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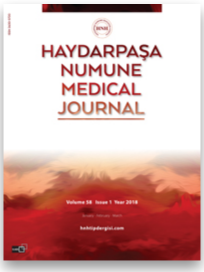

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ORIGINAL ARTICLE

Effects of Prone and Semi-recumbent Position on Abdominal Pressure, Hemodynamics, and Alveolar Oxygenation in Acute Lung Injury (ALI) and Acute Respiratory Distress Syndrome (ARDS) Patients

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Abstract

Introduction: Although intra-abdominal pressure (IAP) increases during prone and semi-recumbent positions, these positions are included in the treatment protocols for patients with Acute Lung Injury (ALI) and Adult Acute Respiratory Distress Syndrome (ARDS).

The aim of the study was to determine the effects of prone and semi-recumbent positions on hemodynamic, ventilatory, and blood gas parameters by IAP elevation.

Methods: After ethics committee approval, the patients (aged 18-60 years) diagnosed with ALI-ARDS according to the American-European consensus were enrolled. Hemodynamic and IAP monitoring were performed with central venous and femoral artery and urinary catheters.

Patients were intubated and mechanically ventilated. Ventilatory mode (adjusted based on blood gas analyses), sedation, and feeding protocols were the same. SOFA, LIS, and APACHE II scores, CVP, IAP, Ppeak, Pmean, VTe, Cdyn, HR, MAP, CI, EVLWI (Pulsion PiCCO), pH, $PaCO_2$, and PaO_2/FiO_2 were measured. Measurement time points: T1 (baseline-supine position), T2, T3 (prone position, 60., 120. minute), T4, T5 (semi-recumbent position, 60., 120. minute).

Results: The study was performed in 15 patients without abdominal support. Oxygenation and IAP were significantly increased in all positions. A significant increase in oxygenation was detected by decreasing EVLWI at T3. A significant decrease in $PaCO_2$ was observed by increasing VTe at T2 and T3, in heart rate at T3, in MAP at T2, and in CI at T4, without any hemodynamic deterioration.

Discussion and Conclusion: Prone and semi-recumbent positions could be used in ARDS to improve oxygenation without unfavorable hemodynamic effects. Our study may provide a protocol for larger studies evaluating prolonged prone and semi-recumbent positions.

Keywords: Alveolar oxygenation; ARDS; intraabdominal pressure; prone position; semi-recumbent position.

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Acute Lung Injury (ALI) and Adult Acute Respiratory Distress Syndrome (ARDS) is a condition with poor prognosis commonly encountered in the intensive care unit (ICU), which has a progressive clinical course starting with moderate pulmonary dysfunction and can lead to fatal lung failure. The incidence is 64.2 to 78.9 cases/100,000 person-years. Mortality is high, ranging from 9% to 75%. ARDS is characterized by pulmonary capillary endothelial and alveolar epithelial dysfunction, interstitial pulmonary edema, bilateral diffuse pulmonary infiltrates, decreased compliance, and impaired oxygen transport. The diagnosis is made on the basis of acute onset (<7 days), evidence of non-cardiogenic pulmonary edema, high concentration of inspired oxygen to maintain an acceptable partial oxygen pressure (PaO_2), severe hypoxemia requiring positive end-expiratory pressure (PEEP) (refractory hypoxemia), and PaO_2/FiO_2 (Harovitz ratio; ratio of partial oxygen pressure to fraction of inspired oxygen; mmHg): $PaO_2/FiO_2<300$: ALI; mild ARDS, PaO2/FiO2<200: moderate ARDS, and $PaO_2/FiO_2<100$: severe ARDS [1-3].

The primary goals of management are to treat hypoxemia, improve alveolar oxygenation without causing additional lung injury, identify predisposing factors early, and treat the underlying disease. In lung failure, improved oxygenation with prone positioning was first reported in 1976 [4]. This finding was confirmed in subsequent studies using prone positioning in patients with ALI/ARDS, with benefits reported in 50% to 75% of patients, both in the early and late phases [1,5,6-10].

The change in patient position improved oxygenation by reducing atelectasis and restoring ventilation-perfusion distribution. Thus, the use of prone and semi-recumbent positions in patients with ALI and ARDS has become increasingly common [1,5,11].

The only contraindications to prone positioning are spinal instability and pregnancy. However, the increase in intra-abdominal pressure (IAP) during prone positioning may lead to additional organ dysfunction in critically ill patients. Normal IAP is 5-7 mmHg. IAP elevation >12 mmHg causes intra-abdominal hypertension (IAH). There are complex interactions between elevated IAP and thoracic or intracranial pressure or hemodynamic status. Systemic effects of elevated IAP include increased intracranial pressure; decreased ventilation, oxygenation, and compliance; and decreased cardiac output (CO). The level of IAP that causes these effects varies depending on the clinical status of the patient [12,13].

The objective of our study was to measure IAP in mechanically ventilated patients diagnosed with ALI and ARDS in both prone and semi-recumbent positions. Additionally, we aimed to evaluate the effects of these positions on cardiovascular function, hemodynamics, oxygenation, respiratory dynamics, and blood gas values.

Materials and Methods

This study was conducted in accordance with the Declaration of Helsinki after receiving approval from the Ethics Committee (Health Science University Haydarpaşa Numune Training and Research Hospital Medical Ethics Committee with the decision no: 06-277/01/06/2006). Written informed consent was obtained from the patients' relatives.

The study was cross-sectional, controlled, observational, and prospective, and it involved patients aged 18-60 years who were diagnosed with ALI-ARDS according to the American-European Consensus Conference [3]. Excluded from the study were patients with a history of intra-abdominal, femoropopliteal bypass, or thoracic surgery, spinal instability, pregnancy, hemodynamic instability (receiving high-dose/double vasoactive support), renal/hepatic/cardiac failure, sepsis, restrictive or obstructive pulmonary disease, pneumothorax, massive pleural effusion, elevated intracranial pressure, or those who could not provide consent.

Patients were enrolled within 24 hours of ALI-ARDS diagnosis.

Power analysis was performed in line with the reference study [6]. Fifteen patients were planned to be included in the study (Standard Effect Size was determined as 1.08 with 5% Margin of Error and 85% Power. G* power 3.1 program) [7]. Patients who met the study criteria within the specified time interval (6 months) were included in the study.

All patients were intubated with a cuffed endotracheal tube (#7.5-8.0) and placed on mechanical ventilation (Servo-Maquet, Sweden). The same mode of ventilatory support (pressure-cycled ventilation-IPPV) with a lung protection strategy [14], sedation-curarization protocol (with BIS value of 40-60), and feeding protocol was used in all patients. No changes were made in PEEP, respiratory rate, or other respiratory parameters set on the basis of blood gas values throughout the study. It was planned to exclude patients if the ventilator mode, fluid resuscitation protocol, or vasoactive agent dose was changed.

Vasoactive agents were titrated to maintain MAP>60 mmHg.

Hemodynamic measurements were performed with a CVP catheter (through the right jugular vein or right subclavian vein) and a femoral artery cannula (through the right or left femoral artery) using the Pulsion PiCCO device. A Foley catheter (14-to-16 Fr) was inserted to monitor urine output.

PiCCO Measurements: Pulsion PiCCO (Pulsion COLD Z-021)

As a pulmonary dilution technique (transpulmonary indicator dilution), temperature changes were recorded by a cold indicator injected via a central line (via Swan Ganz catheter) and a catheter with a thermal sensor (4-F FT Pulsiocath PV 2014L16; Pulsion Medical Systems, Munich, Germany) placed in the femoral artery. Height, estimated body weight, and CVP data were entered into the Pulsion PiCCO device. Measurements were made using the Stewart Hamilton formula. CO was measured, and specific volume index and EVLWI were calculated by the device. For each measurement, after calibration, the cold indicator (0.9% NaCl; <8°C; 15 mL over 5 seconds) was injected into the right atrium via the central venous line. A thermodilution slope was obtained. At least 3 consecutive measurements were performed; the mean value was printed.

Respiratory measurements were simultaneously recorded on a ventilator screen.

Intra-abdominal pressure was measured with an indwelling transurethral catheter. Before measurement, the bladder was emptied by suprapubic pressure. Then, 100 cc of normal saline was instilled into the bladder through the urinary catheter in a sterile manner, and a manometer was placed on the catheter tip after clamping. Measurements were taken with the pubic bone as the zero point.

Systemic arterial blood samples were taken within 3 minutes after hemodynamic measurements and studied in the blood gas analyzer (ABL 800 Flex Denmark-Radiometer Medical A/S) in the intensive care unit.

Data Collection

CVP (mmHg), IAP (cmH_2O), peak pressure (Ppeak; cmH_2O), mean airway pressure (Pmean; cmH_2O), expiratory tidal volume (VTe; mL), dynamic compliance (Cdyn; mL/cmH_2O), heart rate (HR; beats per minute), mean arterial pressure (MAP; mmHg), cardiac index (CI; $L/min/m^2$), extravascular lung water index (EVLWI), pH (log H+ concentration), $PaCO_2$ (partial pressure of carbon dioxide; mmHg), PaO_2/FiO_2 (Harovitz ratio; mmHg).

In all patients, measurements were performed at 5 different time points: T1 (baseline); measurement was performed in the supine position, T2; measurement was performed 60 minutes after placing the patient in the prone position, T3; measurement was performed 120 minutes after placing the patient in the prone position, T4; the patient was placed in the supine and semi-recumbent position after 60 minutes to allow stabilization, measurement was performed thereafter (at minute 60 after placing the patient in the semi-recumbent position), T5; measurement was performed 120 minutes after placing the patient in the semi-recumbent position. Measurements at T2, T3, T4, and T5 were compared with the baseline measurement (T1); in addition, comparisons were made between T2 and T3 and between T4 and T5.

Patient Positioning:

1. Prone position: The patient is placed in the prone position in 2 steps. First, the patient is placed in the lateral position, facing the contralateral side of the bed; in the second step, they are placed in the prone position.

During positioning, at least one experienced physician and two nurses should be available; one must be responsible for protecting the airway, eyes, and vascular lines. All should be checked before and after positioning.

Non-physiologic movement of the upper extremities should not be allowed; the upper extremities should be in a neutral position (parallel to the body); immediate repositioning may be required if serious compromise of cardiopulmonary parameters occurs. No abdominal padding is used. Routine muscle relaxants are not used.

2. Semi-recumbent (upright) position: Head of bed elevated to 45°; padding placed under knees and upper extremities, and the patient placed in anatomical position. During positioning, all hemodynamic parameters were monitored invasively.

Dislodgement of the endotracheal tube and catheters (urinary, CVP, femoral artery), hypotension, bradycardia, bronchospasm, impaired respiratory parameters (decrease in saturation and increase in PaCO2), and decubitus ulcers due to position were identified and recorded as complications during prone and semi-recumbent positioning.

Scoring systems used: APACHE II, LIS, SOFA [15-17].

Statistical Analyses

All statistical analyses were performed using SPSS (Statistical Package for Social Sciences) for Windows, version 10.0. Descriptive statistics were used to analyze the data. Normal data distribution was tested using the Kolmogorov-Smirnov test. Repeated measure ANOVA test was used to compare parameters within groups. Pearson's correlation analysis was used to evaluate associations between parameters. The results were assessed with a 95% confidence interval.

Table 1. Demographic characteristics, ventilatory days, total hospital stay and scores of patients.

Demographic data and scores	Mean±SD
Age (year)	39.33±13.46
Weight (kg)	7333±1047
Height (cm)	168.33±6.45
Ventilatory days (day)	12.53±7.99
Total Hospital stay (day)	12.93±9.06
LIS	2.85±0.35
Apache II	12.60±6.80
SOFA	7.73±1.71
GCS	13.26±2.98

The mean age, weight and height, mean duration of ventilatory days and total hospitalization, and mean LIS: lung injury score; APACHE II, SOFA: sequental organ failure score; GCS: Glascow coma scale; scores of study patients are shown (The data is normally distributed).

Results

There were 24 patients diagnosed with ALI/ARDS during the study period, 4 of them met exclusion criteria, and 5 patients were excluded due to changes in ventilator mode, fluid resuscitation protocol, or dose of vasoactive agent. A total of 15 patients were included in the study, comprising 7 women (46.7%) and 8 men (53.3%). There were no significant differences in demographic characteristics, ventilator days, total hospital stay, and APACHE II, LIS, SOFA, and GCS scores between patients (Table 1).

The mean values of PiCCO parameters, ventilator parameters, CVP, IAP, and blood gas analysis parameters at the specified time points are shown in Table 2.

There was a significant increase in IAP measurements at T2 compared to baseline (T1) ($p<0.01$); the increases remained significant at T3 ($p<0.01$). IAP measurements at T4 and T5 were found to be significantly higher than baseline values (T1) ($p<0.05$) (Table 3).

A significant decrease in HR was found at T3 compared to baseline (T1) ($p<0.05$), and a significant decrease in MAP was found at T2 ($p<0.05$) (Table 3).

No significant difference was observed in CI measurements (Table 4).

A significant increase in PaO_2/FiO_2 measurements was observed at T2 compared to baseline (T1) ($p<0.01$); PaO_2/FiO_2 continued to increase at T3 and remained significant

Table 2. The mean values of PICCO parameters, ventilator parameters, CVP, IAP, blood gas analysis parameters at the specified time points.

Parameteres	Basal Mean±SD	1 Mean±SD	2 Mean±SD	3 Mean±SD	4 Mean±SD
PICCO Parameters					
HR (Beats/min)	116.33±25.39	108.46±20.56	106.27±19.12	107.33±15.85	112.474-13.91
MBP (mmHg)	84.20±21.59	76.20±14.27	82.13±22.24	82.40±16.11	90.60±31.23
CI	4.51±1.33	4.37±1.29	4.29±1.10	3.96±1.02	4.16±1.16
EVLWI	9.4±3.89	8.8±5.49	9.53±5.5	8.67±3.06	9±3.18
Ventilator Parameters					
Ppeak (cmH_2O)	29.2±4.14	29.4±5.01	29.33±5.16	29.47±5.07	29.73±4.92
Pmean (cmH_2O)	17.0±3.87	16.73±4.38	16.53±4.36	16.47±3.96	16.47±4.15
Vte (ml)	521.27±106.35	528.07±72.22	514.53±81.69	528.13±83.97	509.07±101.07
Cdyn (ml/cmH_2O)	28.13±9.69	28.76±8.48	28.59±8.11	29.9±7.7	28.46±8.37
CVP (cmH_2O)	13.07±4.59	14±4.21	14.13±4.19	13.53±2.39	1.53±2.23
IAP (cmH_2O)	14±3.46	17.33±4.08	17.4±4.01	17.67±6.93	18.07±7.02
Blood Gases Parameters					
pH	7.39±0.06	7.40±0.06	7.39±0.07	7.38±0.07	7.38±0.07
$PaCO_2$ (mmHg)	48.83±12.07	46.98±12.41	47.52±13.16	48.87±14.48	49.36±13.84
PaO_2/FiO_2 (harovitz ratio)	127.90±35.89	175±55.22	179.81±58.9	153.6±34	151.39±37.15

Basal; T1-baseline, 1; T2: prone position-60th min, 2; T3: prone position-120th min, 3; T4: semi-recumbent position-60th min, 4; T5: semi-recumbent position-120th min. HR: heart rate; MBP: mean blood pressure; CI: cardiac index; EVLWI: extra vascular lung water index; Ppeak: peak pressure; Pmean: mean pressure; Cdyn: dynamic compliance; CVP: central venous pressure; IAP: intra abdominal pressure. The data is normally distributed).

Table 3. Assessment of changes in IAP, MAP and HR measurements at T2, T3, T4 and T5 compared to baseline (T1).

	IAP (cmH$_2$O) difference		MAP (mmHg) difference		HR (beat/min) difference	
	Mean±SD	**Result (t); p**	**Mean±SD**	**Result(t); p**	**Mean±SD**	**Result (t); p**
T1-T2	-3.33±2.16	t: -5.976; p:0.001**	8.00±12.77	t:2.427; p:0.029*	-12.13±77.62	t:-0.605; p:0.555
T1-T3	-3.40±1.96	t :-6.730; p:0.001**	2.07±10.69	t:0.749; p:0.467	7.86±10.79	t:2.822; p:0.014*
T1-T4	-3.67±5.80	t: -2.447; p:0.028*	1.80±14.100	t:0.465; p:0.649	9.00±20.68	t:1.685; p:0.114
T1-T5	-4.07±5.81	t:-2.710; p:0.017*	-6.40±17.74	t:-1.397; p:0.184	3.87±18.38	t:0.815; p:0.429
T2-T3	-0.07±0.46	t:-0.564; p:0.582	-5.93±12.79	t:-1.796; p:0.094	2.20±10.83	t:0.787; p:0.445
T4-T5	-0.40±0.74	t:-2.103; p:0.054	-8.20±26.77	t:-1.186; p:0.255	-5.13±10.79	t:-1.842; p:0.087

t: Paired samples t test **p<0.01 highly significant; *p<0.05, statistically significant (IAP: intra abdominal pressure, MAP: mean arterial pressure, HR: heart rate). It is seen that IAP increases in all time points compared to the basal measurement, and this increase is highly significant at T2-T3 and statistically significant at T4-T5. However, despite this increase in IAP, a statistically significant decrease was observed in MAP only in T2 and in HR in T3. This decrease did not create clinical significance.

Table 4. Assessment of changes in CI and PaO$_2$/FiO$_2$ measurements at T2, T3, T4 and T5 compared to baseline (T1).

	CI (L/min/m^2) difference		PaO$_2$/FiO$_2$ (mmHg) difference	
	Mean±SD	**Result (t); p**	**Mean±SD**	**Result (t); p**
T1-T2	0.14±0.43	t:1.285; p:0.220	-47.10±34.52	t: -5.285; p:0.001**
T1-T3	0.22±0.63	t:1.346; p:0.200	-51.91±39.75	t: -5.058; p:0.001**
T1-T4	0.56±0.79	t:2.736; p:0.016*	-25.70±41.63	t: -2.391; p:0.031*
T1-T5	0.35±0.75	t:1.833; p:0.088	-23.50±42.05	t: -2.164; p:0.048*
T2-T3	0.08±0.51	t:0.599; p:0.559	-5.25±15.43	t: -1.273; p:0.225
T4-T5	-0.20±0.47	t:-1.646; p:0.122	3.39±25.96	t: 0.488; p:0.633

t: Paired samples t test **p<0.01 highly significant; *p<0.05, statistically significant (CI cardiac index, PaO$_2$/FiO$_2$ Harovitz ratio). A statistically significant decrease was observed in CI values only at T4 compared to the baseline measurement. PaO$_2$/FiO$_2$ Harovitz ratio increased in all measurements compared to the basal measurement, and this increase was high in T2 and T3 and statistically significant in T4 and T5.

Table 5. The relationship between VTe and PaCO$_2$ and correlation between PaO$_2$/FiO$_2$ and EVLWI.

PaCO$_2$	VTe									
	T1		**T2**		**T3**		**T4**		**T5**	
	R	**p**	**R**	**p**	**R**	**p**	**R**	**p**	**R**	**p**
T1	0.567	0.027*								
T2			-0.653	0.008**						
T3					-0.586	0.022*				
T4							-0.432	0.108		
T5									-0.314	0.254
PaO$_2$/FiO$_2$	**EVLWI**									
T1	-0.301	0.276								
T2			-0.292	0.292						
T3					-0.540	0.038*				
T4							0.074	0.793		
T5									-0.360	0.187

r=Pearson's correlation analysis **p<0.01 highly significant; *p<0.05, statistically significant (VTe expiratory tidal volume, PaO$_2$/FiO$_2$ Harovitz ratio, EVLWI extra vascular lung water index). There is a negative, good, statistically significant relationship between VTe and PaCO$_2$ in T1, T2 and T3 measurements. In other words, as VTe increases, PaCO$_2$ also decreases. Although there was a negative relationship between VTe and PaCO$_2$ in T4 and T5 measurements, this was not found to be statistically significant. There is a negative, good, statistically significant relationship between PaO$_2$/FiO$_2$ and EVLWI in T3 measurements. In other words, as EVLWI decreases, PaO$_2$/FiO$_2$ also increases. Although the same relationship was seen in other measurements, this was not found to be statistically significant.

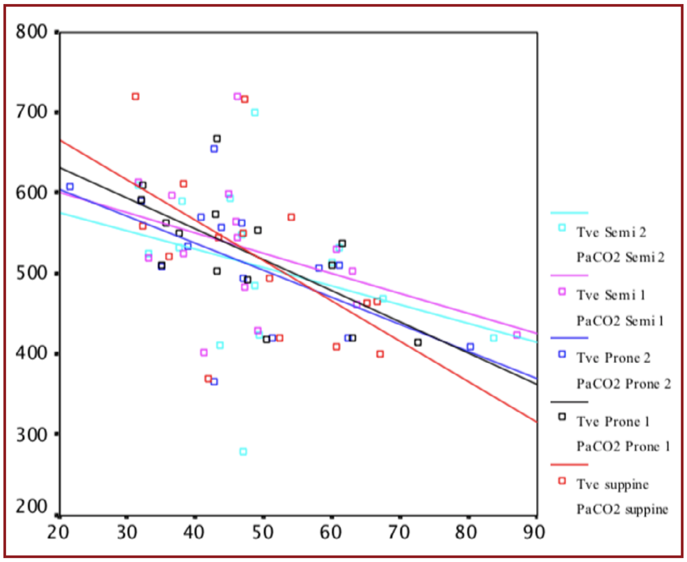

Figure 1. Correlations between VTe and $PaCO_2$ measurements (VTe: expiratuar tidal volume, $PaCO_2$: partial presuure of CO_2)

(Measurement times; T1 red line, T2 black line, T3 blue line, T4 purple line, T5 light blue line).

($p<0.01$). Again, a significant increase in PaO_2/FiO_2 measurements was observed at T4 and T5 compared to baseline ($p<0.05$ for each) (Table 4).

There was a significant, strong negative correlation between VTe and $PaCO_2$ in the supine position ($p<0.05$), meaning that $PaCO_2$ decreased with increasing VTe. At T2 and T3, there was a highly significant, strong, negative correlation between VTe and $PaCO_2$ ($p<0.01$), meaning $PaCO_2$ decreased with increasing VTe. Although a negative correlation was observed between VTe and $PaCO_2$ at T4 and T5, the correlation did not reach statistical significance ($p>0.05$) (Table 5, Fig. 1).

Although a negative correlation was observed between PaO_2/FiO_2 and EVLWI at T1, T2, T3, and T4, the correlation did not reach statistical significance ($p>0.05$) (Table 5).

At T3, there was a significant, strong, negative correlation between PaO_2/FiO_2 and EVLWI ($p<0.01$), meaning that EVLWI decreased with increasing PaO_2/FiO_2 (Table 5).

Discussion

This prospective, controlled study investigated the effects of two different positions on IAP, hemodynamic parameters, and oxygenation in patients with ALI/ARDS in the ICU. In our study, patients were placed in the prone position without abdominal support for 2 hours and in the semi-recumbent position for 2 hours. During this period, a significant increase in IAP was observed; however, a marked improvement in oxygenation was observed without any hemodynamic instability. In the prone position, a decrease in $PaCO_2$ by increasing VTe and an increase in PaO_2/FiO_2 by decreasing EVLWI were observed.

Improved oxygenation has been reported in ALI and ARDS patients placed in the prone position for 20 minutes to 20 hours [1,6-10,18,19], even in patients placed in the prone position without abdominal support [4,16,18]. Although the optimal duration of prone positioning is unclear, studies have evaluated durations ranging from 20 minutes to 20 hours. Studies report that improvement in oxygenation is seen in both the early (30 minutes) and late (20 hours) periods [1,5-10,18,19].

In our study, a significant improvement in oxygenation was observed at hours 1 and 2 in the prone position and hours 1 and 2 in the semi-recumbent position compared to the supine baseline position. In other words, we observed an increase in oxygenation within 2 hours in both positions, in agreement with previous studies.

EVLW, which indicates fluid outside the pulmonary vascular bed, can be used to monitor non-cardiogenic pulmonary edema in ARDS. Therefore, changes in EVLWI are important in ARDS. An increase in EVLW has been associated with the degree of alveolar damage in ARDS and higher mortality.

Different results have been found in studies that have investigated the relationship between EVLWI and the prone position. The interaction mechanisms between EVLWI, oxygenation, and prone positioning have not been clearly determined. Decreased EVLWI may be due to progressive diuresis or a reduction in regional hydrostatic blood and lymphatic pressures, which may play a role in improving pulmonary shunting and gas exchange. Prone positioning may affect both EVLWI and respiratory mechanics, possibly interfering with pulmonary edema reabsorption by increasing central venous pressure, while also decreasing hypoxemic pulmonary vasoconstriction and improving both respiration and oxygenation. The ultimate effect remains uncertain [8,19-22].

In our study, small decreases in EVLWI by position were found to be statistically insignificant. When improved oxygenation was compared with EVLWI, a negative correlation was found between improved oxygenation and EVLWI at all time points; however, only at T3 was a significant increase in oxygenation detected by the reduction in EVLWI.

Studies on the effect of IAP in the prone position on cardiovascular functions have reported different results: no significant differences in MAP, CI, and HR were reported in the prone position with abdominal support for 18 hours, whereas a significant increase in IAP, MAP, and CI and no change in HR and CVP were reported in the prone position without abdominal support for 3 hours. These conflicting findings have been attributed to fluid balance prior to prone positioning [8,18,23]. PaO_2 improvement in the prone position is associated with decreased thoracoabdominal compliance in which abdominal movements weren't restricted, and also CI remained unchanged [9].

Two ARDS treatment protocols reported that, in the absence of contraindications, the semi-recumbent position should be the standard position and the prone position should be used in severe ARDS [24,25]. In another study, hemodynamics were not affected in the semi-recumbent position, and the extent of improvement in oxygenation and lung mechanics was higher in the prone position when compared to the semi-recumbent position [26].

In prone and semi-recumbent positions, an increase, decrease, or no change in CO may be seen with an increase in CVP. The key is the effect of IAP on the factors that ensure venous return to the heart. CO may be a reflection of venous return. The increase in IAP will affect splanchnic blood flow and CO (increase, decrease, or no change) depending on the volume status and cardiovascular status of the patient. Therefore, hemodynamic and CO monitoring are important [19,27].

In our study, a significant increase in IAP was observed at all time points. Patients were placed in the prone position for 2 hours followed by the semi-recumbent position for 2 hours, and a significant but clinically insignificant reduction in heart rate was observed at hour 2 in the prone position. MAP was measured as 76.20±14.27 mmHg, indicating a significant reduction at hour 1 in the prone position. Mean CI was 3.96±1.02, indicating a significant reduction at hour 1 in the semi-recumbent position compared to the supine position. However, this reduction was normalized at hour 2 in the semi-recumbent position. No significant change in CVP values was observed. A marked improvement in oxygenation was observed, but there was no severe negative effect on cardiovascular functions, although IAP increased in both prone and semi-recumbent positions and no abdominal support was used. Our results are in agreement with previous studies.

Compliance and respiratory mechanics are crucial components of oxygenation. Body position, such as prone, semi-recumbent, and Trendelenburg, can also affect respiratory mechanics and intra-abdominal pressure (IAP). Several studies report that prone positioning, with or without abdominal support, for varying periods of time (2-6-8 hours), improves decreased respiratory compliance (Crs) and/or mechanics/lung compliance (CLUNG)/VTe/static compliance/dynamic compliance (Cdyn)/thoracic wall compliance (CCW)/plateau pressure (Pplat) in ARDS [5,6,9,10,13,28]. Umbrello M. et al. [28] reported an increase in respiratory compliance and oxygenation without changes in hemodynamic parameters, even when intra-abdominal pressure was further increased by placing weight on the abdomen in both supine and prone positions.

The study found that applying lower abdominal compression by placing weight on the abdomen in semi-recumbent and supine positions maintained the improved Pplat and Crs [11]. However, in our study without abdominal support, no significant changes in peak pressure, mean airway pressure, and Cdyn were observed with position.

When considering changes in $PaCO_2$ while in the prone position, it is important to take into account factors that may independently influence $PaCO_2$. The studies reporting alterations in $PaCO_2$ kept ventilation strategies and sedation unchanged, thus assuming that CO_2 production was constant. Additionally, the ventilator mode used is also important, as a change in compliance should not be accompanied by any alteration in minute ventilation if volume control is employed. On the contrary, in pressure-limited ventilation, a change in compliance may be associated with a change in tidal volume.

Two studies reported $PaCO_2$ levels during volume-controlled ventilation. Nakos et al. [8] demonstrated an initial increase in $PaCO_2$, followed by a progressive decrease within 24-48 hours despite decreased ventilator support in a patient with ARDS. Kallet RH [7] reported that no significant change in PaCO2 occurred during 2 hours of the prone position compared to the supine position [9]. These contradictory results may be due to the more prolonged prone position in the first study.

Hering's study found no change in $PaCO_2$ and arterial pH among patients placed in the prone position for three hours [18]. Similarly, McAuley's study, using an 18-hour prone position, revealed no significant changes in pH, $PaCO_2$, and VTe during the first two hours. However, a reduction in pH and $PaCO_2$ was detected on the eighteenth hour [23]. Determining the extent to which changes in compliance affect tidal volume and CO_2 exhalation is challenging. It is believed that the decrease in $PaCO_2$ without changes in minute ventilation is a result of improved alveolar ventilation.

In our study, the ventilator mode remained constant throughout the study, and the same sedation-curarization protocol was used. There were no significant changes detected in VTe, pH, and $PaCO_2$ during the first and second hours in both positions (prone and semi-recumbent).

In our study, we observed a significant decrease in $PaCO_2$ during the first two hours in the prone position when VTe was increased. Although a negative correlation was found in these measurements during the first two hours in the semi-recumbent position, it did not reach statistical significance. We attribute these findings to the improvement of alveolar ventilation in areas with better perfusion during prolonged prone ventilation.

Several complications were reported, including unplanned extubation, intubation tube replacement due to occlusion, inadvertent hemodialysis and CVP catheter dislodgement, corneal ulceration, facial edema, transient supraventricular tachycardia, and bilateral nipple necrosis in one patient placed in the prone position for 5 days [9,23]. However, no fatalities were linked to the positions.

In our study, no complications were observed during the positioning process or the position itself. Patients were positioned by staff using a technique supervised by a clinician. Our study found no risk of decubitus ulcer, as the duration of the prone position was less than two hours.

Limitations

The study had a short follow-up duration of 120 minutes for each position and a limited number of cases. Additionally, mortality was not evaluated.

Conclusion

Clinical experience has shown that the prone position can improve oxygenation in patients with ARDS. Repeated and prolonged prone positioning may be even more effective. Although improvements in physiological parameters do not fully explain clinical recovery, prone positioning can reduce oxygen toxicity and ventilator-related lung injury.

Therefore, prone positioning is often used as a treatment protocol to improve oxygenation in patients with ALI and ARDS. However, it is important to consider the effects of IAP elevation during prone positioning on other body systems, and close monitoring of the patient's hemodynamic, pulmonary, and renal functions is necessary.

We concluded that elevating IAP during prone and semi-recumbent positions to improve oxygenation has no adverse effect on hemodynamics in our patient group. Additionally, we found that abdominal support is unnecessary and that the extent of IAP elevation is lower in the semi-recumbent position. Our study may provide a protocol for larger studies to evaluate prolonged prone and semi-recumbent positions in the future.

Ethics Committee Approval: The study was approved by Health Science University Haydarpaşa Numune Training and Research Hospital Medical Ethics Committee (No: 06-27, Date: 01/06/2006).

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