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ORIGINAL RESEARCH / *ÖZGÜN ARAŞTIRMA*

İclal Doruk,
Kubilay Demirağ,
Mehmet Uyar

Does Tube Resistance Compensation Change Metabolic Parameters When Added to Pressure Support Mode During Weaning?

Weaning Sürecinde Basınç Destekli Ventilasyon Moduna Tüp Direnci Kompanzasyonu Eklenmesi Metabolik Parametreleri Değiştirir mi?

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İclal Doruk, Kubilay Demirağ, Mehmet Uyar
Ege University Faculty of Medicine, Department of Anesthesiology and Reanimation, Division of Intensive Care, İzmir, Turkey

İclal Doruk (✉),
Ege University Faculty of Medicine, Department of Anesthesiology and Reanimation, Division of Intensive Care, İzmir, Turkey

E-mail : iclalkaraca83@gmail.com
Phone : +90 532 506 31 07
ORCID ID : orcid.org/0000-0002-3341-7641

ABSTRACT *Objective:* We postulated that adding tube resistance compensation (TRC) to pressure support ventilation (PSV) would have beneficial effects on metabolic parameters in patients scheduled for weaning. Here, the PSV and PSV + TRC were compared by measuring oxygen consumption (VO_2), energy expenditure (EE), and carbon dioxide production (VCO_2).
Materials and Methods: This was a prospective, randomised, crossover study. Seventy-eight adult patients were randomised to receive either PSV or PSV + TRC. Group 1 consisted of patients that started with PSV initially and then switched to PSV + TRC, whereas group 2 first received PSV + TRC and then switched to PSV. After 30 minutes (min) of monitoring and stabilization, an indirect calorimeter was connected and metabolic parameters measurement was taken every 5 min for 30 minutes, and the last measurement values were recorded at the 30th min. The patient was then switched to the second treatment mode, and the procedure was repeated.
Results: TRC + PSV ventilation had no clinical effects on metabolic parameters compared with PSV (EE, 1746 vs. 1763, respectively; VO_2, 255 vs. 260, respectively; VCO_2, 206 vs. 208, respectively; all $p>0.05$).
Conclusion: Adding TRC to PSV did not cause any changes in gas exchange, haemodynamic variables, or metabolic parameters in patients for weaning.
Keywords: Indirect calorimetry, pressure support ventilation, tube resistance compensation, work of breathing

ÖZ *Amaç:* Çalışmamızda weaning planlanan hastalarda basınç destekli ventilasyon moduna (PSV) tüp direnci kompanzasyonu (TRC) eklenmesinin metabolik parametreler üzerinde etkilerinin araştırılması amaçlanmıştır. PSV ve PSV + TRC modları, oksijen tüketimi (VO_2), enerji tüketimi (ET) ve karbondioksit üretimi (VCO_2) ölçülerek karşılaştırıldı.
Gereç ve Yöntem: Çalışmamız prospektif, randomize, crossover bir çalışmadır. Yetmiş sekiz yetişkin hasta başlangıç ventilasyon modları PSV veya PSV + TRC modu olmak üzere randomize edildi. Grup 1 PSV modu ile ventilasyona başlanan daha sonra PSV + TRC modunda ventilasyona devam edilen hastalardan, grup 2 ise önce PSV + TRC modu ile ventile edilen daha sonra PSV modu ile ventilasyona devam edilen hastalardan oluştu. Otuz dakikalık (dk) monitorizasyon ve stabilizasyonun ardından indirekt kalorimetre bağlanarak 30 dk boyunca 5 dk bir metabolik parametre ölçümü yapıldı ve son ölçüm değerleri 30. dk'de kaydedildi. Hasta daha sonra ikinci tedavi moduna geçildi ve işlem tekrarlandı.
Bulgular: PSV + TRC modu ile ventilasyonun, PSV modu ile karşılaştırıldığında metabolik parametreler üzerinde hiçbir klinik etkisi olmamıştır (sırasıyla ET; 1746, 1763, VO_2; 255, 260, VCO_2; 206, 208; tümü $p>0,05$).
Sonuç: PSV moduna TRC eklenmesi, weaning hastalarında gaz değişimi, hemodinamik değişkenler veya metabolik parametrelerde herhangi bir değişikliğe neden olmadı.
Anahtar Kelimeler: İndirekt kalorimetre, basınç destekli ventilasyon, tüp direnç kompanzasyonu, solunum işi

Introduction

Weaning is introduced to decrease the duration of mechanical ventilation and should be initiated as early as possible following elimination of the reasons for acute respiratory failure (1). One of the most important causes of weaning failure is imbalance between respiratory muscle capacity and respiratory workload against the resistance caused by the artificial airway (2). The rate of successful extubation can be increased by decreasing the work of breathing caused by the intubation tube [additional work of breathing (WOBadd)] (3).

Several ventilation modes may be used during weaning, one of the most common of which is pressure support ventilation (PSV) (4). Although the PSV mode has been reported to decrease the work of breathing by reducing resistance due to the artificial airway at pressure support (PS) levels appropriate for the respiratory requirements in the patient (5), this mode has some limitations. Work of breathing caused by the artificial airway is due to the diameter and length of the endotracheal tube, as well as the effort of the patient (6). WOBadd increases as minute (min) ventilation demand increases (6). The flow pattern is variable during each breath and WOB cannot be compensated by constant PS (7). Therefore, PSV mode leads to discomfort in patients because it cannot continuously adjust to changes in the resistance caused by changes in the inspiratory flow of the patient and, thus, provides a suboptimal decrease in the work of breathing (8).

Tube resistance compensation (TRC) [also known as automatic tube compensation (ATC)] has been developed to address this problem and to improve the weaning process (9). This method compensates for the pressure changes due to flow during inspiration and expiration through the continuously calculated tracheal pressure (7). In ventilators with the TRC feature, the pressure changes due to flow through the endotracheal tube is automatically compensated and the WOBadd is reduced (9).

A few studies recognised the reduction in work of breathing as a reduction in oxygen consumption and demonstrated that indirect calorimetry is a suitable bedside method to measure these parameters (10,11). In addition, many studies have evaluated the effects of mechanical ventilation modes on the metabolic parameters by measuring oxygen consumption (VO_2), energy expenditure (EE), and carbon dioxide production (VCO_2) using indirect calorimetry (12-14).

In the present study, we thought that adding TRC to PSV mode would have beneficial effects on metabolic parameters (VO_2, VCO_2, EE) in patients scheduled for weaning. Here we hypothesized that adding TRC to PSV mode would reduce VO_2 and reduce VCO_2 and EE. Therefore, in our study, PSV and PSV + TRC modes were compared by measuring VO_2, VCO_2 and EE by indirect calorimetry.

Materials and Methods

This prospective, randomised, crossover study was conducted in a mixed intensive care unit of a university hospital after receiving approval from the Ege University Clinical Research Ethics Committee (decision no: 14-9.2/6, date: 07.11.2014). The study population consisted of 78 adult patients after obtaining written informed consent from their relatives. According to the protocol of our clinic, patients with hemodynamic and respiratory stable, inspiratory PS below 10 cmH_20, positive end-expiratory pressure: 5-8 cmH_2O and fraction of inspired oxygen (FiO_2) level 40% and below, core body temperature <38 °C were considered to be ready for weaning. Patients who met the weaning criteria, had mechanical ventilation for more than 24 hours, had hemodynamic and respiratory stability, had hemoglobin >8 g/dL and core body temperature <38 °C were included in the study.

Patients with a respiratory rate (RR) >35 min-1, asynchrony with the ventilator, core body temperature >38 °C, SpO_2<90%, PaO_2<60 mmHg, $PaCO_2$>50 mmHg, or haemodynamic instability were excluded from the study.

The patients were randomised to receive either PSV or PSV with TRC (PSV + TRC) (Hamilton Raphael or Hamilton-G5; Hamilton, Rhazuns, Switzerland). Group 1 consisted of patients started with PSV mode initially followed by switching to PSV + TRC, whereas group 2 initially received PSV + TRC and were then switched to PSV. After a 30 min stabilisation period and normalisation of blood gas values, measurements were made using an indirect calorimetry device (Metabolic Monitor; Datex Ohmeda, Helsinki, Finland). VO_2, VCO_2, and EE were recorded after 30 min. The patient was then switched to the other mode and the same procedure was repeated.

Group 1 patients were followed with PSV mode for 30 min and after stabilization was achieved, they were connected to the indirect calorimeter and metabolic parameters were measured every 5 min for 30 min, and the last 30th min measurement values were recorded. Then, PSV + TRC mode was started. After 30 min of monitoring and stabilization, an indirect calorimeter was connected and metabolic parameters measurement was taken every 5 min for 30 min, and the last measurement values were recorded at the 30th min.

Group 2 patients were followed with PSV + TRC mode for 30 min and after stabilization was achieved, they were connected to the indirect calorimeter and metabolic parameters measurements were taken every 5 min for 30 min, and the measurement values were recorded at 30 min. Then, PSV mode was started. After 30 min of monitoring and stabilization, an indirect calorimeter was connected and metabolic parameters measurement was taken every 5 min for 30 min, and the last metabolic parameters measurement values were recorded at the 30th min.

During the entire study period, RR, heart rate (HR), mean arterial pressure (MAP), oxygen saturation (SPO_2), tidal volume (Vt), peak airway pressure (Ppeak), and PS level were recorded every 10 min, and pH, partial arterial oxygen pressure (PaO_2), partial arterial carbon dioxide pressure ($PaCO_2$), and base excess and bicarbonate (HCO_3) levels were measured and recorded at 30 min intervals following the baseline measurements.

No interventions, such as tracheal aspiration, positioning, or wound dressing, were performed over the course of the study period. If any intervention was required, the measurement was terminated, and the procedure was repeated from the beginning when the patient was in a suitable condition.

Statistical Analysis

The data were evaluated by the Biostatistics and Medical Information Department of University Hospital. Demographic and clinical data were evaluated using the chi-square test. Metabolic, haemodynamic, respiratory parameters, and blood gas analysis results were compared using the paired t-test. In all analyses, $p<0.05$ was taken to indicate statistical significance.

Results

Seventy eight patients were selected for the study. The mean age, the mean acute physiology and chronic health evaluation-II score were 54.8±21.6 years and 20.7±6.5.

The demographic and clinical data of the patients are listed in Table 1.

Table 1. Demographic and clinical data of the patients

Variables	Values
Male, n (%)	49 (62.8%)
Female, n (%)	29 (37.2%)
Age (years) (mean ± SD)	54.8±21.6
APACHE-II score (mean ± SD)	20.7±6.5
Ideal body weight (kg) (mean ± SD)	64.4±9.07
Size of endotracheal tube, n (%)	7 (2, 2.69%) 7.5 (24, 30.8%) 8 (51, 65.4%) 9 (1, 1.3%)
PaO_2/FiO_2 (mmHg)	312.4±81.62

SD: Standard deviation, APACHE-II: acute physiology and chronic health evaluation-II

Table 2. Reasons for mechanical ventilation

Reasons for mechanical ventilation	Values
Postoperative, n (%)	20 (25, 6%)
Trauma, n (%)	16 (20, 5%)
Cardiovascular, n (%)	6 (7, 7%)
Gastrointestinal, n (%)	4 (5, 1%)
Respiratory, n (%)	5 (6, 4%)
Anoxic coma, n (%)	2 (2, 6%)
Hematological, n (%)	1 (1, 3%)
Neurological, n (%)	13 (16, 7%)
Others, n (%)	11 (14, 7%)

The most common reason for mechanical ventilator support was postoperative respiratory failure (Table 2).

There were no statistically significant differences in metabolic parameters (VO_2, VCO_2, and EE) between PSV and PSV + TRC periods in either group 1 or 2 ($p>0.05$) (Figure 1).

There were no statistically significant differences in metabolic parameters (VO_2, VCO_2, and EE) between PSV and PSV + TRC periods in group 1 ($p>0.05$) (Figure 2).

There were no statistically significant differences in metabolic parameters (VO_2, VCO_2, and EE) between PSV and PSV + TRC periods in group 2 ($p>0.05$) (Figure 3).

There were no significant differences in metabolic parameters, HR, MAP, Ppeak, Vt, RR, SPO_2 or blood gas values between the PSV and PSV + TRC periods ($p>0.05$) (Table 3).

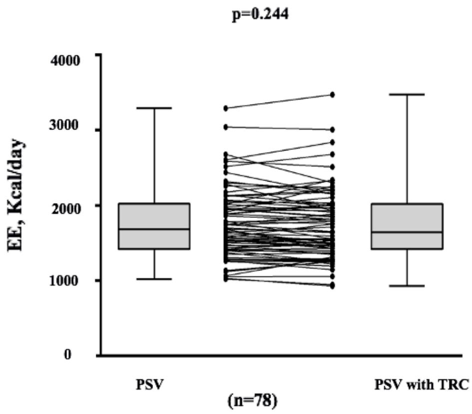

Figure 1a. There were no statistically significant energy expenditure (EE) between PSV and PSV + TRC periods in either group 1 or 2 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

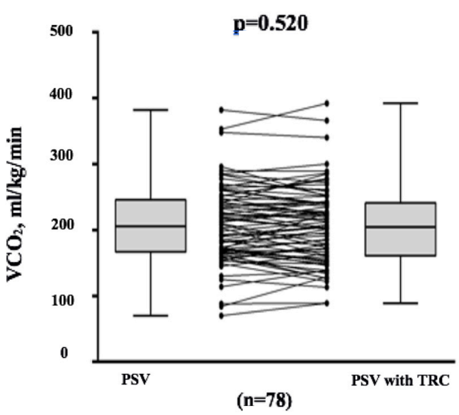

Figure 1b. There were no statistically significant carbon dioxide production (VCO_2) between PSV and PSV + TRC periods in either group 1 or 2 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

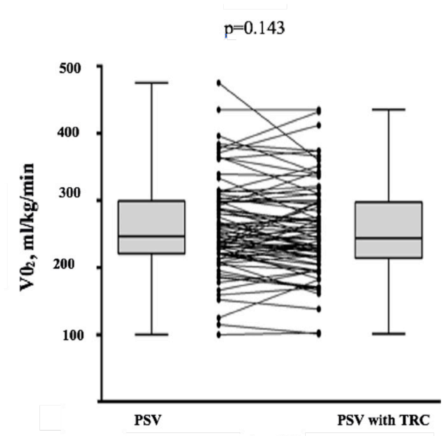

Figure 1c. There were no statistically significant oxygen consumption (VO_2) between PSV and PSV + TRC periods in either group 1 or 2 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

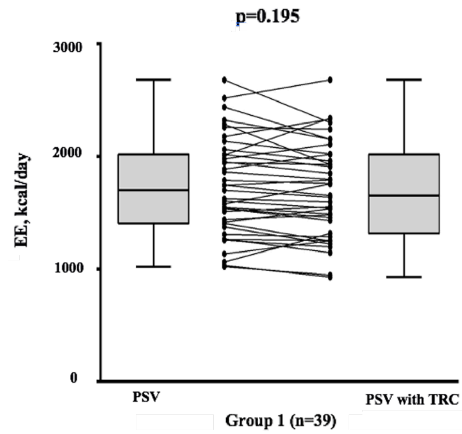

Figure 2a. There were no statistically significant differences energy expenditure (EE) between PSV and PSV + TRC periods in group 1 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

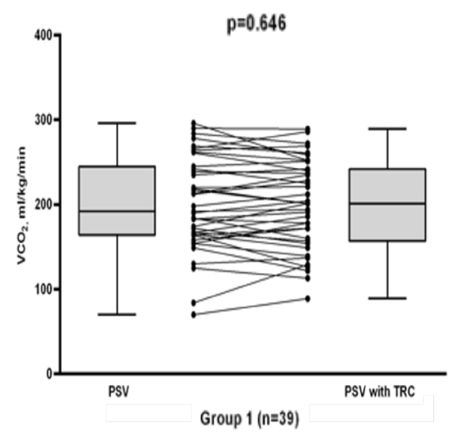

Figure 2b. There were no statistically significant differences carbon dioxide production (VCO_2) between PSV and PSV + TRC periods in group 1 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

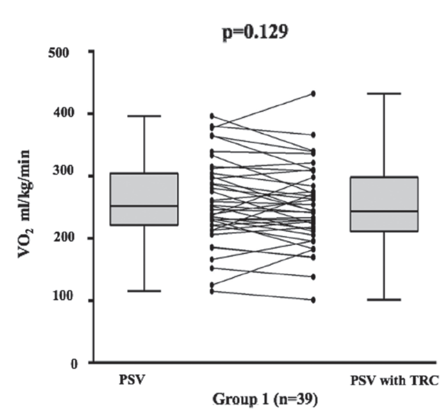

Figure 2c. There were no statistically significant differences oxygen consumption (VO_2) between PSV and PSV + TRC periods in group 1 ($p>0.05$)
PSV: Pressure support ventilation, TRC: tube resistance compensation

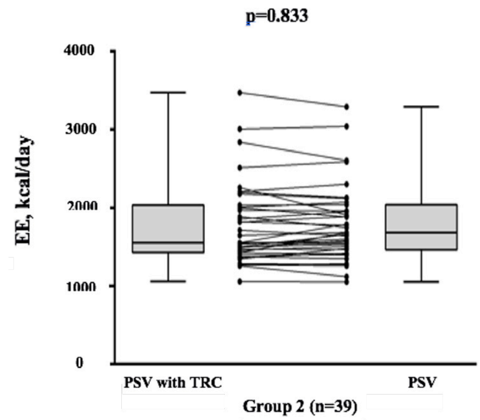

Figure 3a. There were no statistically significant energy expenditure (EE) between PSV and PSV + TRC periods in group 2 (p>0.05)
PSV: Pressure support ventilation, TRC: tube resistance compensation

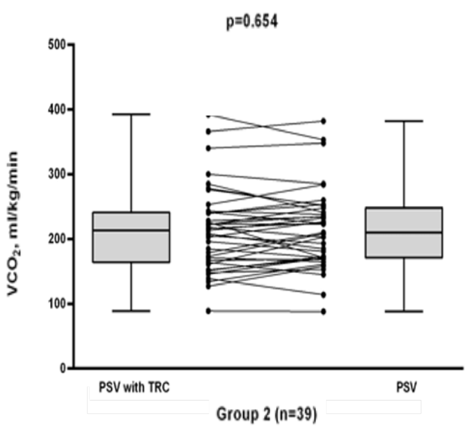

Figure 3b. There were no statistically significant differences carbon dioxide production (VCO_2) between PSV and PSV + TRC periods in group 2 (p>0.05)
PSV: Pressure support ventilation, TRC: tube resistance compensation

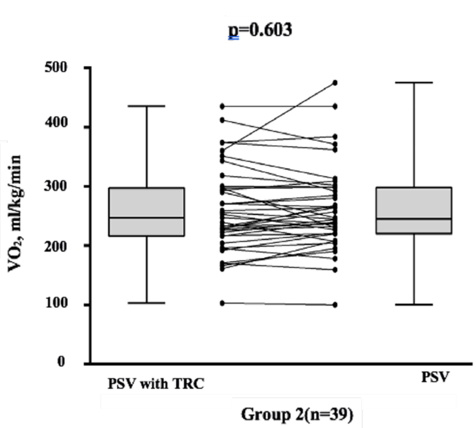

Figure 3c. There were no statistically significant oxygen consumption (VO_2) between PSV and PSV + TRC periods in group 2 (p>0.05)
PSV: Pressure support ventilation, TRC: tube resistance compensation

Table 3. Parameters measured during the PSV and PSV with TRC period

Variables	PSV (n=78)	PSV with TRC (n=78)	p-value
EE, (kcal/day) mean ± SD	1763.9±464.9	1746.3±476.9	0.24
VO_2, (mL/kg/min) mean ± SD	260.4±69.9	255.1±68.8	0.14
VCO_2, (mL/kg/min) mean ± SD	208±58.4	206.4±59.1	0.52
Vt, (mL) mean ± SD	437.5±101.6	437.1±103.9	0.87
RR, (breaths/min) mean ± SD	21.2±4.35	21.3±4.49	0.32
MAP, (mmHg) mean ± SD	79.1±10.3	78.9±10.7	0.55
HR, (beats/min) mean ± SD	90.5±18.3	90.4±18.08	0.76
SPO_2, (%) mean ± SD	96.6±1.5	96.7±1.57	0.26
Peak pressure, (cmH_2O) mean ± SD	16.6±3.59	16.7±3.5	0.48
pH, mean ± SD	7.47±0.04	7.47±0.04	0.85
PO_2, (mmHg) mean ± SD	93.4±23.7	93.1±23.8	0.76
PCO_2, (mmHg) mean ± SD	36.8±5.3	36.9±5.1	0.16
HCO_3, (mmol/L) mean ± SD	26.4±3.3	26.7±3.4	0.05
BE, (mmol/L) mean ± SD	3.4±4.2	3.3±4.2	0.22
FiO_2 (%) mean ± SD	37.6±3.3	37.5±3.4	0.15
VE (L/min) mean ± SD	8.7±1.3	8.6±1.5	0.76
PEEP (cmH_2O) mean ± SD	5.8±1.2	5.6±1.3	0.45

VO_2: Oxygen consumption, EE: energy expenditure, VCO_2: carbon dioxide production, HR: heart rate, MAP: mean arterial pressure, SPO_2: peripheral oxygen saturation, Vt: tidal volume, FiO_2: fraction of inspired oxygen, VE: minute ventilation, PEEP: positive end expiratory pressure, RR: respiratory rate, PaO_2: partial arterial oxygen pressure, $PaCO_2$: partial arterial carbondioxide pressure, SD: standard deviation, PSV: pressure support ventilation, TRC: tube resistance compensation

Discussion

In the present study, adding TRC to the PSV mode did not change the metabolic parameters in patients during the study period. Fabry et al. (9) investigated WOB imposed by the endotracheal tube (WOBadd) in the ATC and PSV mode with different PS in two populations of patients during intubated spontaneous respiration. Imposed WOB was compensated with ATC and PSV settings of 10-15 cmH_2O in the postoperative patients without pulmonary injury (min ventilation 7.6±1.7 L/min), whereas PSV of 5 cmH_2O did not compensate for WOB. In severely ill patients with increased respiratory demand (min ventilation, 16.8±3.0 L/min), WOBadd increased significantly and none of the PSV levels could compensate for the WOB. It was noted that imposed WOB (WOBadd) could be compensated only by ATC. The patients included in the present study had min ventilation <10 L/min. Adding TRC to PSV did not significantly reduce these metabolic parameters. Therefore, we assumed that the effect of TRC on WOBadd was negligible in patients requiring low min ventilation.

Oczenski et al. (15) compared the effects of PSV, continuous positive airway pressure (CPAP), and CPAP with ATC on the oxygen consumption and respiratory pattern by measuring VO_2 with indirect calorimetry in 21 post-cardiac operation patients with normal ventilatory demand without pulmonary disease. There were no significant differences among the groups in oxygen consumption, respiratory pattern (Vt, RR), blood gas values, or haemodynamic parameters. They concluded that the clinical effect of the presumed benefits of ATC was low in patients with no increased ventilatory demand.

Lagoa et al. (12) randomised 40 mechanically ventilated intensive care patients into two groups in a prospective, randomised, crossover study. One group was ventilated in ATC with CPAP mode first and then only in CPAP mode, while the other group was ventilated in CPAP first and then in CPAP with ATC mode. Metabolic parameters were then measured by indirect calorimetry for 30 min. The researchers noted that there were no significant differences in the VO_2, EE, or VCO_2 values of the patients measured during the period with and without ATC.

In the present study, we compared the effects of TRC mode on metabolic parameters by measuring VO_2, VCO_2, and EE values by indirect calorimetry and found that TRC had no statistically significant effects on these parameters. The duration of measurement by indirect calorimetry was 30 min in the present study. We believe that our sample size was sufficient compared to other studies. In addition, although our primary aim was not to investigate the effects of TRC on haemodynamic and respiratory parameters, we did not find significant differences in these parameters between the periods with and without TRC.

We did not evaluate WOB directly or use the pressure-time product related to oxygen consumption by the respiratory muscles. Instead, we evaluated WOB indirectly by calorimetry to estimate oxygen consumption of the body as a whole.

In addition, the limitation of our study is that power analysis was not performed to determine the number of the study population.

Conclusion

In conclusion, adding TRC to the PSV mode did not cause any changes in metabolic parameters in patients scheduled for weaning.

Ethics

Ethics Committee Approval: This prospective, randomised, crossover study was conducted in a mixed intensive care unit of a university hospital after receiving approval from the Ege University Clinical Research Ethics Committee (decision no: 14-9.2/6, date: 07.11.2014).

Informed Consent: The study population consisted of 78 adult patients after obtaining written informed consent from their relatives.

Authorship Contributions

Surgical and Medical Practices: İ.D., Concept: K.D., M.U., Design: K.D., M.U., Data Collection and Process: İ.D., Analysis or Interpretation: İ.D., Literature Search: İ.D., Writing: İ.D.

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

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