Effect of Trendelenburg position during prone ventilation in fifteen COVID-19 patients. Observational study

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Abstract

Background
Prone position ventilation has shown to improve oxygenation and mortality in severe ARDS. The data of prone position ventilation during severe ARDS secondary to COVID-19 have shown similar benefit in oxygenation and mortality. Usually, patient placed in prone position are placed flat or in reverse Trendelenburg positioning to decrease risk of aspiration and abdominal girth compressing the chest. To date, no studies are available to compare the effects of positioning the bed in different angles during the prone position ventilation.

Methods
An observational study in fifteen patients with severe ARDS secondary to COVID-19 who were placed in the prone position for the first time. All the patients were sedated and chemically paralyzed with no spontaneous effort. All patients were ventilated with the pressure-controlled mode with set PEEP according to the pressure-volume curves. Five patients had esophageal balloon manometry to estimate pleural pressures and trans-pulmonary pressures. Patients were initially placed in reverse Trendelenburg position and later in Trendelenburg position. Tidal volume and respiratory compliance were observed for 30 minutes after bed positioning has been achieved. Tidal volume and total respiratory compliance in both Trendelenburg and reverse Trendelenburg position were compared. Ventilator settings were not changed during the observation.
No patients were suspected of increased intra-cranial or intra-ocular pressures. T-test was done to compare the values.

Results
Tidal volume significantly increased by 80.26 ± 23.4 ml/breath (95% CI 37.7 - 122.9) from 391.3 ± 52.7 to 471.6 ± 60.9 (20.5%) P 0.001. The respiratory system compliance significantly increased by 4.9 ml/cmH_2O (95% CI 1.4 - 8.4) from 34.6 ± 4.7 to 39.5 ± 4.6 (14%) P 0.001. Of the five patients with esophageal balloon, the lung compliance significantly increased by 16.7 ml/cmH_2O (95% CI 12.8 – 20.6) from 66.6 ± 1.7 to 83.3 ± 3.3 (25%) P 0.001. The chest wall compliance had small but non-significant increase by 1.5 ml/cmH_2O (95% CI -1.3 – 4.3) from 65 ± 1.4 to 66.5 ± 2.3 (2%) P 0.085.

Conclusion
In this study, statistically significant increase in tidal volume, lung and respiratory system compliance were observed in patients placed in the Trendelenburg position during prone position ventilation. The results reflect the effect of body positioning during prone position ventilation. These effects may be the reflection of altered ventilation distribution throughout the lungs and change in pleural pressure as well as trans-pulmonary pressure during body positioning. More studies need to be done to confirm and examine this phenomenon. Precautions should be taken as this maneuver can increase the intra-cranial and intra-ocular pressures.

Keywords: COVID-19, Trendelenburg, Reverse Trendelenburg, ARDS

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Introduction

Prone position has long been proven to improve oxygenation and mortality in the severe acute respiratory distress syndrome (ARDS). [1] The mechanism by which the prone position exerts such beneficial effects are numerous including improved lung homogeneity, alveolar recruitment, ventilation-perfusion mismatch, changes in lung and chest wall compliances, reduced compression on the lungs by the heart and abdominal organs, improved right ventricular function and hemodynamics. [2] Not surprisingly, the prone position has emerged as important maneuver in the fight against SARS-CoV-2 (COVID-19) in mechanically ventilated patients with moderate to severe ARDS, [3,4] as well as awake and non-mechanically ventilated patients. [5]

Given the known benefits of the upright sitting position with head elevated in the supine position on respiratory mechanics [6] and possible reduction in risk of aspiration, [7] most of patients in the prone position have their bed angled up in the reverse Trendelenburg position. The benefits of this position have been evaluated in one small study [8] that showed improved oxygenation compared to the flat prone position. No studies have evaluated the different bed position (Trendelenburg, flat, or reverse Trendelenburg) during the prone position. In this observational study, we examine the effect of different bed positioning during prone ventilation by comparing the tidal volume and respiratory compliance in patients placed in reverse Trendelenburg position (RT) and Trendelenburg position (T).

Methods

Over a period of three months, fifteen patients with COVID-19 pneumonia with moderate to severe ARDS requiring initiation of prone positioning ventilation were included in this study. The study was approved by the local hospital IRB.

Patient characteristics are included in table 1. All patients were ventilated with the pressure-controlled mode using the Hamilton G-5 ventilator (Hamilton Medical AG, Bonaduz, Switzerland) with varying PEEP according to the interpretation of the pressure-volume curve or esophageal balloon based on the treating physician. All patients were sedated and chemically paralyzed using propofol, fentanyl and continuous cisatracurium drips. Patients who were not paralyzed were not included in this observation.

Patients initiating prone position ventilation are placed in reverse Trendelenburg defined by head of bed angled up 15 degrees and later on in Trendelenburg positioning defined by head of bed angled down 15 degrees. Tidal volume and respiratory compliance were observed for 30 minutes after each bed position was achieved. No patients were suspected of increased intra-cranial or intra-ocular pressures. T-test was done to compare the values.

Patient demographics, ventilator settings, tidal volume, respiratory mechanics are summarized in table 1. Respiratory system (CRS), chest wall (CCW) and lung (CL) compliances calculated in patients with esophageal balloon monitoring using the end-inspiratory and end-expiratory hold maneuvers in the volume-controlled mode with constant flow. [9]

All patients were monitored in intensive care unit, with continuous ECG, arterial and central venous catheters, end tidal CO_2 monitoring.

Statistics

Data are presented as mean with ± standard deviation (SD), 95% confidence interval (CI) were calculated. Paired T-test for equal variance was done to compare tidal volume (V_T), total respiratory compliance (C_{RS}), Lung (C_L), and chest wall compliance (C_{CW}) between RT and 30 min after T positions. P 0.05 was considered significant.

Results

Tidal volume significantly increased by 80.26 ± 23.4 ml/breath (95% CI 37.7 - 122.9) from 391.3 ± 52.7 to 471.6 ± 60.9 (20.5%) P 0.001. The respiratory system compliance significantly increased by 4.9 ml/breath (95% CI 1.4 - 8.4) from 34.6 ± 4.7 to 39.5 ± 4.6 (14%) P 0.001. In the five subjects with esophageal balloon, the lung compliance significantly increased by 16.7 ml/breath (95% CI 12.8 – 20.6) from 66.6 ± 1.7 to 83.3 ± 3.3 (25%) P 0.001. The chest wall compliance had small but non-significant increase by 1.5 ml/breath (95% CI -1.3 – 4.3) from 65 ± 1.4 to 66.5 ± 2.3 (2%) P 0.085. Results are summarized in table 2, figures 1 & 2.

Patients	**Characteristics**
Age	55 ± 12
Gender	9 males and 6 females
BMI	30.3 ± 6.6
SAPS II	60 ± 7
Days since hospitalization	6 ± 4
Time of proning after mechanical ventilation (hours)	16 ± 13
PaO_2/FiO_2	72 ± 16
PEEP	15 ± 3
Tidal volume (m/Kg)	6.1 ± 0.4

Table 1 BMI: body mass index, PaO_2/FiO_2: partial pressure of arterial oxygen to fraction of inspired oxygen, PEEP: positive end expiratory pressure, SAPS II: Simplified Acute Physiology Score

	Reverse Trendelenburg (RT)	Trendelenburg (T)	Difference	P value
Tidal volume (ml)	391.3 ± 52.7	471.6 ± 60.9	80.26 (20.5%)	0.001
Tidal volume (m/Kg)	6.1 ± 0.4	7.27 ± 0.8	1.17 (19%)	0.001
CRS (ml/cmH_2O)	34.6 ± 4.7	39.5 ± 4.6	4.9 (14%)	0.001
CL (ml/cmH_2O)	66.6 ± 1.7	83.3 ± 3.3	16.7 (25%)	0.001
CCW (ml/cmH_2O)	65 ± 1.4	66.5 ± 2.3	1.5 (2%)	0.085

Table 2: CCW: chest wall compliance, CL: lung compliance, CRS: total respiratory compliance

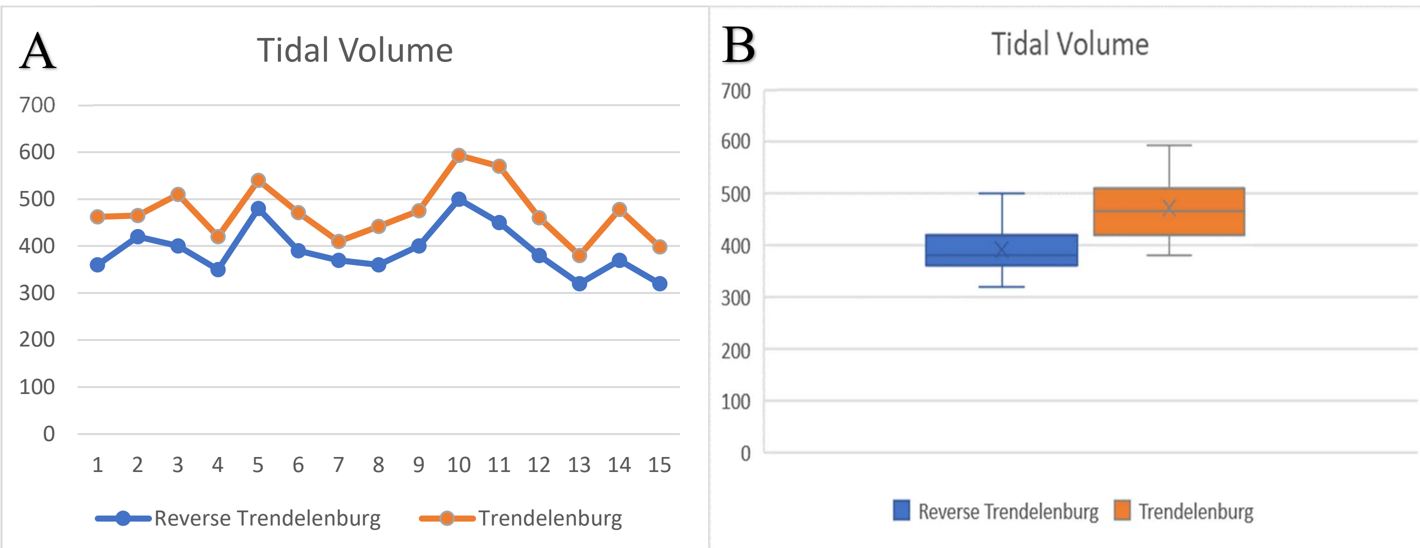

Figure 1. A: Tidal volume in ml for each subject in both positions. B: Mean tidal volume (X) in ml in each position with error bars for lowest and highest values

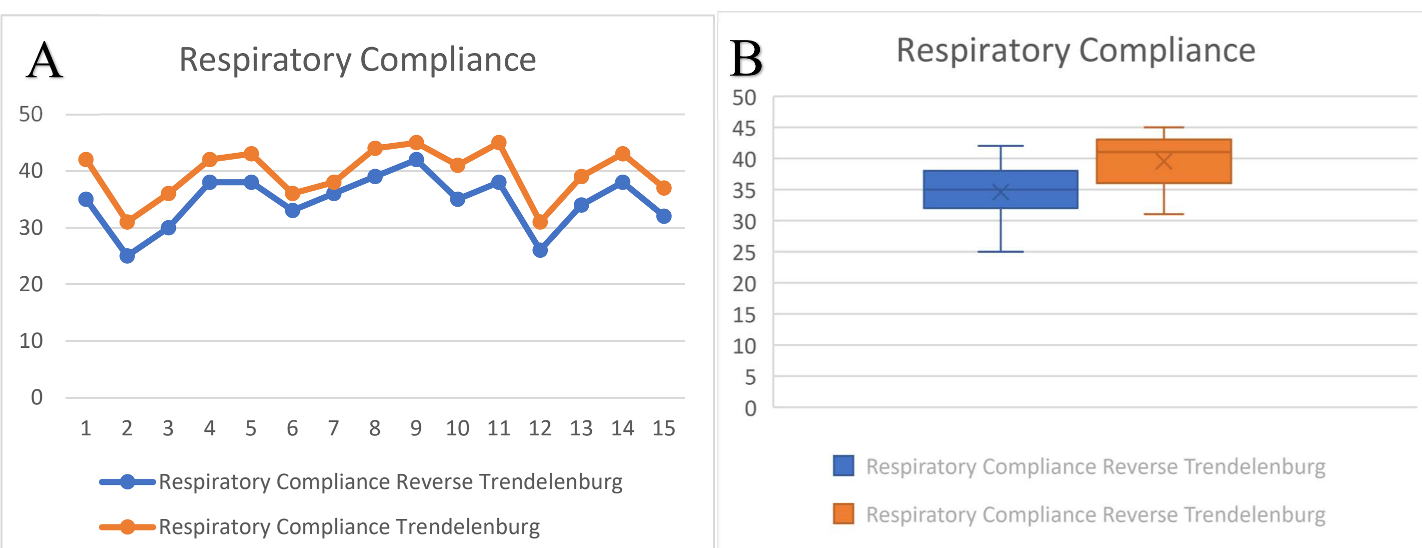

Figure 2. A: Total respiratory compliance in ml/cmH_2O for each subject in both positions. B: Mean total respiratory compliance (X) in each position with error bars for lowest and highest values

Discussion

The change in ventilation, perfusion, and gas exchange between the supine and the prone position in healthy and diseased lungs are well understood and documented. [10] Alongside those effects, the mortality benefits of the prone position in the moderate-severe ARDS [1] made sense to place the patients with acute respiratory failure secondary to COVID-19 in the prone position. The prone position was encouraged in the surviving sepsis guidelines for COVID-19 early in the pandemic. [11] However, some researchers suggested that the ARDS caused by COVID-19 though meeting the berlin definition of ARDS, might not be the same with significant pathological differences in lung injury. [12]

Same researchers suggested that different phenotypes of COVID-19 ARDS might respond differently to ventilatory strategies especially tidal volumes, PEEP, and to prone position. [13] Regardless, prone position has proven to improve oxygenation, ventilation. [14] The effect on mortality has been controversial, some researchers found no improvement in mortality [15] while others found evidence of improved mortality. [16]

Our institution policy as well as other institutions online policies are to raise the head of the bed to some degree (RT) during the prone position. Our study originated accidentally from an observation that the proned patients' tidal volume increased when the bed was placed flat from the reverse Trendelenburg, and on further tilting the head of the bed down to 15-20 degrees (Trendelenburg position), the tidal volume increased. The increase returned to the previous level when the bed was tilted up again.

We could not find any studies examining the effect of Trendelenburg position on the respiratory mechanics during the prone position. One study examined the effect of different body positions (sitting, supine, Trendelenburg) on lung ventilation distribution in the perioperative setting in healthy lungs in patients undergoing prostatectomy but not proned. Their conclusion was that the Trendelenburg position caused increased atelectasis compared to the supine and sitting positions, but to be noted the patients in the Trendelenburg position had capnoperitoneum which might have worsened the chest wall compliance. [17]

A small study of twenty patients shown that the prone and upright position (20 degrees) had better oxygenation compared to prone and flat position but there was no change in respiratory mechanics. [18]

We only included patients who were chemically paralyzed with cisatracurium and did not analyze those who were not as they might have inspiratory muscle effort (Pmus) that can change the tidal volume during the pressure-controlled ventilation (dynamic compliance).

Though no studies compared the Trendelenburg and reverse Trendelenburg positions in the prone position, most of studies showed improved respiratory compliance in the prone position compared to supine position. [19] Our study showed improved respiratory compliance in the Trendelenburg position compared to the reverse Trendelenburg position during proning.

Though speculative, the reasons for this improved compliance could be due to the gravitational ventilation redistribution in the dorsal lung units now in a higher vertical position compared to being dependent in the RT position because the lung mass is anatomically greater in dorsal regions (nondependent in Trendelenburg) than in ventral regions (dependent in Trendelenburg), the increased aeration and recruitment of the dorsal regions might exceed the decreased aeration and derecruitment of the ventral regions.

The changes in pleural pressure gradient in different regions on the lung could have played a role in such an observation. Physiologic studies have shown that gravity might explain the difference in ventilation but not perfusion in different body positions in healthy and injured lungs. [20]

Another plausible reason could be the change in position and the shape of the three-dimensional diaphragm and the forces it acts on the dorsal part of the lungs. Though the initial thought was the abdominal organs would push downwards on the bases of the lungs that might reduce the chest wall compliance. Prone position is documented to reduce the chest wall compliance [21] because the dorsal chest wall is less compliant than the ventral chest wall that is contact with the mattress during the prone position and impeded from expansion.

However, in the five subjects who had esophageal balloon manometry, we only observed minimal increase in the estimated pleural pressures (about 1.2 cmH_2O) that maintained almost same chest wall compliance which concludes that the increase tidal volume was secondary to improved lung compliance not the chest wall compliance. Lung compliance was calculated as follows [9, 22] :

1 / (1/ Total respiratory system compliance) - (1/ Chest wall compliance)

A case report using electrical impedance tomography showed over distention in the ventral lung regions in a patient when placed in the prone position, [23] this could explain the increased tidal volume, though overdistention can cause worsening lung compliance.

Our average subjects are considered obese class I per their BMI. Obesity might cause worsening chest wall and thus respiratory mechanics. Studies have shown that strong independent risk factor for hospitalization, increases the need for critical care and invasive mechanical ventilation vulnerable to an adverse clinical course due to COVID-19. [24]

Our study subjects had a lower average respiratory system compliance compared to the Gattinoni group [12] were they subdivided COVID-19 respiratory failure as two phenotypes, L & H. It is important to recognize the effect of changing body position in accordance with the respiratory system compliance, PEEP levels, the Phenotype of COVID-19 ARDS, body weight, timing of proning. All those factors may influence the response to proning and different body position.

Our study has some limitations, and the results should be evaluated with caution until larger more vigorous investigation of our results is confirmed. We did not measure the ventilation distribution between the two positions, measuring ventilation distribution can be performed radiologically mostly using computerized tomography scan (CT) and quantifying the lung weight and ventilation distribution in different lung zones, [25] or using electrical impedance tomography, [26] or using inert gas washout [27] that might give insight to our findings.

Additionally, we did not measure the effect on oxygenation or ventilation using arterial blood gases or recording SpO_2 or $EtCO_2$, or calculation of dead space fraction given that our observation was only brief, and no anticipated changes were expected in that brief period. Though none of our subjects were expected to have increased intra-ocular or intra-cranial pressure, some studies showed increased intra-ocular pressures in healthy volunteers in the prone Trendelenburg position, [28] and increase in intra-cranial pressures. [29]

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