VIEW POINT

Trendelenburg Ventilation in Patients of Acute Respiratory Distress Syndrome with Poor Lung Compliance and Diaphragmatic Dysfunction

Saiteja Kodamanchili[1], Saurabh Saigal[2], Abhijeet Anand[3], Rajesh Panda[4], Priyanka TN[5], Gowthaman Thatta Balakrishnan[6], Krishnkant Bhardwaj[7], Pranav Shrivatsav[8]

Abstract

Background: Patients with acute respiratory distress syndrome (ARDS) are generally ventilated in either 45° head elevation or prone position as they are associated with decreased incidence of ventilator-associated pneumonia and mortality, respectively.[1,2] But in patients with poor lung compliance and super-added diaphragmatic weakness/dysfunction, generating a minimum amount of adequate tidal volume (TV) would be very difficult in propped up/supine/prone position, leading to worsening hypoxia and CO_2 retention. We noticed a sustained increase in TV for patients with poor lung compliance (Cs <15 mL/cm H_2O) and diaphragmatic dysfunction (bilateral diaphragmatic excursion <1 cm, on spontaneous breaths) when the patients are switched to Trendelenburg position with the same ventilator settings.

Patients and methods: A case report with possible explanation for the observed changes has been mentioned.

Results: Trendelenburg ventilation delivered more TV than propped up or prone ventilation in patients of ARDS with poor lung compliance and diaphragmatic dysfunction.

Conclusion: Trendelenburg ventilation increases static lung compliance and delivers more TV when compared to propped up/supine/prone ventilation in patients of ARDS with poor lung compliance and diaphragmatic dysfunction. Although the exact mechanism behind this is not known till now, we formulated few theories that could explain the possible mechanism.

Keywords: ARDS, Proning, Trendelenburg.

Indian Journal of Critical Care Medicine (2022): 10.5005/jp-journals-10071-24127

Perspective

Hypothesis

"Trendelenburg ventilation delivers more tidal volume (TV) than propped up or prone ventilation in patients of acute respiratory distress syndrome (ARDS) with poor lung compliance and diaphragmatic dysfunction."

Patients with ARDS are generally ventilated in either 45° head elevation or prone position as they are associated with decreased incidence of ventilator-associated pneumonia (VAP) and mortality, respectively.[1,2] But in patients with poor lung compliance and super-added diaphragmatic weakness/dysfunction, generating a minimum amount of adequate TV would be very difficult in propped up/supine/prone position, leading to worsening hypoxia and CO_2 retention. We noticed a sustained increase in TV for patients with poor lung compliance (Cs <15 mL/cm H_2O) and diaphragmatic dysfunction (bilateral diaphragmatic excrusion <1 cm, on spontaneous breaths) when the patients are switched to Trendelenburg position from either supine or prone with the same ventilator settings. Although this increase in TV (with the same respiratory rate, inspiratory time, flows and inspiratory pressure) helped in washing out CO_2, its impact on oxygenation was very minimal. This increase in TV with Trendelenburg position is contradictory to many previous studies stating that Trendelenburg position reduces lung compliance and TV,[3] which have not included patients of ARDS with poor lung compliance and diaphragmatic dysfunction. Going through literature, we could not find any reports asserting this kind of experience thereby any explanation for it.

[1,3,4,6–8]Department of Anaesthesia and Critical Care Medicine, All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India

[2]Department of Anaesthesia and Intensive Care, All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India

[5]Department of Cardiac Anaesthesia, Sri Jayadeva Institute of Cardiovascular Sciences and Research, Bengaluru, Karnataka, India

Corresponding Author: Saiteja Kodamanchili, Department of Anaesthesia and Critical Care Medicine, All India Institute of Medical Sciences, Bhopal, Madhya Pradesh, India, Phone: +91 9491758129, e-mail: saiteja306@gmail.com

How to cite this article: Kodamanchili S, Saigal S, Anand A, Panda R, Priyanka TN, Balakrishnan GT, *et al*. Trendelenburg Ventilation in Patients of Acute Respiratory Distress Syndrome with Poor Lung Compliance and Diaphragmatic Dysfunction. Indian J Crit Care Med 2022;26(3):319–321.

Source of support: Nil

Conflict of interest: None

We tried to explain few theories behind this increase in TV with Trendelenburg position.

Theory 1: Functional Residual Capacity (FRC) Theory

In Trendelenburg position, the weight of the abdominal contents moves the weak/paralyzed diaphragm more cranially when compared to supine and propped-up positions. This relative increase in cranial displacement of the diaphragm causes more fall in FRC than usual.[3] So for the next inspiratory breath, inflation from a lower FRC to the same total lung capacity, with no change inspiratory pressure, flow and time results in an increased TV with increase in lung compliance (Fig. 1).

Theory 2: Parachute Theory

When we assume that the weakened diaphragm due to mechanical ventilation, muscle relaxants, corticosteroids use or by inflammation from the disease process itself is similar to that of the diaphragmatic weakness in spinal cord injured patients.[4] Placing an abdominal binder or Trendelenburg position would reconfigure the shape of the diaphragm, so that it resembles parachute or dome. The reconfiguration increases TV and improves efficiency of ventilator mechanics by increasing the zone of apposition of diaphragm relative to the caudal circumference of the rib cage. The domed diaphragm lifts the lower edges of the ribcage by using the intestines as fulcrum.[5]

Theory 3: Pulmonary Vascular Fluid Theory

During Trendelenburg ventilation, a shift in pulmonary blood volume from basilar to apical lung regions would be expected to reduce hydrostatic pressure surrounding basilar alveoli, thus enabling them to accommodate a greater volume of gas as shown by increase in alveolar minute ventilation and static lung compliance.[5]

Theory 4: Rigid Chest Wall Theory

In patients with ARDS and on muscle relaxants—the lax abdominal wall due to muscle relaxation and diaphragmatic weakness makes the abdomen relatively more compliant leading to adaptive migration of the abdominal contents and decreased anteroposterior chest wall dimensions with each inspiration. This increased compliance in the abdominal wall is offset by stiffening of ribcage.[6] This could be due to a larger fraction of pressure/flow getting used up for displacing the diaphragm thereby overinflating the already distended alveoli adjacent to diaphragm and relative atelectasis of ventral and dorsal lung regions. Here, Trendelenburg positioning could displace the abdominal contents cranially sitting adjacent to diaphragm altering the pattern of breathing such that the upper chest moves, and expansion of the lower ribs with decent of diaphragm is prevented leading to effective opening up of recruitable dorsal and ventral lung regions (Fig. 2).

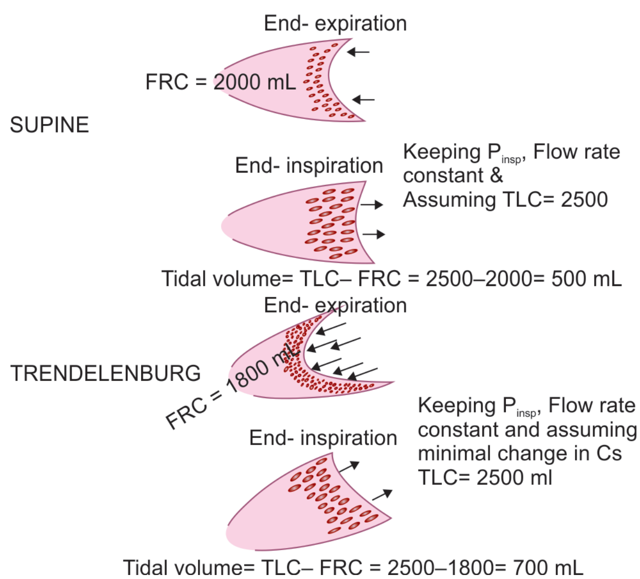

Fig. 1: Functional residual capacity (FRC) theory. TLC, total lung capacity; Cs, static lung compliance; P_{insp}, inspiratory pressure. Increase in TV can be noticed in Trendelenburg ventilation with constant inspiratory pressures and flow

Limitations

- Is the increase in TV with Trendelenburg position is universally seen in all patients of ARDS with low lung compliance and diaphragmatic dysfunction?
- If yes, can this be proved by using CT or Electrical Impedance tomography?
- Does the increase in TV effect is sustained in all patients? If yes, then till how much time?
- Is there any threshold for lung compliance and diaphragmatic function below which this effect will be seen?
- Reason for relatively minimal change in oxygenation—V/Q mismatching, cardiac dysfunction due to increase in afterload?
- Effect of muscle relaxation?

We noticed this effect in few of our ICU patients with prolonged mechanical ventilation, steroid and muscle relaxant use.

Case

A 25-year-old female referred to our center with c/o of fever × 1 month, shortness of breath × 15 days for which she had taken treatment in a local private hospital with oxygen supplementation and steroids. On Day 2 in our ICU, her condition worsened requiring mechanical ventilator support. Static lung compliance on the day of intubation was 13.7 mL/cm H_2O, and driving pressures were 16 limiting the plateau pressures to 30 cm H_2O. Even with propped up positioning/

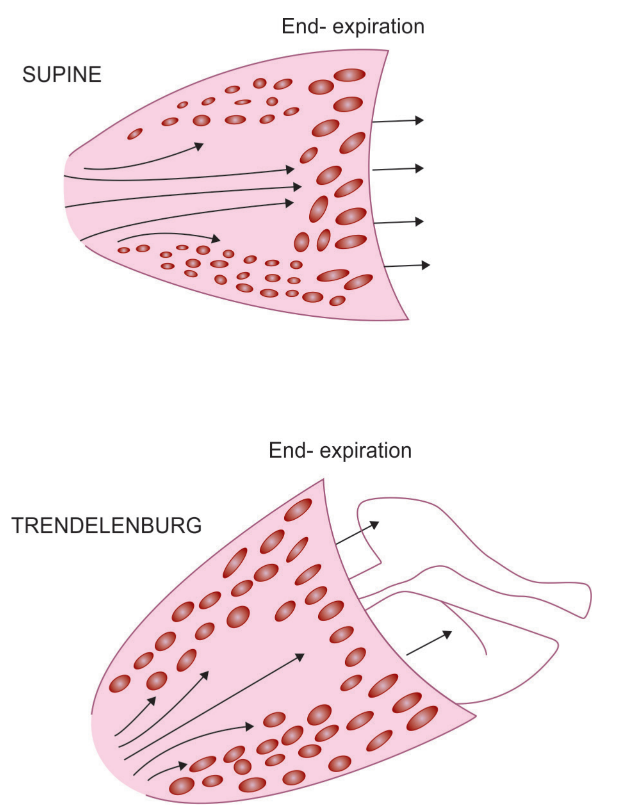

Fig. 2: Rigid chest wall theory. Rigid Chest wall and diaphragmatic restriction facilitate the ventilation of ventral and apical lung regions

Table 1: Comparison of ventilator parameters between propped-up and Trendelenburg ventilation

Settings	*Propped-up position at 30°*	*Trendelenburg position*
Mode of ventilation	PCV+in Hamilton C-3 ventilators	PCV+in Hamilton C-3 ventilators
Inspiratory pressure (Pi)	23 cm H_2O	23 cm H_2O
PEEP	7 cm H_2O	7 cm H_2O
Others (I:E, FiO_2)	1:1, 100%	1:1, 100%
TV	210–230 mL	300–320 mL
Cs	13.7 mL/cm H_2O	19.3 mL/cm H_2O
PaO_2	52 mm Hg	49 mm Hg (60 minutes post-Trendelenburg position)
$PaCO_2$	112 mm Hg	78 mm Hg (60 minutes post-Trendelenburg position)
pAO_2	573 mm Hg	615.5 mm Hg

PCV, pressure-controlled ventilation; PEEP, positive end expiratory pressure; I:E, inspiratory and expiratory ratio; FiO_2, fraction of inspired oxygen; TV, tidal volume; PO_2, partial pressure of oxygen in arterial blood; $PaCO_2$, partial pressure of carbon dioxide in arterial blood; Cs, static lung compliance; pAO_2, alveolar oxygen tension in mm Hg

proning, adequate sedation and muscle paralysis, maximum TV that has been achieved was around 210–230 mL. Patient was Hypoxic and retaining CO_2. Off relaxant, her diaphragm excrusion was <1 cm bilaterally. Assuming diaphragmatic weakness and atrophy with very poor lung compliance and almost no improvement with prone ventilation, we placed the patient in Trendelenburg position with sedation and paralysis hoping for the above mechanisms to act. Her TV increased to 300–320 mL. Patient lung compliance in propped up was 13.7 mL/cm H_2O and 19.3 mL/cm/H_2O in Trendelenburg position, increasing with Trendelenburg position. Alveolar oxygen concentration (pAO_2) also increased with Trendelenburg ventilation marking an increase in lung recruitment. Although patients PaO_2 did not change significantly, her CO_2 decreased, pAO_2 increased, with an increase in TV (with same RR, inspiratory time and flow) (Table 1).

Highlights

Trendelenburg ventilation increases static lung compliance and delivers more TV when compared to propped up/supine/prone ventilation in patients of ARDS with poor lung compliance and diaphragmatic dysfunction. Although the exact mechanism behind this is not known till now, we formulated few theories that could explain the possible mechanism. Being the largest COVID center in the state with 60 bedded ICU, we experienced these changes in few of our patients which has to be validated by a large scale RCT aided with latest technologies like computed tomography and electrical impedance tomography.

Orcid

Saiteja Kodamanchili https://orcid.org/0000-0003-1033-0321
Saurabh Saigal https://orcid.org/0000-0002-2364-2271
Abhijeet Anand https://orcid.org/0000-0001-6498-5388
Rajesh Panda https://orcid.org/0000-0001-7123-876X
Priyanka TN https://orcid.org/0000-0002-2322-2226
Gowthaman Thatta Balakrishnan https://orcid.org/0000-0002-0301-3793
Krishnkant Bhardwaj https://orcid.org/0000-0002-2207-0654
Pranav Shrivatsav https://orcid.org/0000-0003-1637-1271

References

1. Güner CK, Kutlutürkan S. Role of head-of-bed elevation in preventing ventilator-associated pneumonia bed elevation and pneumonia. Nurs Crit Care 2021;nicc.12633. DOI: 10.1111/nicc.12633.
2. Guérin C, Reignier J, Richard J-C, Beuret P, Gacouin A, Boulain T, et al. Prone positioning in severe acute respiratory distress syndrome. N Engl J Med 2013;368(23):2159–2168. DOI: 10.1056/NEJMoa1214103.
3. Regli A, Habre W, Saudan S, Mamie C, Erb TO, von Ungern-Sternberg BS, et al. Impact of Trendelenburg positioning on functional residual capacity and ventilation homogeneity in anaesthetised children. Anaesthesia 2007;62(5):451–455. DOI: 10.1111/j.1365-2044.2007.05030.x.
4. Peñuelas O, Keough E, López-Rodríguez L, Carriedo D, Gonçalves G, Barreiro E, et al. Ventilator-induced diaphragm dysfunction: translational mechanisms lead to therapeutical alternatives in the critically ill. Intensive Care Med Exp 2019;7(S1):48. DOI: 10.1186/s40635-019-0259-9.
5. Gutierrez CJ, Stevens C, Merritt J, Pope C, Tanasescu M, Curtiss G. Trendelenburg chest optimization prolongs spontaneous breathing trials in ventilator-dependent patients with low cervical spinal cord injury. J Rehabil Res Dev 2010;47(3):261. DOI: 10.1682/jrrd.2009.07.0099.
6. Wadsworth BM, Haines TP, Cornwell PL, Paratz JD. Abdominal binder use in people with spinal cord injuries: a systematic review and meta-analysis. Spinal Cord 2009;47(4):274–285. DOI: 10.1038/sc.2008.126.