

Evaluation of the Effects of Volume-Controlled and Pressure-Controlled Ventilation on Cerebral Oxygen Saturation, Perfusion Index, and Pleth Variability Index in Septoplasty Surgical Cases: An Observational Prospective Study

Septoplasti Cerrahi Vakalarında Hacim Kontrollü ve Basınç Kontrollü Ventilasyonun Serebral Oksijen Satürasyonu, Perfüzyon İndeksi ve Pleth Değişkenlik İndeksi Üzerindeki Etkilerinin Değerlendirilmesi: Gözlemsel Prospektif Çalışma

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Abstract

Background: This study aimed to assess the reliability of pleth variability index (PVI), perfusion index (PI), and regional cerebral oxygen saturation (rSO₂) across two ventilation strategies in patients undergoing septorhinoplasty under general anaesthesia.

Materials and Methods: After induction, patients were ventilated with a volume-controlled mode for 20 minutes, during which heart rate (HR), PI, PVI, peripheral oxygen saturation (SpO₂), non-invasive blood pressure (NIBP), and rSO₂ were recorded at 5-minute intervals. Subsequently, ventilation was switched to a pressure-controlled mode for another 20 minutes with repeated measurements at the same intervals.

Results: Fifty patients with American Society of Anesthesiologists (ASA) I-III classification and a body mass index (BMI) under 30 were included. Preoperative PI values were significantly lower compared with intraoperative recordings under both ventilation strategies (p<0.05). Preoperative PVI was higher than subsequent measurements, with significantly elevated values during volume-controlled ventilation (VCV) at the 10-minute mark (p<0.05). Left-sided rSO₂ values showed a gradual decrease relative to baseline, whereas right-sided rSO₂ demonstrated progressive increases; however, fluctuations remained within 10%.

Conclusions: Parameters including HR, PI, PVI, SpO₂, NIBP, and rSO₂ were not interchangeable between the two ventilatory modes. Overall, the transition from VCV to pressure-controlled ventilation (PCV) did not yield significant alterations in these variables.

Keywords: Ventilation mode; pleth variability index; perfusion index; regional cerebral oxygen saturation

Öz

Amaç: Bu çalışma, genel anestezi altında septorinoplasti geçiren hastalarda iki ventilasyon stratejisi boyunca plet variabilite indeksi (PVI), perfüzyon indeksi (PI) ve rejyonel serebral oksijen satürasyonu (rSO₂) güvenilirliğini değerlendirmek amacıyla yapılmıştır.

Materyal ve Metod: İndüksiyondan sonra, hastalara 20 dakika boyunca hacim kontrollü modda ventilasyon uygulandı ve bu süre boyunca kalp atım hızı (HR), PI, PVI, periferik oksijen satürasyonu (SpO₂), non-invaziv kan basıncı (NIBP) ve rSO₂ 5 dakikalık aralıklarla kaydedildi. Ardından, ventilasyon 20 dakika boyunca basınç kontrollü moda geçirildi ve aynı aralıklarla ölçümler tekrarlandı.

Bulgular: Amerikan Anesteziyologlar Derneği (ASA) I-III sınıflandırmasına sahip ve vücut kitle indeksi (BMI) 30'un altında olan 50 hasta çalışmaya dahil edildi. Ameliyat öncesi PI değerleri, her iki ventilasyon stratejisinde de ameliyat sırasındaki kayıtlara kıyasla anlamlı olarak daha düşüktü (p<0,05). Ameliyat öncesi PVI, sonraki ölçümlere göre daha yüksekti ve hacim kontrollü ventilasyon (VCV) sırasında 10. dakikada anlamlı olarak yükseldi (p<0,05). Sol taraf rSO₂ değerleri bazal değere göre kademeli bir düşüş gösterirken, sağ taraf rSO₂ değerleri kademeli bir artış gösterdi; ancak dalgalanmalar %10 içinde kaldı.

Sonuç: HR, PI, PVI, SpO₂, NIBP ve rSO₂ gibi parametreler iki ventilasyon modu arasında birbirinin yerine kullanılamadı. Genel olarak, VCV'den basınç kontrollü ventilasyona (PCV) geçiş bu değişkenlerde önemli değişikliklere yol açmadı.

Anahtar Kelimeler: ventilasyon; plet variabilite indeksi; perfüzyon indeksi; rejyonel serebral oksijen satürasyonu

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Introduction

Advances in anaesthesia practice have increasingly emphasized the significance of monitoring microcirculatory changes, as new technologies allow improved tissue perfusion and may help reduce postoperative morbidity (1). Reliable and easily applicable non-invasive tools are therefore essential to evaluate fluid responsiveness in real time. In recent years, the preference for non-invasive monitoring methods over invasive approaches has markedly expanded. Among these, the Pleth Variability Index (PVI), Perfusion Index (PI), and Regional Cerebral Oxygen Saturation (rSO₂) have attracted growing attention (2).

Near-infrared Spectroscopy (NIRS) enables continuous assessment of cerebral oxygen balance by distinguishing oxy- and deoxy-haemoglobin signals non-invasively (3). Monitoring rSO₂ provides clinicians with valuable insight into the balance between cerebral oxygen supply and demand. PVI, another non-invasive modality, has been reported to predict intraoperative hypotension and fluid requirements (4). PI, derived from infrared light absorption in the fingertip vasculature, reflects peripheral perfusion status. Variations in PI serve as a sensitive marker of microcirculatory changes and may guide anaesthesiologists in making timely therapeutic decisions (5).

In routine practice, both volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) are employed to maintain general anaesthesia. However, the accuracy of non-invasive parameters such as PI, PVI, and rSO₂ in reflecting haemodynamic responses under PCV compared with VCV remains under debate (6).

To address this knowledge gap, the present study was designed to evaluate the reliability of PVI, PI, and rSO₂ measurements in patients undergoing septorhinoplasty under general anaesthesia, comparing outcomes between volume- and pressure-controlled ventilation modes.

Materials and Methods

This prospective observational study was approved by the Harran University Clinical Research Ethics Committee (date: 29.06.2020; decision number: HRU/20.12.17). From the observed differences and under the assumption of a one tailed α -value of 0.05 (sensitivity: 95%) and a β -value of 0.05 (study power: 95%, effect size: 0.43), we determined that at least 50 patients were required for our study (using the G-Power 3 program for power analysis). Fifty patients aged between 18 and 80 years, classified as American Society of Anesthesiologists (ASA) I–III, scheduled for septorhinoplasty, were included.

Exclusion criteria were; liver or kidney failure, obesity (Body Mass Index (BMI) ≥ 30), malignancy, trauma, ASA IV patients, emergency procedures, arrhythmia, pacemaker implantation, or chronic pain disorders.

Monitoring and Anaesthesia Protocol

Standard monitoring was applied upon arrival in the operating room. Baseline measurements of systolic arterial pressure (SBP), oxygen saturation (SpO₂), and heart rate (HR) were obtained. A pulse oximeter probe was placed on the index finger to measure PI and PVI, while two cerebral oximetry probes were attached to the forehead to record initial rSO₂ values.

Anaesthesia was induced with propofol (2 mg/kg) and fentanyl (2 μ g/kg), followed by rocuronium (0.6 mg/kg) to facilitate intubation with a reinforced endotracheal tube. Anaesthesia was maintained using 0.5–1.0 Minimal Anesthesia Concentration (MAC) sevoflurane in a 50% oxygen-air mixture.

Ventilatory parameters were standardized: tidal volume 8 mL/kg (according to ideal body weight), respiratory rate 12 breaths/min, end-tidal CO₂ maintained at 35–45 mmHg, Inspiratory/ Expiratory (I:E) ratio of 1:2, and Positive End-Expiratory Pressure (PEEP) 5 cmH₂O. The inspiratory pressure limit was set at 35 cmH₂O. Additional fentanyl (0.5–1 μ g/kg) was administered to maintain systolic arterial pressure within $\pm 20\%$ of baseline.

Ventilation Protocol

Initially, all patients were ventilated in volume-controlled ventilation (VCV) mode for 20 minutes. HR, PI, PVI, SpO₂, NIBP, and rSO₂ values were recorded every 5 minutes. At the 20-minute mark, ventilation mode was switched to pressure-controlled ventilation (PCV), adjusting inspiratory pressure to achieve the same tidal volume (8 mL/kg). Data collection continued every 5 minutes for another 20 minutes.

Statistical Analysis

Data analysis was performed using Statistical Package for Social Sciences (SPSS) version 21 (IBM, Armonk, NY, USA). Continuous variables were expressed as mean \pm standard deviation, and categorical variables as numbers and percentages. Correlation analyses were conducted with the Spearman test. A p-value < 0.05 was considered statistically significant.

Results

Study population

A total of 50 patients (25 females, 25 males) who underwent septorhinoplasty at SBU Mehmet Akif Inan Training and Research Hospital between 27/04/2020 and 25/03/2021 were analysed. The mean age was 25.38 ± 4.65 years (range: 19–38). Average body weight was 75.9 ± 13.05 kg (range: 52–105), and mean height was 168.22 ± 5.81 cm (range: 158–183). None of the patients had comorbidities, but 42% (n=21) were active smokers. Mean surgical duration was 53.9 ± 10.89 minutes (range: 35–75). The demographic and baseline clinical characteristics of the study were similar and are presented in Table 1 and Table 2.

Hemodynamic measurements

Perfusion Index (PI): Preoperative PI values were significantly lower than all subsequent intraoperative recordings in both ventilation strategies ($p < 0.05$).

Pleth Variability Index (PVI): Preoperative PVI was higher than all intraoperative measurements. A significant elevation was observed at the 10th minute under VCV compared with other time points ($p < 0.05$).

Table 1. Demographic characteristics of the patients-1

n:50	Min	Max	Mean	std.dev (±)
Age	19	38	25,38	4,651
Height (cm)	158	183	168,22	5,814
Weight (kg)	52	105	75,9	13,054
Operation time (min)	35	75	53,9	10,893

Table 2. Demographic characteristics of the patients-2

		N	%
Gender	Male/Female	25/25	50/50
ASA	1	29	58
	2	21	42
Smoker	Yes	21	42
Previous Surgery	Yes	9	18

ASA: American Society of Anesthesiologists Physical Status Classification

Regional Cerebral Oxygen Saturation (rSO_2)

Left hemisphere: Baseline rSO_2 during VCV was significantly higher compared with PCV at the 5th and 20th minutes. Within VCV, the 5th-minute value was higher than the 15th-minute reading, and the 10th-minute value exceeded the 15th-minute measurement ($p < 0.05$).

Right hemisphere: Baseline values were significantly lower compared with subsequent time points in both ventilation modes. PCV at the 5th minute was also significantly lower than corresponding VCV measurements (baseline, 5th, 10th, 15th, and 20th minutes).

Heart Rate (Pulse): Baseline HR in VCV was significantly higher compared with most subsequent measurements, except at the 5th minute. HR at VCV 5 minutes was higher than at later time points, while VCV 10 minutes was higher compared with subsequent intervals. Under PCV, HR at the 20th minute was lower than all other measurements, except VCV 20 minutes and PCV 15 minutes.

The hemodynamic measurements in the study are presented in Table 3 and Figure 1.

In the subgroup analysis comparing smokers and non-smokers, no statistically significant differences were observed in preoperative or intraoperative PI, PVI, cerebral oxygen saturation (left/right rSO_2), mean arterial pressure (MAP), peripheral capillary oxygen saturation (SpO_2), or heart rate (HR) values under either VCV or PCV ventilation modes (all $p > 0.05$). The only significant difference was age, with smokers being significantly older than non-smokers ($p < 0.001$). These findings suggest that smoking status did not substantially influence perioperative hemodynamic or cerebral oxygenation parameters in the present cohort, although the higher age in smokers may act as a potential confounding factor.

Discussion

Several indices have been developed to predict fluid responsiveness, with respiratory-induced changes in stroke volume and related parameters being among the most widely studied. During mechanical ventilation, cyclic variations in intrathoracic pressure reduce left ventricular preload, and this mechanism can be exploited to assess preload dependency and cardiac output responsiveness (7). Dynamic parameters such as PVI have consistently been shown to outperform static indices in predicting stroke volume increases after fluid administration, and they are now frequently applied in perioperative fluid management (8).

Mechanical ventilation is essential in many surgical procedures under general anaesthesia. Among various ventilation strategies, VCV and PCV are the most commonly employed in septorhinoplasty. While VCV provides ventilation with predetermined tidal volume and PEEP, PCV relies on set inspiratory pressures, with tidal volume varying depending on pulmonary compliance and airway resistance (9).

Comparative studies have suggested that both modes exert similar overall haemodynamic effects, though PCV has been associated with lower inspiratory pressures and reduced systemic vascular resistance in some cohorts (10).

Despite numerous investigations, no clear consensus exists on how different ventilation strategies influence haemodynamics. Parameters such as PI, PVI, and rSO_2 are widely used to evaluate tissue perfusion and oxygenation, yet their responses to different ventilation modes remain uncertain, and available studies are limited. In a randomized study evaluating ΔPP values, results demonstrated significant variability between VCV and PCV, indicating that dynamic indices obtained under different ventilation strategies cannot be considered interchangeable (11).

The PI, which reflects pulsatile versus non-pulsatile flow within peripheral capillaries, is sensitive to alterations in cardiac output, vasomotor tone, and skin temperature. It offers the advantage of continuous non-invasive monitoring and can serve as a surrogate for cardiac output when confounding factors are minimized (12). Based on the PI distribution in healthy adult population, a PI cut-off point, less than 1.4 is used as a very sensitive point in identifying abnormal peripheral perfusion associated with vasoconstriction in critically ill patients (13). In the present study, preoperative PI was significantly lower than intraoperative values, but no meaningful differences were detected between the two ventilation modes.

PVI is based on the calculation of the change in pulse oximeter signals with the respiratory cycle, based on the PI. Both parameters have been used to evaluate peripheral perfusion dynamics from changes in peripheral vascular tone, provides a dynamic assessment of fluid responsiveness (14). Most studies evaluating dynamic pulse oximetry indices such as PVI, were performed with closed chest, at least 7 to 8 ml/kg tidal volume and sinus rhythm with controlled ventilation.

Table 3. Hemodynamic measurements at timeline

	SpO ₂	HR	MAP	PI	PVI	LEFT rSO ₂	RIGHT rSO ₂
Preop.	97.9 ± 1.177	88.02 ± 10.89	86.04 ± 9.06	1.567 ± 0.5781	18.94 ± 5.494	66.89 ± 4.693	66.75 ± 4.37
VCV initial	99.14 ± 1.021	94.78 ± 11.067	82.29 ± 9.876	4.97 ± 1.4738	14.52 ± 4.353	71.26 ± 6.466	70.84 ± 5.577
VCV 5 min.	99.16 ± 1.007	94.13 ± 12.344	85.16 ± 8.749	4.503 ± 1.542	13.94 ± 5.798	70.63 ± 6.789	71.94 ± 6.133
VCV 10 min.	99.67 ± 0.718	83.63 ± 12.613	76.71 ± 8.237	4.879 ± 2.1396	12.7 ± 4.142	70.48 ± 6.29	71.72 ± 5.843
VCV 15 min.	99.51 ± 0.82	78.22 ± 11.935	73.76 ± 8.161	5.188 ± 2.2251	11.82 ± 4.111	68.26 ± 4.646	71.03 ± 4.802
VCV 20 min.	99.53 ± 0.739	74.89 ± 8.767	70.49 ± 4.888	5.0085 ± 2.1935	12.776 ± 4.601	66.74 ± 4.082	69.66 ± 4.021
PCV initial	99.31 ± 0.871	74.67 ± 7.84	68.76 ± 11.855	4.8148 ± 2.1235	11.79 ± 3.049	67.04 ± 5.734	68.56 ± 4.235
PCV 5 min.	99.22 ± 0.941	75.39 ± 6.725	68.87 ± 4.47	4.588 ± 1.734	12.48 ± 2.537	66.33 ± 4.412	66.72 ± 3.401
PCV 10 min.	99.41 ± 0.888	75 ± 6.484	68.49 ± 4.521	5.203 ± 1.8721	13.55 ± 6.006	68.44 ± 5.444	68.72 ± 4.144
PCV 15 min.	99.41 ± 0.864	74.33 ± 6.092	69.42 ± 3.893	4.879 ± 1.5286	13.85 ± 4.57	68.07 ± 4.242	68.78 ± 3.28
PCV 20 min.	99.45 ± 0.679	71.15 ± 6.143	71.04 ± 5.58	4.479 ± 1.3465	11.42 ± 2.562	66.04 ± 3.458	68.38 ± 4.062

VCV: volume-controlled ventilation, PCV: pressure-controlled ventilation, min: minute, PVI: Pleth Variability Index, PI: Perfusion Index, rSO₂: Regional Cerebral Oxygen Saturation, MAP: mean arterial pressure, SpO₂: peripheral capillary oxygen saturation, HR: heart rate, Preop: preoperative

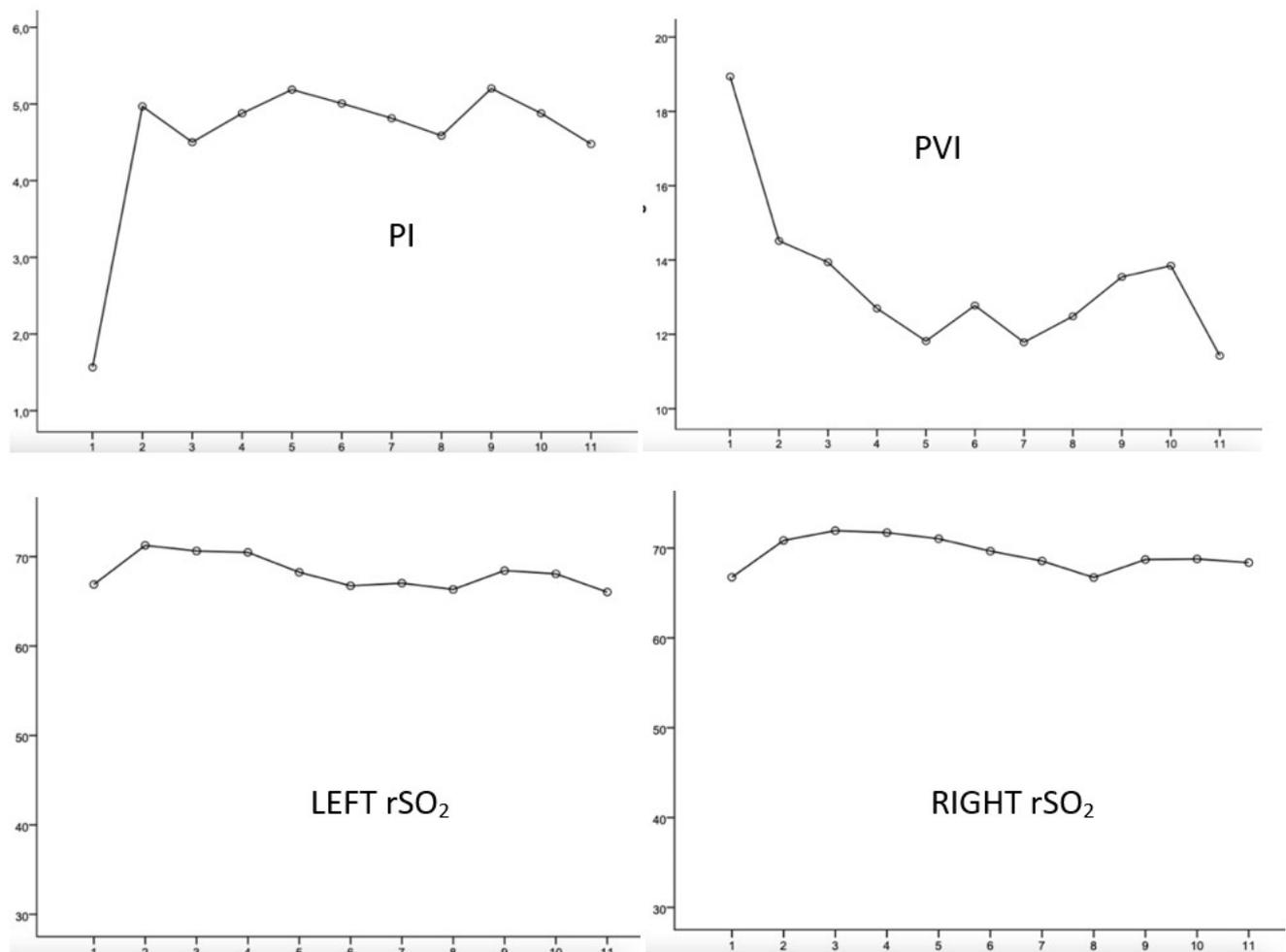


Figure 1. PI, PVI, Left rSO₂ and Right rSO₂ graphics at timeline (1: Preop, 2: VCV baseline, 3: VCV 5min, 4: VCV 10min, 5: VCV 15min, 6: VCV 20min, 7:PCV baseline, 8:PCV 5min, 9:PCV 10min, 10:PCV 15min, 11:PCV 20min)

VCV: volume-controlled ventilation, PCV: pressure-controlled ventilation, min: minute, PVI: Pleth Variability Index, PI: Perfusion Index, rSO₂: Regional Cerebral Oxygen Saturation

The use of PVI during spontaneous breathing is often questioned, as low and variable tidal volumes do not create as stable an interaction between respiration and circulation as during controlled positive pressure ventilation (15). While its use is validated under controlled mechanical ventilation with adequate tidal volumes, evidence is lacking regarding

its reliability across different ventilatory strategies. In our study, preoperative PVI was higher than subsequent intraoperative measurements, and a significant increase was observed during VCV at the 10th minute. PVI has been well validated for predicting fluid responsiveness in mechanically ventilated patients in both the operating theatre and

the ICU. The PVI can be relied upon to predict fluid responsiveness, provided that intrathoracic pressure changes are sufficiently pronounced and that cardiopulmonary interactions between respiratory cycles remain stable (16). However, to our knowledge, no study has been conducted to determine which mode is more effective. In this regard, our article may be the first in its field. We can explain the increase in our findings as follows: at high lung volumes, the heart is compressed in the cardiac fossa in a manner similar to cardiac tamponade. As lung volume increases, the pressure difference between airway and pleural pressure also increases. When this pressure difference exceeds pulmonary artery pressure, the pulmonary vessels collapse as they transition from the pulmonary arteries to the alveolar space, thereby increasing pulmonary vascular resistance. Hyperinflation impedes right ventricular ejection by increasing pulmonary vascular resistance. This may explain the pressure increase according to the mode (17).

rSO₂, measured non-invasively via NIRS, is a valuable real-time marker of cerebral oxygenation and is increasingly applied to guide intraoperative management. rSO₂ guides the prevention and reduction of cerebral ischemia and hypoxia damage in real time and plays a guiding role in anaesthesia management during the operation (18). More studies have been conducted on children or newborns rather than adults regarding how rSO₂ will be influenced by the ventilation modes. In a randomized controlled study on newborns, 30 newborns scheduled for video-assisted thoracoscopic surgery (VATS) for management of tracheoesophageal fistula (TEF) under general anaesthesia were randomized to the VC group (n = 15) receiving VCV or the PC group (n = 15) receiving PCV. rSO₂ was monitored throughout the surgery by documenting episodes of cerebral desaturation. rSO₂ was significantly higher in the PC group than in the VC group at the baseline and was significantly higher in the VC group after 15 minutes (P = 0.041). As a result, VCV was found to be safer than PCV in terms of cerebral oxygenation during VATS in newborns (19). In another study, conducted on premature babies with Respiratory Distress Syndrome (RDS) and very low birth weight (VLBW), the patients were ventilated in pressure-controlled assist control (PC-AC) mode for 3 hours, and this was followed by 3 hours of volume guaranteed assist control ventilation (VG-AC) and as a result, in terms of rSO₂, it has been stated that the VG mode is more stable than PC ventilation during VG and its use should be supported in premature babies (20). In our study, left-sided rSO₂ values were higher at baseline compared to later measurements, whereas right-sided baseline values were lower than subsequent recordings. These changes, however, remained within a 10% margin, suggesting clinically modest variations.

Limitations

This study has several limitations. First, it was conducted as a single-centre trial, which may restrict the generalizability of the findings. Second, haemoglobin concentration was not

measured. Although blood loss during septorhinoplasty is usually minimal, the absence of Hb monitoring may have limited the interpretation of rSO₂ results. Third, the findings obtained from surgical cases lasting as little as 40 minutes may be insufficient for generalisation. The other is, the potential cardiac depressant effects of a short-acting agent such as propofol could have affected the measurements obtained during the initial 20 minutes of VCV. Conducting research on longer surgical procedures in different patient groups could have provided more robust and generalizable findings for the study. Additionally, in future studies, various perioperative factors such as room temperature, patient warming methods, the use of vasopressors or epinephrine-containing solutions, and intraoperative fluid management should be considered as they may affect PI, PVI, and even rSO₂.

Conclusions

In this prospective study comparing two ventilation modes during septorhinoplasty, preoperative PI values were significantly lower than intraoperative measurements, while preoperative PVI values were higher, with a notable increase observed at the 10th minute of volume-controlled ventilation. Left-sided rSO₂ was higher at baseline, whereas right-sided rSO₂ was initially lower compared to subsequent recordings. Despite these variations, overall fluctuations remained within a clinically acceptable range. Importantly, HR, PI, PVI, SpO₂, NIBP, and rSO₂ values obtained under VCV and PCV were not interchangeable. Transitioning from volume-controlled to pressure-controlled ventilation did not result in consistent or clinically significant differences across these parameters.

Ethical Approval: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Harran University (Date: 29.06.2020; decision number: HRU/20.12.17).

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Writing manuscript: A.K., M.A.K.

Critical revision of manuscript: A.K, M.A.K, T.B.T, Z.A., M.T.

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