ORIGINAL RESEARCH

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Investigation of Dynamic $ETCO_2$ Values With Side Stream in The Treatment of PTX: A Prospective Study

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Abstract

Objective: Pneumothorax (PTX) is the accumulation of air in the pleural space, and it poses significant concerns in emergency settings. End-tidal carbon dioxide ($ETCO_2$) monitoring is potentially significant in PTX management, particularly regarding treatment response. This study aimed to elucidate the role of $ETCO_2$ monitoring in patients undergoing PTX, particularly in assessing treatment response following tube thoracostomy.

Materials and Methods: This prospective cross-sectional study was conducted at Ankara Bilkent City Hospital's emergency department. It included 43 patients diagnosed with spontaneous or traumatic PTX. $ETCO_2$ levels were measured before and after tube thoracostomy, along with other clinical parameters.

Results: Statistical analysis revealed significant differences in $ETCO_2$ values before tube insertion and at 2 and 4 hours post-insertion($p<0.001$). P-values were also less than 0.001 for all pairwise comparisons in the post hoc analysis. Changes in $ETCO_2$ levels post-treatment indicated the potential of this parameter for monitoring treatment efficacy. However, no significant difference was observed between spontaneous and traumatic PTX cases.

Conclusion: $ETCO_2$ monitoring emerges as a promising tool in PTX management, providing insights into treatment response. Further research is warranted to optimize its integration into clinical practice to enhance PTX patient care.

Keywords: PTX, tube thoracostomy, end-tidal carbon dioxide ($ETCO_2$)

Introduction

Pneumothorax (PTX) is defined as the accumulation of air in the pleural space [1]. PTX can develop secondary to various etiologies, and in some cases, there may be no identifiable lung abnormality[2]. PTX can be classified as spontaneous or traumatic [1]. The pathogenetic mechanisms leading to spontaneous PTX can be associated with lung-related abnormalities and environmental factors, such as smoking [2]. Traumatic PTX is another commonly encountered classification in the emergency department. Traumatic PTX can be further classified as iatrogenic or non-iatrogenic [3]. PTX can compromise lung tissue perfusion in the affected area and increase intrathoracic pressure, thereby impeding venous return and posing a potential life-threatening situation. Therefore, PTX necessitating urgent intervention is a significant concern in emergency departments [4].

End-tidal carbon dioxide ($ETCO_2$) provides insight into carbon dioxide levels resulting from lung perfusion and serves as a respiratory parameter providing information about the prognosis of many critical illnesses [5]. Physiologically, it is expected to be between 35-40 mmHg, with lower values expected in cases of impaired lung perfusion. One of the most important factors

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determining lung perfusion is the effective lung area [6]. The effective lung area can be influenced by many factors. One of the most important conditions for emergency departments is pneumothoraces. PTX resolves with emergency intervention, and an effective lung area is established. Perfusion and venous return improve. Based on the relationship between effective lung area and $ETCO_2$, it has been hypothesized that $ETCO_2$ may be affected in cases of PTX, and studies have explored the hypothesis that PTX can be monitored with $ETCO_2$ [5].

The present study aimed to investigate the changes in $ETCO_2$ levels following tube thoracostomy in patients undergoing PTX. Prior to tube insertion, we expected lower $ETCO_2$ values, and we measured them at intervals after tube insertion to assess the effectiveness of treatment and highlight the importance of etiology. We believe that the obtained data could be valuable for monitoring treatment response in patients with PTX.

Materials and Methods

Study Design

This study was conducted between August 15, 2023, and February 6, 2024, in patients diagnosed with isolated PTX who presented to the emergency department of Ankara Bilkent City Hospital, a tertiary care research hospital. The study has a prospective and cross-sectional design. Ethical approval was obtained from the Ankara Bilkent City Hospital No. 1 Clinical Research Ethics Committee (decision number: E1/387072023, date: 06.09.2023).

Patient Selection

The study included patients aged 18 years and above, without any comorbidities, diagnosed with spontaneous or traumatic PTX, who underwent tube thoracostomy, and did not have any other organ damage or injury. Participants were selected from volunteers who signed informed consent forms after being provided with detailed information about the study criteria. The study was completed in 43 patients.

Exclusion Criteria

- Patients aged below 18 years or over 65 years
- Patients who refused to participate in the study
- Pregnant women
- Individuals diagnosed with acute/chronic lung disease
- Patients with a history of advanced heart failure
- Patients with advanced systemic diseases
- Individuals with a history of malignancy (cancer)
- Chronic liver disease
- Individuals using sedative and analgesic drugs with neuropsychiatric effects
- Patients with a history of psychological or neurological diseases
- Patients with acute organ damage or failure other than PTX

The summary of the study and the flowchart are presented separately in Figure 1.

Study Variables and Definitions

In the study, a GE-brand patient monitor (GE Medical Systems Information Technologies, Germany) was used for vital parameter measurements, while a Medtronic-brand Capnostream 35 respiratory monitor device (Oridion Medical 1987 Ltd., Israel) was used for $ETCO_2$ measurement. $ETCO_2$ measurements of patients were conducted using a device that measures $ETCO_2$ levels in breaths delivered through the mouth and nose (sidestream measurement). $ETCO_2$ values were measured before tube thoracostomy insertion and at the 2nd and 4th hours after tube insertion in patients with indications for tube thoracostomy. The diagnosis of PTX was made using chest X-ray. The tube thoracostomy procedure was performed by chest surgeons or emergency physicians. Indications for tube thoracostomy were determined by chest surgeons.

Patients' age, gender, height, weight, vital signs, smoking history, PTX causes, lateral and apex collapse amount (in mm), procedures performed, $ETCO_2$ values before and after tube insertion at 2 and 4 hours, complete blood count, biochemistry, and arterial blood gas values were recorded on case report forms. Additionally, the length of hospital stay of patients was recorded using archive numbers through the hospital automation system.

According to the English guidelines, a large PTX is defined as a distance of more than 2 cm between the parietal and visceral pleura at the level of the hilum on chest X-ray, or a distance of more than 3 cm from the apex according to American guidelines [7]. Additionally, the percentage of PTX volume was calculated using the Collins method. The PTX percentage was calculated using the Collins method with the formula: % Collins="4.2 + 4.7(a + b + c)", where "a" represents the maximum apical interpleural distance, "b" represents the interpleural distance at the midpoint of the upper half of the lung, and "c" represents the interpleural distance at the midpoint of the lower half of the lung [8].

The first $ETCO_2$ ($ETCO_2$-0) was defined as the $ETCO_2$ measured during the emergency department visit. $PaCO_2$ was defined as the partial pressure of carbon dioxide measured during the first arterial blood gas analysis performed during the emergency department visit. After lung expansion, $ETCO_2$ was calculated as the average value of $ETCO_2$ measured 2 to 4 hours after tube thoracostomy ($ETCO_2$-1/$ETCO_2$-2). The increase in $ETCO_2$ after expansion was defined as the increase in $ETCO_2$ after closed

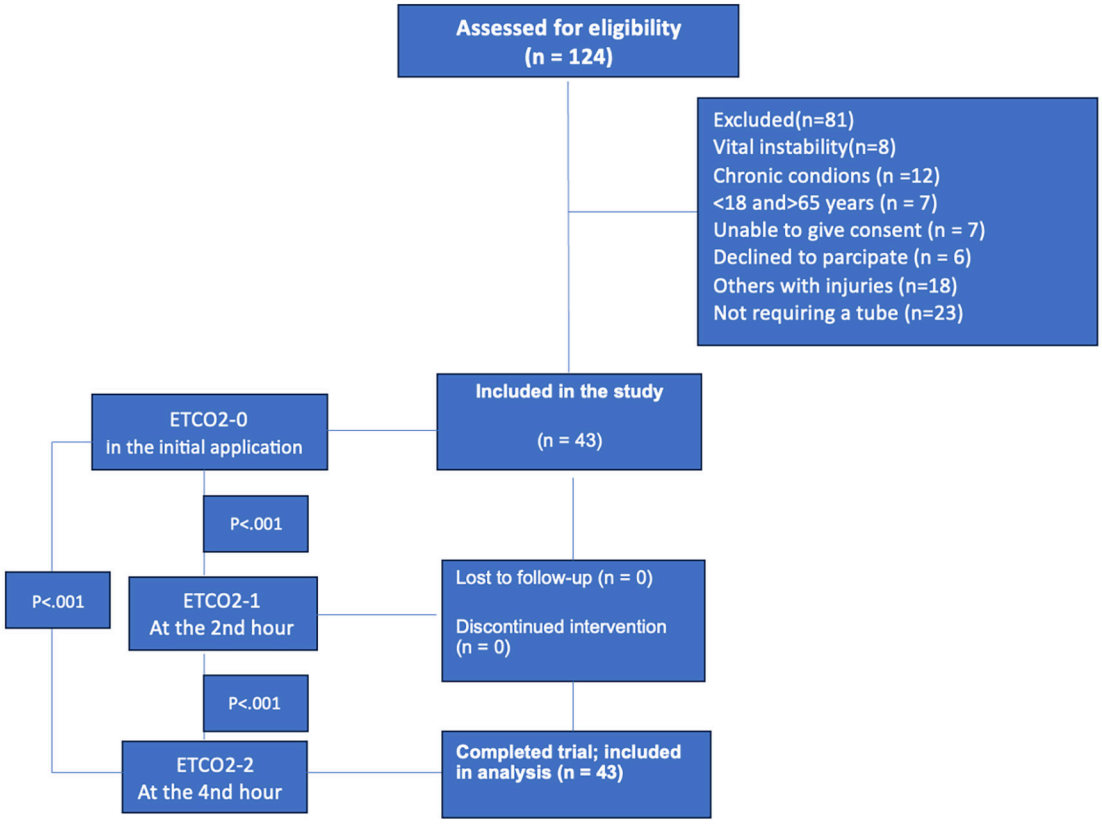

Figure 1. The flowchart and summary of the study

ETCO: End-tidal carbon dioxide

tube thoracostomy (Increase in $ETCO_2$ after drainage=$ETCO_2$ after tube thoracostomy-first $ETCO_2$). The change from $ETCO_2$-0 to $ETCO_2$-1 was determined as delta $ETCO_2$-1 ($\Delta ETCO_2$-1), and the change from $ETCO_2$-0 to $ETCO_2$-2 was determined as $\Delta ETCO_2$-2.

Outcomes

The primary endpoint of the study was the relationship between $ETCO_2$-0, $ETCO_2$-1, $ETCO_2$-2, $\Delta ETCO_2$-1, and $\Delta ETCO_2$-2 with Ac expansion after PTX treatment. The secondary endpoints included the differences between the traumatic and non-traumatic groups, relationship between hospital stay and $ETCO_2$ values, collapse percentage, PLR, and NLR indices.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics for MacOS version 28.0 (Armonk, NY: IBM Corp). The normality of continuous data was assessed using the Shapiro-Wilk test, Q-Q plots, and histograms. Normally distributed parameters were presented as mean, standard deviation, and 95% confidence interval, whereas parameters with non-normal distributions were expressed as median and interquartile range. Independent Samples t-test was used to assess the mean and mean differences for parameters with normally distributed data between the two groups. Descriptive statistics for continuous data included mean standard deviation and median, while frequency percentages were provided for nominal variables. The suitability of $ETCO_2$ for consecutive measurements was confirmed, and repeated measures ANOVA was conducted with post hoc pairwise comparisons adjusted using the Bonferroni method. Finally, Spearman's correlation test was performed for $ETCO_2$ values and other parameters.

Sample Size

Lee et al. [5] calculated that a minimum of 32 patients should be included in the study based on their data, with an 80% power and a 5% type 1 error rate. However, considering possible data losses, the study was planned to be conducted with 45 patients (5).

Results

Patient Information and Blood Parameters

The demographic characteristics of the patients, along with their blood parameters upon admission and the percentage of PTX volume, are presented in Table 1.

$ETCO_2$ Measurements

The statistical analysis revealed a significant difference among all measurement groups in the $ETCO_2$ values obtained before

Table 1. Table showing the demographic characteristics of the patients

Variables		n (%)	Median (25-75%)	Mean (SD)
Gender	Male	36 (83.7)		
	Female	7 (16.3)		
PTX cause	Spontaneous	23 (53.5)		
	Traumatic	20 (46.5)		
Age			41 (24-60)	41.88 (17.61)
Height			174 (168-178)	173.07 (7.09)
Weight			75 (65-80)	73.26 (12.19)
SBP			125 (110-140)	127.09 (16.59)
DBP			80 (70-90)	79.19 (11.38)
SpO_2			89 (88-91)	87.56 (12.54)
Pulse rate			87 (80-94)	85.33 (15.27)
RR			19 (17-20)	18.93 (2.14)
Cigarettes (quantity)			10 (0-20)	13.72 (15.54)
Years of smoking			0 (0-20)	8.51 (12.48)
pH			7.36 (7.34-7.40)	7,36 (0.04)
PCO_2			42.9 (38.1-47.2)	42.96 (8.08)
PO_2			41.8 (35.4-50.4)	43.92 (10.82)
Laktat			1.64 (1.27-2.35)	1.96 (0.93)
Hemoglobin			14.6 (13.1-15.7)	14.21 (1.87)
WBC			11 (7.91-13.12)	11.05 (3.47)
Platelet			251 (211-288)	251.3 (59.78)
Hematocrit			42.5 (40-47.4)	42.93 (5.47)
Neutrophil			7.47 (6.3-10.77)	8.69 (3.69)
Lymphocyte			1.3 (0.81-1.65)	1.43 (0.88)
Na			140 (138-141)	139.2 (3.11)
K			4.3 (4.2-4.6)	4.34 (0.46)
Bun			30 (20-42)	33.12 (18.25)
Creatinine			0.84 (0.74-0.92)	0.88 (0.30)
Length of hospital stay			6 (4-8)	6.98 (3.73)
Volume percentage (%)			29.11 (23.99-42.79)	34.44 (14.47)

SBP: Systolic blood pressure, DBP: Diastolic blood pressure, SpO_2: Oxygen saturation, RR: Respiratory rate, WBC: White blood cell, Bun: Blood urea nitrogen , PLR: Platelet lymphocyte ratio, NLR: Neutrophil-lymphocyte ratio, PTX: Pneumothorax

tube insertion and at 2 and 4 hours after tube insertion ($p<0.001$). Further post hoc analysis indicated that all groups differed from each other (Table 2, Figure 2). Additionally, a statistically significant difference was found in the comparison of $\Delta ETCO_2$ values between $\Delta ETCO_2$-1 and $\Delta ETCO_2$-2 (Table 2).

When examining the correlations between length of hospital stay and $ETCO_2$, along with other parameters, a statistically significant relationship was found between the percentage of PTX volume and length of hospital stay. However, the relationship between length of hospital stay and other parameters was statistically insignificant (Table 3).

Statistically, no significant difference was found in both the $ETCO_2$ values and the $\Delta ETCO_2$ values when comparing spontaneous and traumatic PTX cases (Table 4).

Discussion

The evaluation of lung function based on $ETCO_2$ and its relationship with lung volume is an ongoing debate. This study aimed to elucidate the relationship between volume changes and $ETCO_2$ in patients with PTX. To the best of our knowledge, this study is the first prospective investigation of this hypothesis. According to the results obtained herein, the $ETCO_2$-0 value measured before tube thoracostomy, which was

Table 2. Distribution of $ETCO_2$ levels in patients and the relationship between values before and after tube thoracostomy

	Mean (SD)		p	95% CI	
				Lower bound	Upper bound
$ETCO_2$-0	26.86 (4.72)		<0.001*	25.408	28.313
$ETCO_2$-1	31.27 (4.97)			29.749	32.810
$ETCO_2$-2	32.97 (4.01)			31.741	34.212
Post-hoc pairwise comparisons		**Mean diff**	**p**		
$ETCO_2$-0	$ETCO_2$-1	-4.419	<0.001**	-6.199	-2.638
	$ETCO_2$-2	-6.116	<0.001**	-8.027	-4.205
$ETCO_2$-1	$ETCO_2$-2	-1.698	0.001**	-2.785	-0.611
Comparison of ΔETCO2 values					
ΔETCO-1	-4.42 (4.68)		<0.001†	0.818	2.577
ΔETCO-2	-6.12 (5.02)				

The mean difference is significant at the .05 level,

*Repeated Measured ANOVA (Greenhouse-Geisser), †Paired Sample T Test, **Adjustment for multiple comparisons: Bonferroni,

SD: Standard daviation, CI: Confidence interval, ETCO: End-tidal carbon dioxide

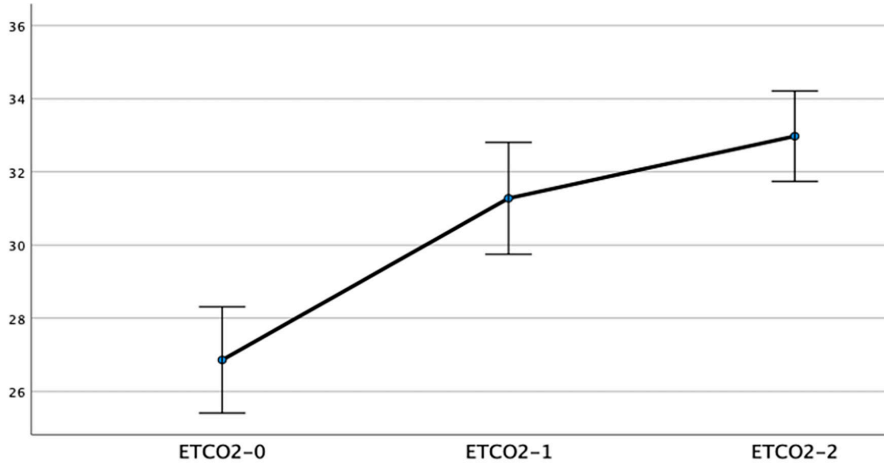

Figure 2. Changes in $ETCO_2$ levels following chest tube insertion

ETCO: End-tidal carbon dioxide

below the normal reference range and started to rise after tube thoracostomy, suggested a close relationship between $ETCO_2$ and lung volume, which may be significant for monitoring treatment efficacy.

When examining the characteristics of our study population, it is evident that there is a predominance of males and a representation of a young demographics. Concerning PTX, we observed that our population differed from the standard expected asthenic constitution. It is important to note that our population, which is consistent with the literature regarding gender distribution, exhibits differences in body morphology [9]. We can consider the increasingly sedentary lifestyle prevalent worldwide and in our country as a possible reason for this difference.

Normal healthy individuals typically have an expected normal range of $ETCO_2$ between 35 and 40 mm Hg, and values below or above these limits are considered pathological [6]. Studies have shown that $ETCO_2$ levels are a prognostic indicator in conditions such as severe infection, trauma, and cardiac arrest [10,11,12]. In patients with PTX, $ETCO_2$ values are expected to be lower than normal due to the dead space associated with the condition[6]. In a study conducted, differences between primary spontaneous and secondary spontaneous PTX were investigated, and it was reported that $ETCO_2$ values of all patients were lower before tube thoracostomy and higher after tube thoracostomy [5]. Our study findings support the existing literature, showing a similar relationship between patients' $ETCO_2$-0 and $ETCO_2$-1 and $ETCO_2$-2 values. This indicates how the

Table 3. Correlation of $ETCO_2$, collapse rates, and blood parameters with length of hospital stay					
Length of hospital stay		$ETCO_2$-0	$ETCO_2$-1	$ETCO_2$-2	Volume percentage
	Spearman's rho	-0.202	0.022	-0.008	0.412
	p	0.193	0.891	0.961	0.006
		BUN	Laktat	HMG	WBC
	Spearman's rho	-0.226	-0.005	-0.225	0.134
	p	0.144	0.974	0.147	0.391

Table 4. Comparison of $ETCO_2$ between spontaneous and traumatic pneumothorax					
		Mean (SD)	Mean diff	p	95% CI
ETCO-0	Spontaneous	27.30 (4.9)	0.95	0.5*	-1.979-3.888
	Traumatic	26.35 (4.6)			
ETCO-1	Spontaneous	30.96 (5.4)	-0.69	0.65*	-3.794-2.407
	Traumatic	31.65 (4.5)			
ETCO-2	Spontaneous	32.61 (4.4)	-0.69	0.53*	-3.288-1.705
	Traumatic	33.40 (3.6)			
$\Delta ETCO_2$-1	Spontaneous	-3.65 (4.62)	1.64	0.25*	-1.23-4.52
	Traumatic	-5.30 (4.70)			
$\Delta ETCO_2$-2	Spontaneous	-5.30 (4.81)	1.74	0.26*	-1.34-4.83
	Traumatic	-7.05 (5.21)			

*Independent Samples Test,

SD: Standard davitation, CI: Confidence interval, ETCO: End-tidal carbon dioxide

ventilation changes over time and returns to normal once full expansion is achieved. However, our results differ numerically from the literature. Our findings do not support the literature regarding pre- and post-expansion values and the amount of increase. The increased values at 2 and 4 h after expansion can be attributed to initial edema occurring acutely after expansion and its subsequent reduction over time. Follow-ups after PTX are typically based on clinical findings, vital parameters, and radiological findings. Although bedside X-rays are commonly used, they are not always readily available and involve radiation [13]. $ETCO_2$ measurement is a continuous and easily accessible method. Additionally, the increase observed over time is valuable for monitoring whether the tube is functioning properly and for tracking potential additional complications. When comparing the results of our study with those of the study conducted by Lee et al. [5] although they only included patients with primary and secondary spontaneous PTX and conducted their study retrospectively, there were similarities in terms of hospital stay durations and volume percentages. However, our $ETCO_2$ values did not show statistical significance with hospital stay duration. Only a statistically significant correlation was observed between volume percentage and hospital stay duration.

In a study of trauma patients, a comparison was made between patients with and without PTX. Parameters such as hemoglobin (Hgb), hematocrit (Hct), platelet, neutrophil, and lymphocyte counts, sodium (Na), potassium (K), and length of hospital stay were compared. It was noted that, except for Hgb and Hct, all other parameters were higher in the PTX group [14]. When the averages and standard deviations of patients in the PTX group in this study were examined numerically, Hgb and Hct were found to be higher. Among the other parameters, Na, K, platelet, and lymphocyte counts were found to be numerically close. However, in our study, the neutrophil count and average were numerically lower. Additionally, the average and standard deviation values for hospital stay in our study are similar to those in this previous study. We believe that these results are related to our study population. The reason for this discrepancy may be the inclusion of patients with isolated PTX without any additional diseases in our study.

In a study examining unilateral AC contusion, it was highlighted that changes in $ETCO_2$ levels are significant for evaluating the ventilation-perfusion (V/Q) balance of the lungs. Specifically, low $ETCO_2$ levels in diseased lungs can be an indicator of decreased ventilation [15]. Although our study focused on patients with isolated PTX, the findings are consistent with the existing literature. In cases of pulmonary embolism, a reduction in $ETCO_2$ is significantly associated with decreased pulmonary perfusion and increased alveolar dead space, leading to elevated venous CO_2 levels and consequently increasing the arterial CO_2-$ETCO_2$ gradient [16]. Although we did not present calculations for the CO_2-$ETCO_2$ gradient in our study, the direction of changes in $ETCO_2$ was consistent with that presented in the literature. An analysis involving patients with chronic obstructive pulmonary disease indicated that

higher $ETCO_2$ levels tend to decrease with treatment and may serve as a guide for intubation decisions; however, the changes observed in our study were in the opposite direction [17]. This discrepancy may be due to differences in pathophysiological mechanisms. Additionally, another study reported a decline in $ETCO_2$ levels among patients with pulmonary embolism [18]. The results of our study indicate that the collapse in AC caused a corresponding disruption in V/Q, which is in agreement with the literature. In conclusion, $ETCO_2$ monitoring can be used as a parameter for tube management and is a more convenient and harmless method than other existing methods. Conducting further studies on this topic would enhance our understanding.

Study Limitations

Our patient population primarily consisted of relatively young patients. Therefore, studies involving larger patient groups, including more elderly patients, or focusing specifically on elderly patients should be conducted. Another limitation is that we only included isolated PTX cases in our study; $ETCO_2$ values may vary in patients with multiple traumas, additional injuries, or other medical conditions. Hence, studies with a larger sample size that also include patients with such additional complaints or diseases can be conducted.

Conclusion

Our study provides valuable insights into the potential benefits of $ETCO_2$ monitoring in the management of PTX cases. By examining changes in $ETCO_2$ levels before and after tube thoracostomy, our aim was to evaluate treatment efficacy and underscore the significance of the etiology. Our results support the hypothesis that $ETCO_2$ values are influenced by PTX, suggesting that they could be a useful parameter for monitoring treatment response. Additionally, it offers a convenient and noninvasive approach. Further studies are needed to validate our findings and optimize patient care in the management of PTX. Overall, our study contributes to the growing body of evidence supporting the valuable role of $ETCO_2$ monitoring in the management and monitoring of patients with PTX. Further clinical research is required to fully elucidate its clinical implications and to integrate it into routine practice.

Ethics

Ethics Committee Approval: Ethical approval was obtained from the Ankara Bilkent City Hospital No. 1 Clinical Research Ethics Committee (decision number: E1/387072023, date: 06.09.2023).

Informed Consent: Retrospective study.

Footnotes

Authorship Contributions

Surgical and Medical Practices: S.D., A.Ş., H.O., Concept: S.D., A.Ş., N.İ.I., M.Y., İ.A., H.O., Design: S.D., A.Ş., N.İ.I., M.Y., İ.A., H.O., Data Collection or Processing: S.D., A.Ş., H.O., Analysis or Interpretation: S.D., A.Ş., N.İ.I., M.Y., İ.A., Literature Search: S.D., A.Ş., N.İ.I., M.Y., İ.A., Writing: S.D., A.Ş., N.İ.I., İ.A.

Conflict of Interest: No conflict of interest was declared by the authors.

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