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THE VALUE OF INTEGRATED PULMONARY INDEX MONITORING AFTER ELECTROCONVULSIVE THERAPY

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Abstract
Aim: The Integrated Pulmonary Index (IPI) is an algorithm integrated 4 major parameters [end-tidal carbon dioxide ($EtCO_2$), respiratory rate (RR), oxygen saturation (SpO_2), and pulse rate (PR)] measured by commercially available monitors in order to provide a simple indication of the patient's overall ventilatory status. IPI provides to determine the need for additional clinical assessment or intervention by evaluating respiratory status of patient. The aim of the study was to study the value of IPI monitoring for assessment of respiratory status and recovery from anesthesia after electroconvulsive therapy (ECT).
Methods: Total 64 patients, ranging in age from 18 to 65 years and undergoing ECT for various psychiatric disorders, were enrolled in this prospective observational study. All patients were anesthetized with a standardized technique. After the return of spontaneous breathing, in addition to the standard monitoring, all patients were monitored with microstream $EtCO_2$, is a portable bedside monitor that continuously monitors a patient's $EtCO_2$, RR, SpO_2, PR and IPI. All those parameters and Modified Aldrete Score (MAS) were recorded during the first 5 minutes immediately after neuromuscular blockage recovery and the first 10 minutes in the post anesthesia care unit (PACU) stay, at 1-min intervals. Supplemental oxygen requirement, any interventions improving the patency of airway and any complications such as apnea, bradypnoea, tachypnoea etc. were also recorded.
Results: There were 1088 IPI readings ranging from 1 to 10. IPI values during 5 minutes of recovery period were significantly lower in the respiratory intervention group, and significantly low in patients who needed supplement oxygen in the PACU. Additionally, significant correlations were found between IPI and MAS or SpO_2 during follow-up in PACU.
Conclusions: The IPI monitorization can be useful over the standard monitorization in terms of better evaluation of respiratory status, and provide to make decision about PACU recovery, after ECT.

Keywords: *Integrated pulmonary index, end-tidal carbon dioxide, electroconvulsive therapy, Modified Aldrete Score.*

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Introduction

Accurate assessment of patient's respiratory status is an essential requirement of good patient care in all clinical settings: from pre-hospital and emergency care, through the spectrum of acute care within the hospital, and finally on the general medical surgical ward, respiratory status is a cornerstone of patient management.[1] Spot checks of respiratory rate and percentage of oxygen saturation cannot provide a complete picture of respiratory status. Continuous monitoring of oxygenation and ventilation using capnography and pulse oximetry allows providers to review trends in respiratory parameters not captured by intermittent monitoring and promotes timely medical intervention that may prevent a respiratory complications and arrest.[2]

The Integrated Pulmonary Index (IPI) is an algorithm that integrated 4 major parameters: end-tidal carbon dioxide ($EtCO_2$), respiratory rate (RR), oxygen saturation (SpO_2), and pulse rate (PR) measured by commercially available monitors in order to provide a simple indication of the patient's overall ventilatory status.[3]

It gives results in a single value representing respiratory status on a scale of 1 (critical respiratory insufficiency) to 10 (optimal respiratory status). IPI provides to determine the need for additional clinical assessment or intervention by evaluating respiratory status of patient (Table 1).[3]

This is the first commercially available tool incorporating ventilation and oxygenation into a single respiratory index score, and also the first example of a fused respiratory vital signs index based on implementing an expert rule system using fuzzy logic.[3]

Electroconvulsive therapy (ECT) is a unique therapy that intentionally provokes seizure by applying electrical current to the human central nervous system.[4] Although respiratory care during ECT can be completed within 10 min, inappropriate management interferes with the efficacy of the therapy and increases the risk of complications.[5-7]

Table 1. Classification of the patient status according to the IPI score.[3]

IPI	Patient status
10	Normal
8-9	Within normal range
7	Close to normal range, requires attention
5-6	Requires attention and may require intervention
3-4	Requires intervention
1-2	Requires immediate intervention

Abbreviations: IPI, integrated pulmonary index.

In this context, a prospective observational trial was designed to study the value of IPI monitoring for assessment of respiratory status (primary outcome) and recovery from anesthesia (secondary outcome) after electroconvulsive therapy.

Materials and Methods

This study was approved by the Institutional Investigation and Ethics Committee with the approval number of 12/90 in July 2019 and conducted at Cukurova University in Turkey.

Patients and intervention

For this prospective observational clinical study, sixty-four American Society of Anesthesiologists (ASA) physical status class I-II patients over the age of 18 who needed ECT due to various psychiatric problems were included in their first ECT sessions, between August 2019 and February 2020. Patients with cerebrovascular disease, ischemic heart disease, severe pulmonary disease that limits patient's daily activities, body mass index over 35 kg / m^2, and age over 65 were excluded from the study.

Patients who were taken to the ECT room after 6 hours of fasting, were monitored by electrocardiogram (ECG), pulse oximeter, non-invasive blood pressure (BP), and non-invasive microstream $EtCO_2$ monitoring (*Medtronic capnostream 35*). Microstream $EtCO_2$ monitoring is a portable bedside monitor that continuously monitors a patient's $EtCO_2$, RR, SpO_2, PR and IPI. $EtCO_2$ monitoring was performed using a combined nasal cannula, one side of which was used to sample CO_2 for measurement of $EtCO_2$, whereas the other delivered low-flow oxygen (2L/min).

Outcome and follow-up

The initial baseline BP, PR, $EtCO_2$, SpO_2, RR and IPI values, and age, gender, ASA score, psychiatric diagnosis, weight and height of the patients were recorded. Standard general anesthesia protocol for ECT was applied to all patients. Anesthesia was induced with 3-5 mg/kg intravenous (iv) thiopental sodium until the response for verbal command and the eyelash reflex disappeared. After loss of consciousness, 1 mg/kg iv succinylcholine chloride was administered, and ventilation was assisted using a face mask and 100% oxygen. Ventilation was performed by anesthesia residents with more than 2 years' experience in the position. One minute after the injection of succinylcholine, an electrical stimulus was applied bilaterally for 5 seconds at the minimal stimulus intensity by a trained psychiatrist using an ECT stimulator.

After the return of spontaneous breathing, in addition to the standard monitoring, all patients were monitored again with microstream $EtCO_2$ monitoring. All parameters measured by $EtCO_2$ monitoring (IPI, SpO_2, $EtCO_2$, RR, PR) and also Modified Aldrete Score (MAS) (Table 2)[8] were recorded during the first 5 minutes immediately after neuromuscular blockade recovery which was evaluated by return of spontaneous respiration and body movement, and the first 10 minutes in the post-anesthesia care unit (PACU) stay, at one minute intervals. Any interventions to improve respiratory status such as supplemental oxygen, mask ventilation, jaw-thrust maneuver to open the airway, and any complications such as apnea, bradypnoea, hypopnea, tachypnoea and hypercapnia etc. were recorded during these periods.

Table 2. Modified Aldrete Score[8]

Criteria	Characteristics	Points
Activity	Able to move 4 extremities	2
	Able to move 2 extremities	1
	Unable to move extremities	0
Respiration	Able to breathe deeply and cough freely	2
	Dyspnea or limited breathing	1
	Apneic	0
Circulation	BP +/- 20% of pre-anesthetic level	2
	BP +/- 20-49% of pre-anesthetic level	1
	BP +/- 50% of pre-anesthetic level	0
Consciousness	Fully awake	2
	Arousable on calling	1
	Not responding	0
Oxygen saturation	Able to maintain O_2 saturation >92% on room air	2
	Needs oxygen to maintain O_2 saturation >90%	1
	O_2 saturation <90% even with supplemental oxygen	0

The descriptions of the respiratory events to be treated and the types of intervention were as follows:

Events:

- Apnea: Absence of an $EtCO_2$ waveform for 10 seconds
- Bradypnea: RR<8/min + $EtCO_2$ > 50 mmHg
- Hypopnea: RR<12/min + $EtCO_2$ < 30 mmHg
- Tachypnea: RR>25/min
- Hypercarbia: $EtCO_2$>50 mmHg
- SpO_2 < 93% (in operation room)
- SpO_2 < 90% (in PACU)
- Apnea episodes detected by clinical observation

Interventions:

- Jaw thrust maneuver (JT)
- Assisted mask ventilation (AMV)
- JT + AMV
- Supplemental oxygen

Statistical analysis

Statistical analysis of the study was performed using SPSS software (version 23; IBM, New York, USA). Data are expressed as mean (SD) and categorical variables as count (%). Statistical differences between groups were evaluated using independent sample t tests. Relationship between IPI and MAS or SpO_2 was tested with Pearson correlation test. The statistical significance value was accepted as $p<0.05$.

Results

Eighty-two patients who were in the first session of their ECT were evaluated for the study within six months. 18 patients were excluded from the study because of not meeting inclusion criteria or declined to participate. Thus, 64 patients (36 female, 28 male) in the ASA I-II status, aged 18-65 years (mean age 39.86 ± 12.76 years), were included in the study. Total 1088 IPI readings ranging from 1 to 10 were consecutively recorded for these 64 patients. Descriptive statistics of IPI values and corresponding physiological parameters were presented in table 3.
A total of 38 (59.3%) patients requiring intervention were documented in the first 5 minutes of the follow-up. Of these events 16 (42%) were for SpO_2 < 93, 14 (37%) were for IPI <6, 8 (21 %) were for other reasons.

Table 3. Mean physiological parameters corresponding to IPI values

IPI	n	SpO_2[a]	$EtCO_2$[a]	Respiratory rate[a]	Heart rate[a]
1	3	88.00±9.17	29.33±10.21	14.00±13.11	97.33±28.87
2	3	93.67±6.81	31.33±20.55	11.67±12.42	102.00±13.00
3	2	91.50±9.19	31.00±18.38	14.50±9.19	100.00±21.21
4	24	92.04±4.13	34.17±15.39	19.21±7.96	100.00±14.18
5	39	92.38±3.73	41.21±9.59	21.69±10.09	98.74±12.78
6	76	93.36±2.45	41.88±9.13	19.68±7.74	96.79±12.21
7	203	93.30±2.42	41.61±7.68	20.34±6.55	94.05±11.19
8	268	94.82±1.74	39.98±6.72	20.87±6.22	94.75±11.44
9	239	93.71±1.79	38.90±4.65	18.37±3.60	92.64±10.42
10	229	96.97±1.80	38.84±4.21	16.66±3.50	89.66±12.27

Abbreviations: IPI, integrated pulmonary index; SpO_2, peripheral oxygen saturation; $EtCO_2$, end-tidal carbondioxide.
[a]*Values are given as mean±standard deviation.*

Table 4. Comparison of the IPI, SpO_2, $EtCO_2$, RR, and HR values for the first five minutes between the intervention group and the non-intervention group

Parametres	Intervention group[a] n=38	Non-intervention group[a] n=26	p value
Baseline IPI	9.63±0.71	9.77±0.58	0.41
Baseline SpO_2	97.84±1.58	98.23±1.75	0.36
Baseline $EtCO_2$	35.63±4.37	35.38±4.57	0.95
Baseline RR	17.08±4.76	16.62±3.34	0.67
Baseline HR	84.05±15.70	80.73±15.62	0.40
1. min IPI	6.05± 1.94	7.81± 1.20	0.00*
1. min SpO_2	95.92± 3.23	97.12± 3.10	0.14
1. min $EtCO_2$	38.92±13.14	42.42±6.91	0.00*
1. min RR	14.95±9.03	18.92±7.27	0.07
1. min HR	99.61±16.19	93.38±13.63	0.11
2. min IPI	7.03±2.41	7.92±1.23	0.06
2. min SpO_2	95.26±4.48	96.46±2.92	0.23
2. min $EtCO_2$	39.13±3.67	42.96±5.61	0.18
2. min RR	17.37±8.54	20.77±6.51	0.91
2. min HR	99.26±14.26	91.12±21.14	0.70
3. min IPI	6.63±2.31	8.38±1.13	0.00*
3. min SpO_2	94.34±3.54	96.23±2.68	0.02*
3. min $EtCO_2$	40.32±12.72	40.12±6.96	0.94
3. min RR	18.79±8.71	20.19±5.76	0.47
3. min HR	98.32±14.24	93.92±12.73	0.21
4. min IPI	6.92±2.04	8.42±1.06	0.00*
4. min SpO_2	93.84±3.77	96.12±2.70	0.01*
4. min $EtCO_2$	40.68±8.94	40.77±7.07	0.96
4. min RR	19.89±6.25	19.85±5.14	0.97
4. min HR	97.66±13.42	93.19±11.34	0.17
5. min IPI	7.58±1.65	8.54±1.02	0.00*
5. min SpO_2	94.18±3.14	95. 38±2.49	0.10
5. min $EtCO_2$	40.79±6.80	40.08±6.51	0.67
5. min RR	20.00±5.45	19.81±4.29	0.88
5. min HR	97.18±12.21	94.00±10.91	0.29

Abbreviations: IPI, integrated pulmonary index; SpO_2, peripheral oxygen saturation; $EtCO_2$, end-tidal carbon dioxide; RR, respiratory rate; HR, heart rate.
[a]Values are given as mean±standard deviation.
**These values indicate statistical significance ($p<0.05$).*

The distribution of the IPI, SpO_2, $EtCO_2$, RR, and HR values for the first five minutes between the intervention group and the non-intervention group was shown in table 4. IPI values at 1, 3, 4 and 5 minutes were significantly lower in the intervention group (Figure 1). SpO_2 values were also significantly lower in the intervention group at 3 and 4 minutes, but all mean saturation percentages were greater than 94 for the first 5 minutes (Figure 2). At that period, mean $EtCO_2$ values were similar between the groups and were within the normal range. According to this table, SpO_2 or $EtCO_2$ alone cannot determine the need for intervention in the early recovery period as much as IPI. Modified Aldrete Scores were also similar between intervention groups.

During the follow-ups in the PACU, it was observed that 15 (23.4%) patients needed intervention in the first 10 minutes. Since the patients were classified as those with and without supplemental oxygen requirement in the PACU, IPI values were significantly lower in the group requiring supplemental oxygen at 1, 2, 4, and 6 minutes. However, the mean IPI values were 6 and above at all times, except for 1 minute (Table 5).

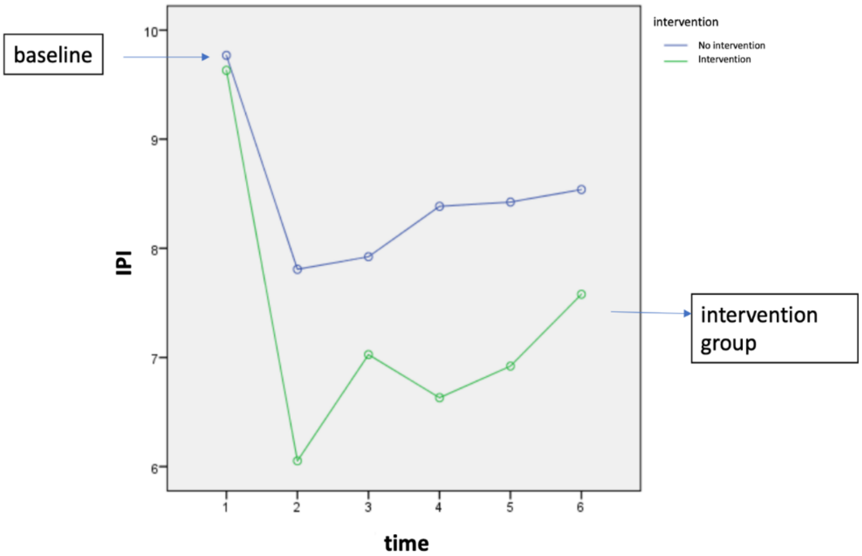

Figure 1. Time distribution of IPI values between the intervention group and the non-intervention group.

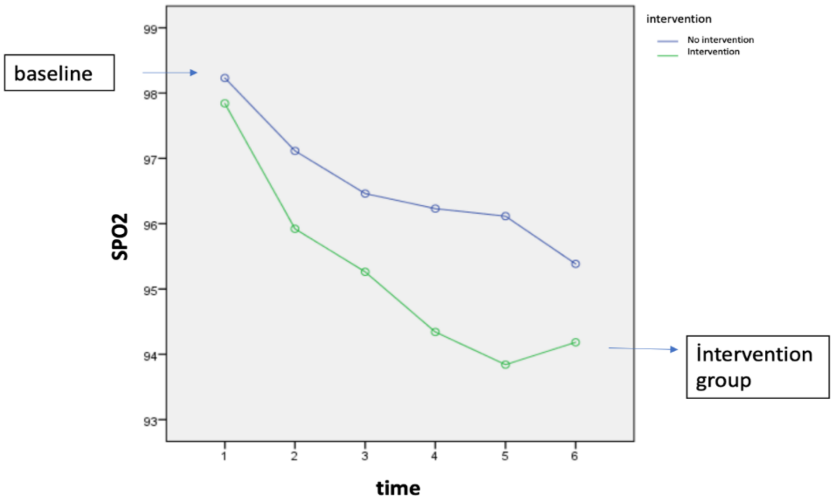

Figure 2. Time distribution of SpO_2 values between the intervention group and the non-intervention group.

When the correlation between IPI and SpO_2 or MAS was evaluated, there was a significant correlation between IPI and SpO_2 in the first 5 minutes of recovery, but there was no correlationbetween IPI and MAS except for 5 minutes (Table 6). In PACU, there was a significant correlation between IPI and SpO_2 or MAS at all follow-up periods (Table 7). The overall incidence of respiratory complications is summarized in table 8.

Discussion

In this prospective observational study, in patients requiring respiratory intervention during the recovery period after ECT, integrated pulmonary index monitoring was found to be an accurate and easier indicator than SpO_2 or $EtCO_2$ monitoring alone. While there was no significant difference or abnormality in $EtCO_2$ and SpO_2 in patients who needed intervention, IPI levels were found to be significantly lower. Moreover, in the PACU, the IPI was measured low in patients who needed supplement oxygen in the early post-anesthesia period. While there was no correlation between IPI and MAS in the first 5 minutes of recovery, there was a significant correlation between IPI and MAS in follow-ups in PACU. It was detected that this significant correlation also existed between IPI and SpO_2.

Activation of the autonomic nervous system and related hemodynamic changes and alterations in cerebrovascular dynamics as a physiological response to ECT, as well as complications related to the respiratory system, are common problems during anesthesia management.[7] Although the restoration of the respiratory system during ECT is relatively short, careful monitoring of all systems is vital during this process, which results in the activation of many physiologic systems in the body. Capnography can be used to determine the adequacy of ventilation in mechanically ventilated or unconscious patients, or in patients undergoing procedural sedation.[9] The presence of a normal waveform indicates a patent airway and spontaneous breathing, and normal $EtCO_2$ levels (35 to 45 mmHg) indicate adequate ventilation and perfusion.[10] Several systematic reviews and meta-analyses show that early intervention through capnography monitoring reduces the incidence of adverse respiratory events such as hypoxemia.[11-13] As a consequence, proper monitoring of the respiratory system can reduce respiratory complications and furthermore, it has been reported that $EtCO_2$ monitoring can stabilize hemodynamic changes during ECT and it is thought to be useful for safe and effective anesthesia management of patients undergoing ECT.[5]

Table 5. Relationship between supplement oxygen requirement and IPI at PACU

IPI	Supplement Oxygen requirement[a]	No supplement Oxygen requirement[a]	p value
1. min at PACU	9(14%) 5.44±1.01	55(86%) 7.89±1.67	0.00*
2. min at PACU	7(11%) 6.00±0.81	57(89%) 8.25±1.25	0.00*
3. min at PACU	4(6%) 8.00±1.41	60(94%) 8.23±1.22	0.71
4. min at PACU	6(9%) 7.67±0.51	58(91%) 8.33±1.17	0.02*
5. min at PACU	2(3%) 8.00±0.00	62(97%) 8.19±1.11	0.17
6. min at PACU	9(14%) 7.00±0.70	55(86%) 8.62±1.06	0.00*
7. min at PACU	4(6%) 9.00±0.00	60(94%) 8.53±1.29	0.00*
8. min at PACU	3(5%) 8.33±1.15	61(95%) 8.57±1.00	0.68
9. min at PACU	1(2%) 8.00±0.00	63(98%) 8.52±1.20	0.66
10. min at PACU	1(2%) 7.00±0.00	63(98%) 8.75±0.99	0.08

Abbreviations: IPI, integrated pulmonary index; PACU, post-anesthesia care unit.
[a]Values are given as n(%) and mean±standard deviation.

Table 6. Correlation of IPIs with SPO_2 and MAS at the first 5 minutes after recovery

Time	Correlation coefficient (r) IPI ~ SPO2	Correlation coefficient (r) IPI ~ MAS
1. min	0.13	0.04
2. min	0.35**	0.28*
3. min	0.35**	0.23
4. min	0.66**	0.20
5. min	0.50**	0.37**

Abbreviations: IPI, integrated pulmonary index; SpO_2, peripheral oxygen saturation; MAS, Modified Aldrete Score
**Correlation is significant at the 0.05 level (2-tailed).*
***Correlation is significant at the 0.01 level (2-tailed).*

Table 7. Correlation of IPIs with SPO_2 and MAS at PACU

Time	Correlation coefficient (r) IPI ~ SPO2	Correlation coefficient (r) IPI ~ MAS
1. min at PACU	0.62**	0.44**
2. min at PACU	0.72**	0.53**
3. min at PACU	0.31*	0.28*
4. min at PACU	0.62**	0.31*
5. min at PACU	0.60**	0.33**
6. min at PACU	0.52**	0.30*
7. min at PACU	0.42**	0.38**
8. min at PACU	0.14	0.33**
9. min at PACU	0.48**	0.43**
10. min at PACU	0.39**	0.18

Abbreviations: IPI, integrated pulmonary index; PACU, post-anesthesia care unit; SpO_2, peripheral oxygen saturation; MAS, Modified Aldrete Score
**Correlation is significant at the 0.05 level (2-tailed).*

Moreover, in a trial conducted in the pediatric population, it was reported that $EtCO_2$ monitoring was more sensitive than peripheral oxygen saturation monitoring in determining the need for respiratory support in the seizure and postictal period, and capnography evaluation showed a high correlation with blood gases.[14]

In ECT procedures, airway management is maintained with mask ventilation instead of endotracheal intubation unless there is a risk of aspiration. However, there is always a risk of ineffective ventilation during mask ventilation, particularly in patients with obesity, beard or obstructive sleep apnea disorder, despite appropriate ventilation technique.[15]

Table 8. Incidence of overall respiratory complications

Complication	n (%)
Bradypnea	5 (7.8%)
Hypopnea	9 (14.1%)
Tachypnea	28 (43.8%)
Hypercarbia	18 (28.1%)
Apnea	12 (18.7%)

On the other hand, monitorization of end-tidal CO_2 is important in ECT, because the increased carbon dioxide tension due to apnea episode immediately after the electrical stimulation, accelerated cerebral metabolism during the electrically induced seizure, or muscle fasciculations caused by succinylcholine may contribute the adverse respiratory outcomes.[5]

Therefore, instead of evaluating respiratory functions only with SpO_2 during recovery from anesthesia, following patients with capnography improves patient outcomes in ECT procedures. In addition, to evaluate the respiratory status of the patient, instead of interpreting the individual parameters such as respiratory rate, SpO_2 or $EtCO_2$ level on the monitor, ensuring this aim with a single variable like IPI, which is a newly developed index for non-invasive respiratory monitoring, provides the chance for faster and timely intervention. In this study, SpO_2 or $EtCO_2$ monitoring alone did not always guide the group in need of respiratory intervention. IPI monitoring appears to be a simple and rapid trigger for response to respiratory adverse events.

In the current study, statistical analysis have shown that, among the physiological parameters of patients, $EtCO_2$, RR and HR are mostly unchanged at different IPI values or respiratory intervention groups. These findings revealed that the IPI algorithm alone could drive the intervention requirement. Similarly, other previous studies have reported that IPI correlates with the respiratory physiological parameters of patients undergoing procedural sedation.[16,17]

In a study in which IPI was used to evaluate the respiratory status of postoperative patients, it was reported that IPI monitoring increased the number of interventions to improve the patients' respiratory conditions compared to standard clinical care.[18] In the present study, although the number of patients requiring intervention in the PACU was low, IPI was significantly lower in patients requiring supplement oxygen.

There are some studies reporting that the incidence of adverse respiratory events for 24 hours is 46-47% in patients followed up with capnograph in the postoperative period.[18,19] However, these studies were conducted in patients receiving general anesthesia using long-acting opioids. The ECT procedure is accompanied by a superficial and short-term anesthesia application, and opioids are often not needed. Therefore, the respiratory system is restored also in a short period. In this study, the incidence of apnea, hypercarbia, and hypopnea in the early recovery period, within the first 5 minutes of the postictal period, was found to be 18.7%, 28.1%, 14.1%, respectively, and none of the patients developed late-stage respiratory depression, despite the fact that their clinical relevance is uncertain. The PACU course progressed smoothly in almost all patients. Except for the first 2 minutes, IPI and MAS levels were always high in PACU. For this reason, we are in the opinion that the IPI monitoring will not contribute significantly to the care of patients with ECT in the late period. Nevertheless, significant correlations were found between IPI and MAS or SpO_2 during follow-up in PACU and further, monitoring the respiratory system with more than one method does not affect the incidence of adverse respiratory events and improves exactly patient safety. Similarly, in a study conducted in high-risk patients receiving general anesthesia, it was shown that IPI can predict the occurrence of respiratory complications in the PACU. For this reason, it has been reported that it may be useful for respiratory monitoring in PACUs and intensive care units after general anesthesia.[20]

This study had some limitations. First, since we did not have comparable arms, such as the IPI monitor arm and the standard monitor arm, assured comparison of events occurrences and interventions was not completely achieved. Second, our relatively small sample size was insufficient to identify additional risk factors for adverse respiratory events. Third, study was not blinded. Although most of the care giver were not accustomed to IPI monitor, anesthesiologists and PACU staff were not blinded of all parameters (IPI, $EtCO_2$, RR) displayed by $EtCO_2$ monitoring. This may have caused bias. Finally, we could not determine threshold values for IPI because the follow-up period was short and patients were relatively free of the risk of residual effects of anesthesia. On the other hand, it was valuable that we evaluated interventions by eliminating opioid use, which is a major risk factor for respiratory adverse events.

Conclusion

Although electrically induced seizure in ECT is self-limiting and adverse outcomes are uncommon, application of an end-tidal carbon dioxide monitoring is considered beneficial for safe and effective anesthesia management for patients undergoing ECT. The objective of the IPI algorithm is to simplify patient monitoring through real-time analysis of $EtCO_2$, RR, SpO_2, and PR, providing a single number that accurately indicates a patient's respiratory status in a simple and objective manner. The IPI monitorization can be useful over the standard monitorization in terms of better evaluation of respiratory status. On the other hand, the presented data in this study are limited, thus, prospective comprehensive large sample sized studies are required to investigate the value of routine use of IPI monitoring during ECT.

Author contributions
Author read and approved the final manuscript.

Conflict of interest
Author declares that they have no conflict of interest.

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Ethical approval
This study was approved by the Institutional Investigation and Ethics Committee with the approval number of 12/90 in July 2019 and conducted at Cukurova University in Turkey.

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