with respiratory failure who were followed up in the emergency department between June 1, 2019 and September 1, 2019, and we compared the results of Glasgow Coma Scale and integrated pulmonary index in making the endotracheal intubation decision.

RESULTS: Endotracheal intubation was applied to 30% of the 90 patients included in the study. The area under the curve was calculated as 0.906 for integrated pulmonary index and 0.860 for Glasgow Coma Scale in predicting endotracheal intubation. There was no significant difference between the area under the curves of integrated pulmonary index and Glasgow Coma Scale. According to the best cutoff values determined in the estimation of endotracheal intubation, sensitivity was 74.07% and specificity was 95.24% for integrated pulmonary index, and sensitivity was 74.07% and specificity was 85.71% for Glasgow Coma Scale.

CONCLUSION: The integrated pulmonary index monitoring provides an objective evaluation in the follow-up of critically ill patients with spontaneous breathing in the emergency department and is predictive in deciding on timely endotracheal intubation.

KEYWORDS: Intensive care unit. Glasgow Coma Scale. Critical care.

INTRODUCTION

The critically ill patients are a group of physiologically unstable patients, whose clinics should be followed closely and whose treatment should be given attention and speedily[1]. In emergency departments (ED) and intensive care units (ICU), the Glasgow Coma Scale (GCS) is a universal scoring system and is used as a basic part of critically ill patients' follow-up in evaluating the neurological status of patients and deciding on advanced airway application[2]. GCS is a scoring system used for the assessment of impaired consciousness in all types of critically ill and trauma patients. The scale evaluates patients according to eye-opening, verbal, and motor responses, and reports each one separately, giving a result between 3 and 15[3]. GCS gives a general idea when stated verbally; however, some studies show that GCS presents differences between registrants among the inadequacies of scoring in prognosis follow-up, and it is stated that it causes delays in the decision of the physician to apply the neurological status and advanced airway[4-6]. It has also been shown in studies that GCS predicts mortality well in the extremes but poorly in the moderate range, and therefore its prediction capacity is anchored by the endpoints. It has been stated that there is a need for easier, understandable scoring in critical patient's follow-up[7].

In critically ill patient's follow-up in the ED and ICUs, oxygen saturation (SpO_2), respiratory rate (RR), heart rate (HR), blood pressure, central venous pressure, mixed venous oxygen saturation, and lactate are the most important follow-up parameters[8]. Many scoring systems have been developed for the neurological follow-up of critically ill patients and in deciding on advanced airway application. In addition to these scorings, the use of devices containing objective data will help physicians to follow up critically ill patients quickly and effectively. In the studies conducted on high-risk patients' follow-up in the ICU, it was emphasized that integrated pulmonary index (IPI) could predict respiratory failure in high-risk patients and could be objective and useful for respiratory monitoring in the ICU[9].

The IPI algorithm is a real-time continuous measurement of the patient's respiratory status that uses the end-tidal carbon dioxide ($PetCO_2$), HR, RR, and SpO_2 parameters to evaluate the patient's ventilation and oxygenation,

[1]University of Health Sciences, Sultan 2 Abdülhamid Han Training and Research Hospital, Department of Emergency Medicine – Istanbul, Turkey.
[2]University of Health Sciences, Cam Sakura City Hospital, Department of Emergency Medicine – Istanbul, Turkey.
*Corresponding author: drdilay09@gmail.com

Conflicts of interest: the authors declare there is no conflicts of interest. Funding: none.
Received on July 17, 2023. Accepted on July 24, 2023.

and combines them in a mathematical model to obtain an index value. It is a non-invasive scoring system in which it is reduced to a single value where it is represented[10,11]. In our study, we investigated the effectiveness of the IPI in the follow-up of non-intubated critically ill patients in the ED and its efficacy in deciding on advanced airway application in comparison with the GCS.

METHODS

Study design and setting

This is a single-center, prospective, methodological study. The medical records of 90 patients who were admitted to the Emergency Medicine Department of Kanuni Sultan Süleyman Training and Research Hospital between June 1, 2019 and September 1, 2019, with a diagnosis of respiratory failure and planned for invasive mechanical ventilation support were examined. We informed all patients about the study and its procedures and collected informed consent on paper from the patients before their inclusion in the study. The common feature of all patients was that they were followed up in the emergency intensive care unit (EICU) with respiratory failure and invasive mechanical ventilation support was planned because there was no effective response after appropriate medical treatment and non-invasive mechanical ventilation treatment, and if the indication occurred, the patients were intubated in the EICU. A total of 5689 patients, who were followed up with red area triage coding in the ED with major and minor trauma, cases with emergency surgical intervention indication, and patients who were referred to an external center were excluded from the study, whereas 90 patients who were treated and followed up with respiratory failure in the EICU were included in the study.

Patients

We reviewed the demographic characteristics and the IPI algorithm of 90 patients followed up with respiratory failure in the EICU and evaluated its efficacy in predicting 30-day mortality and making the decision for endotracheal intubation (ETI) in comparison with GCS.

Test methods

The IPI algorithm is a non-invasive algorithm that uses the patient's respiratory status and displays it as a single index value from 1 to 10, where 8–10 indicates nearly normal ventilation, a level of ≤6 indicates that intervention may be necessary, and a level of ≤4 indicates that intervention is ultimately necessary[11].

When we look at the literature, we see that the IPI is mostly used to evaluate the weaning process and to confirm pulmonary embolism in patients admitted to the ED with respiratory failure[9,10,12]. We recorded the value at the 10th minute of the measurement of the IPI of the critically ill patients whom we examined and treated in the EICU using the Capnostream-20 monitor. We compared the scoring results with admission GCS and laboratory parameters. The ethical approval was obtained from the ethics committee of Kanuni Sultan Süleyman Training and Research Hospital *(KAEK/2019.05.130).* It was conducted in compliance with the principles of the Declaration of Helsinki. The results of this study were reported according to the recommendations of Strengthening the Reporting of Observational Studies in Epidemiology (STROBE)[13].

Statistical analysis

Descriptive analyses were presented using median [Interquartile range (IQR)] for non-normally distributed data or n (%) for categorical variables. The Shapiro–Wilk test was used to test the normality of the data. The receiver operating characteristic (ROC) curve analysis was applied to determine the optimal cutoff point of IPI and GCS for predicting the ETI, ICU stays, and 30-day mortality. The area under the curve (AUC), sensitivity, specificity, positive likelihood ratio (+LR), negative likelihood ratio (-LR), and accuracy were calculated and reported with 95% confidence intervals. Delong et al.'s method was used for the comparison of AUCs [ref]. The optimal cut-off point of measurements was determined as the value of the maximum Youden index. Statistical analysis was performed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY). A two-sided p-value <0.05 was considered statistically significant[14].

RESULTS

A total of 90 patients were included in the study. The median age of the patients (n=90) included in the study was 71 years (IQR: 62–80). Of note, 52.2% of the patients were males. The number of patients who had the habit of smoking was 22 (24.4%). The comorbid diseases and the laboratory values of the patients are shown in Table 1. ETI was applied to 30% of the patients followed in the EICU, whereas 44.4% were treated in the ICU, 34.4% were in the service, 20% were discharged, and 1 patient died. The patients had a 30-day mortality rate of 25.6% and a median mortality time of 2.5 days.

The AUC was calculated as 0.906 (95%CI: 0.826–0.957) for IPI and 0.860 (95%CI: 0.771–0.924) for GCS in predicting ETI. There was no significant difference between the AUC

Table 1. Demographic characteristics and the final diagnosis of the patients.

Variables (n=90)	
Age, median (IQR)	71 (62–80)
Gender, n (%)	
Female	43 (47.8)
Male	47 (52.2)
Smoking, n (%)	22 (24.4)
HT, n (%)	37 (41.1)
CAD, n (%)	17 (18.9)
DM, n (%)	9 (10)
Arrival examination, median (IQR)	
pH	7.32 (7.28–7.4)
Lactate	2.24 (1.58–3.41)
PCO_2	47.35 (39.9–57.2)
HGB	12.25 (10.5–14.1)
PLT	238 (161–315)
WBC	9.99 (8.42–14.09)
Urea	45.5 (33–68)
Creatinine	1 (0.75–1.46)
Sodium	138 (135–140)
Potassium	4.5 (4.1–5.2)
CRP	39.08 (2.82–98.23)
IPI, median (IQR)	7 (4-8)
GCS, median (IQR)	13 (10–15)
Endotracheal intubation	27 (30)
Hospital discharge	
ICU	40 (44.4)
Service	31 (34.4)
Discharge	18 (20)
Exitus	1 (1.1)
30-day mortality, n (%)	23 (25.6)
Mortality, n (%)	39 (43.3)
Mortality day, median (IQR)	2.5 (1–35)

CAD: coronary artery disease; CRP: C-reactive protein; DM: diabetes mellitus; GCS: Glasgow Coma Scale; HGB: hemoglobin; HT: hypertension; ICU: intensive care ünit; IQR: interquartile range; IPI: integrated pulmonary index; PLT: platelet; WBC: white blood cell count.

values of IPI and GCS (p=0.413). For IPI and GCS, the best cutoff values determined by the Youden index in estimating intubation were ≤4 and ≤12 (Table 2). According to the best cutoff values determined, sensitivity was 74.07% and specificity was 95.24% for IPI, and sensitivity was 74.07% and specificity was 85.71% for GCS. Accuracy was 88.9% (+LR: 15.56 and -LR: 0.27) for IPI and 82.2% (+LR: 5.19 and -LR: 0.3) for GCS (Table 3).

For the 30-day mortality estimate, the AUC for IPI was 0.794 (95%CI: 0.696–0.872) and 0.851 (95%CI: 0.761–0.918) for GCS. The difference between the AUC values of IPI and GCS was not significant (p=0.282). For IPI and GCS, the best cutoff values determined by the Youden index in predicting 30-day mortality were ≤4 and ≤12 (Table 3). According to the best cutoff values determined, sensitivity was 60.87% and specificity was 86.57% for IPI, and sensitivity was 73.91% and specificity was 82.09% for GCS. Accuracy was 80% (+LR: 4.53 and -LR: 0.45) for IPI and 80% (+LR: 4.13 and -LR: 0.32) for GCS (Table 3).

DISCUSSION

This study aims to evaluate IPI monitoring in comparison with GCS in making ETI decisions in critically ill patients' follow-up in the EICU. In the 4th National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society (NAP4) study in England, due to complications that may develop during emergency airway provision, it has been reported that 31% of ED patients and 60% of ICU patients have permanent neurological damage or death. Based on the cases reported to NAP4 from ED and ICUs, it was reported that the airway could not be evaluated frequently, and more importantly, it was stated that the high-risk patient could not be identified and followed up with an appropriate airway strategy[15]. A complete airway assessment in critically ill patients has often been reported to be impractical[16]. Loss of situational awareness was determined as the most common cause of problems in 40% of the cases reported to NAP4 and it is recommended that critically ill patients be monitored and evaluated with SpO_2, $PetCO_2$, electrocardiography, and non-invasive blood pressure[17].

IPI monitoring can improve clinicians' ability to recognize patients with respiratory distress earlier, by collecting four variables in a single parameter and tracking trends in a single variable instead of four separate variables. Recognition of this downward trend in IPI may allow early recognition of clinical deterioration and timely intervention in patients and may prevent time-wasting in making intubation decisions.

Yasutoshi et al. reported that the evaluation of the IPI monitoring might be useful for respiratory monitoring in post-anesthesia care units (PACUs) and ICUs after general anesthesia. Therefore the IPI can predict the occurrence of respiratory compromise in high-risk patients in PACUs[9]. Ramandeep et al., in their study on the association of low IPI values with extubation failure, observed that decreasing IPI measurements over

Table 2. Comparison of area under the curves of the receiver operating characteristic curves of integrated pulmonary index and Glasgow Coma Scale data.

	IPI	GCS	p
Endotracheal intubation			
AUC (95%CI)	0.906 (0.826–0.957)	0.860 (0.771–0.924)	0.413
Youden index	0.693	0.598	
Associated cutoff	≤4	≤12	
ICU stay			
AUC (95%CI)	0.808 (0.711–0.883)	0.789 (0.690–0.868)	0.724
Youden index	0.480	0.465	
Associated cutoff	≤7	≤14	
30-day mortality			
AUC (95%CI)	0.794 (0.696–0.872)	0.851 (0.761–0.918)	0.282
Youden index	0.474	0.560	
Associated cutoff	≤4	≤12	

AUC: area under the curve; GCS: Glasgow Coma Scale; IPI: integrated pulmonary index.

Table 3. Cross-tabulation of integrated pulmonary index and Glasgow Coma Scale results by the occurrence of endotracheal intubation, emergency intensive care unit stay, and 30-day mortality in the patients.

	Not occurred, n (%)	Occurred, n (%)	Sensitivity (95%CI)	Specificity (95%CI)	+LR (95%CI)	−LR (95%CI)	Accuracy
Endotracheal intubation							
IPI>4	60 (95.2)	7 (25.9)	74.07 (53.7–88.9)	95.24 (86.7–99)	15.56 (5–48)	0.27 (0.1–0.5)	88.9
IPI≤4	3 (4.8)	20 (74.1)					
GCS>12	54 (85.7)	7 (25.9)	74.07 (53.7–88.9)	85.71 (74.6–93.3)	5.19 (2.7–9.9)	0.3 (0.2–0.6)	82.2
GCS≤12	9 (14.3)	20 (74.1)					
EICU stay							
IPI>7	29 (58)	4 (10)	90 (76.3–97)	58 (43.2–71.8)	2.14 (1.5–3.0)	0.17 (0.07–0.4)	72.2
IPI≤7	21 (42)	36 (90)					
GCS>14	27 (54)	3 (7.5)	92.5 (79.6–98.4)	54 (39.3–68.2)	2.01 (1.5–2.7)	0.14 (0.05–0.4)	71.1
GCS≤14	23 (46)	37 (92.5)					
30-day mortality							
IPI>4	58 (86.6)	9 (39.1)	60.87 (38.5–80.3)	86.57 (76.0–93.7)	4.53 (2.3–9.0)	0.45 (0.3–0.8)	80
IPI≤4	9 (13.4)	14 (60.9)					
GCS>12	55 (82.1)	6 (26.1)	73.91 (51.6–89.8)	82.09 (70.8–90.4)	4.13 (2.3–7.3)	0.32 (0.2–0.6)	80
GCS≤12	12 (17.9)	17 (73.9)					

EICU: emergency intensive care unit; +LR: positive likelihood ratio; -LR: negative likelihood ratio.

time predicted extubation failure in subjects after extubation[18]. In another study, the correlation of IPI monitoring with arterial blood gas values was evaluated in patients treated under invasive and non-invasive mechanical ventilation in ICU. In this study, a correlation was found between IPI's SpO_2 and $PetCO_2$ values and arterial blood gas saturation and $PaCO_2$ measurements. With these results, it has been reported that IPI monitoring, which is a non-invasive and continuous measurement method, can be preferred to blood gas monitoring, which is an invasive method in the follow-up of patients in ICU[19].

In our study, we compared the IPI with GCS in making ETI decisions in critically ill patients. When the AUC values of IPI and GCS were compared, 0.906 for IPI and 0.860 for GCS were calculated, and no significant difference was found between the AUC values (p=0.413). According to the best cutoff values, sensitivity was 74.07% and specificity was 95.24% for IPI, and sensitivity was 74.07% and specificity was 85.71% for GCS and sensitivity values were similar. This showed us that IPI has an accuracy equivalent to GCS in the early prediction of respiratory failure and ETI indication in critically ill patients, and timely interventions to prevent the progression of these patients to respiratory failure.

In our study, we also evaluated the effectiveness of IPI in predicting the length of stay in the ICU and predicting the 30-day mortality of critically ill patients. According to the best cutoff values determined, the sensitivity and specificity of IPI in predicting 30-day mortality were similar to the sensitivity and specificity of GCS cutoff values.

Unlike previous studies, in our study, it was thought that evaluating the deterioration in vital parameters of critically ill patients with bedside monitoring and controlling the patient's breathing by timely ETI decision would be effective and sufficient in preventing secondary complications that may develop without delay in airway management. We believe that continuous respiratory monitoring with IPI can prevent delay in making ETI decisions in critically ill patients and therefore allow timely administration of appropriate treatments that can prevent complications associated with instabilities in our decision to follow up with an advanced airway strategy.

This study has some limitations. First of all, this study is a single-center study and its population was limited to adult patients presenting to the ED. In addition, trauma patients and patients who were sedated in the ED and connected to an invasive mechanical ventilator were excluded from the study. Second, since the study was an observational study, no intervention was made according to the IPI value. The third limitation is the requirement for special equipment for IPI monitoring. It was the first study to determine the role of IPI in determining ETI, although there is no literature to evaluate the reliability of IPI in ETI planning of critically ill patients.

CONCLUSION

The IPI monitoring provides an objective evaluation in the follow-up of critically ill patients and is predictive in deciding on timely ETI in the ED.

ETHICS APPROVAL

Approval was obtained from the ethics committee of Kanuni Sultan Süleyman Training and Research Hospital *(KAEK/2019.05.130)*. It was conducted in compliance with the principles of the Declaration of Helsinki.

AUTHORS' CONTRIBUTIONS

DS: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **RG:** Conceptualization, Data curation, Formal Analysis, Methodology, Supervision, Writing – review & editing.

REFERENCES

1. Simbila AN, Kilindimo SS, Sawe HR, Kalezi ZE, Yussuf AO, Manji HK, et al. Predictors and outcome of time to presentation among critically ill paediatric patients at Emergency Department of Muhimbili National Hospital, Dar es Salaam, Tanzania. BMC Pediatr. 2022;22(1):441. https://doi.org/10.1186/s12887-022-03503-y
2. Mehta R, Chinthapalli K. Glasgow coma scale explained. BMJ. 2019;365:l1296. https://doi.org/10.1136/bmj.l1296
3. Jain S, Iverson LM. Glasgow Coma Scale. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023. PMID: 30020670
4. Mkubwa JJ, Bedada AG, Esterhuizen TM. Traumatic brain injury: association between the Glasgow Coma Scale score and intensive care unit mortality. South Afr J Crit Care. 2022;38(2):10.7196/SAJCC.2022.v38i2.525. https://doi.org/10.7196/SAJCC.2022.v38i2.525
5. Reith FCM, Lingsma HF, Gabbe BJ, Lecky FE, Roberts I, Maas AIR. Differential effects of the Glasgow Coma Scale Score and its components: an analysis of 54,069 patients with traumatic brain injury. Injury. 2017;48(9):1932-43. https://doi.org/10.1016/j.injury.2017.05.038
6. Green SM. Cheerio, laddie! Bidding farewell to the Glasgow Coma Scale. Ann Emerg Med. 2011;58(5):427-30. https://doi.org/10.1016/j.annemergmed.2011.06.009
7. Moore L, Lavoie A, Camden S, Sage N, Sampalis JS, Bergeron E, et al. Statistical validation of the Glasgow Coma Score. J Trauma. 2006;60(6):1238-43; discussion 1243-4. https://doi.org/10.1097/01.ta.0000195593.60245.80
8. Mtaweh H, Trakas EV, Su E, Carcillo JA, Aneja RK. Advances in monitoring and management of shock. Pediatr Clin North Am. 2013;60(3):641-54. https://doi.org/10.1016/j.pcl.2013.02.013
9. Kuroe Y, Mihara Y, Okahara S, Ishii K, Kanazawa T, Morimatsu H. Integrated pulmonary index can predict respiratory compromise in high-risk patients in the post-anesthesia care unit: a prospective, observational study. BMC Anesthesiol. 2021;21(1):123. https://doi.org/10.1186/s12871-021-01338-1
10. Riphaus A, Wehrmann T, Kronshage T, Geist C, Pox CP, Heringlake S, et al. Clinical value of the Integrated Pulmonary Index® during sedation for interventional upper GI-endoscopy: A randomized, prospective tri-center study. Dig Liver Dis. 2017;49(1):45-9. https://doi.org/10.1016/j.dld.2016.08.124

11. Chung F, Wong J, Mestek ML, Niebel KH, Lichtenthal P. Characterization of respiratory compromise and the potential clinical utility of capnography in the post-anesthesia care unit: a blinded observational trial. J Clin Monit Comput. 2020;34(3):541-51. https://doi.org/10.1007/s10877-019-00333-9
12. Akbas I, Kocak AO, Celik BK, Menekse TS, Demir M, Gur STA, et al. Performance of integrated pulmonary index for pulmonary embolism in dyspneic patients. Bratisl Lek Listy. 2021;122(1):65-70. https://doi.org/10.4149/BLL_2021_008
13. Vandenbroucke JP, Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. Ann Intern Med. 2007;147(8):W163-94. https://doi.org/10.7326/0003-4819-147-8-200710160-00010-w1
14. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics. 1988;44(3):837-45. PMID: 3203132
15. Cook TM, Woodall N, Frerk C, Fourth National Audit Project. Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 1: anaesthesia. Br J Anaesth. 2011;106(5):617-31. https://doi.org/10.1093/bja/aer058
16. Higgs A, McGrath BA, Goddard C, Rangasami J, Suntharalingam G, Gale R, et al. Guidelines for the management of tracheal intubation in critically ill adults. Br J Anaesth. 2018;120(2):323-52. https://doi.org/10.1016/j.bja.2017.10.021
17. Frerk C, Mitchell VS, McNarry AF, Mendonca C, Bhagrath R, Patel A, et al. Difficult Airway Society 2015 guidelines for management of unanticipated difficult intubation in adults. Br J Anaesth. 2015;115(6):827-48. https://doi.org/10.1093/bja/aev371
18. Kaur R, Vines DL, Liu L, Balk RA. Role of integrated pulmonary index in identifying extubation failure. Respir Care. 2017;62(12):1550-6. https://doi.org/10.4187/respcare.05434
19. Turan G, Kuplay Y, Karip C, Koksal C, Akın C, Akgun N. Integrated Pulmonary Index: a new strategy for respiratory patients evaluation. Int J Anesthetic Anesthesiol. 2016:3(1):042. 10.23937/2377-4630/3/1/1042