The Essentials of Prone Position in Acute Respiratory Distress Syndrome

Abhijit S. Nair[1], Yogesh Manhas[2]

[1]Consultant Anaesthesiologist, Ibra Hospital, Oman
[2]Consultant Intensivist, Ibra Hospital, Oman

Edited by: Dr Kandasamy Subramani, Professor and Head, Surgical Intensive Care Unit, Christian Medical College, Vellore-632004, Tamil Nadu, India

Corresponding author email: abhijitnair95@gmail.com

Published 14 February 2023

KEY POINTS

- In a prone position, overall lung compliance improves due to recruitment of the dorsal lung mass, which is anatomically greater than the ventral lung mass.
- There is a homogeneous distribution of transpulmonary pressures in the prone position due to improved dimension matching between chest wall and lung.
- Prone positioning may improve right heart function by facilitating unloading of the right ventricle.
- In the prone position, pulmonary blood flow is minimally altered and remains preferentially in dorsal regions.
- Although prone ventilation improves oxygenation, it does not necessarily improve carbon dioxide elimination.

INTRODUCTION

Acute respiratory distress syndrome (ARDS) was initially defined in 1994 by the American-European Consensus Conference. This definition saw several changes culminating in the Berlin Definition in 2011[1] (Table 1). The existence of a definition helps to standardise clinical care and research. The Faculty of Intensive Care Medicine and Intensive Care Society Guideline Development Group have provided recommendations for managing patients with ARDS. Prone positioning (PP) is recommended if oxygenation does not improve [**Pao_2/FIo_2 (P/F) ratio $<$ 150**] in the first 48 hours.[2]

PP has been used since the 1970s as an effective method of improving gas exchange in patients with ARDS. The first published paper was by AC Bryan in 1974,[3] who suggested that prone ventilation in an anaesthetized and paralyzed patient could lead to more homogenous lung inflation, improving oxygenation when compared to a supine position. Later, in 1977, Douglas et al[4] used prone positioning to improve oxygenation in 4 mechanically ventilated patients with bilateral infiltrates on chest radiograph and hypoxemic respiratory failure. They performed awake PP in the fifth patient and successfully avoided intubation.[4]

PRONE POSITIONING IN A MECHANICALLY VENTILATED PATIENT

Physiology

In ARDS, there is heterogeneous atelectasis and consolidation, mostly distributed dorsally as discussed by Henderson et al[5] (Figure 1). PP leads to alterations in the distribution of alveolar ventilation and blood flow with improved matching

An online test is available for self-directed continuous medical education (CME). It is estimated to take 1 hour to complete. Please record time spent and report this to your accrediting body if you wish to claim CME points. A certificate will be awarded upon passing the test. Please refer to the accreditation policy here.

TAKE ONLINE TEST

Parameter	Description
Timing	Within 1 week of a known clinical insult, new respiratory symptoms, or worsening of existing respiratory symptoms
CT scan or chest radiograph	Bilateral opacities—not fully explained by effusions, lobar or lung collapse, or nodules
Origin of oedema	Respiratory failure not fully explained by cardiac failure or fluid overload Need objective assessment (echocardiography) to exclude hydrostatic oedema if no risk factor present
Oxygenation	
Mild	200 mm Hg $<$ $Pao_2/FIo_2 \leq$ 300 mm Hg with PEEP or CPAP $\geq$ 5 cm H_2O
Moderate	100 mm Hg $<$ $Pao_2/FIo_2 \leq$ 200 mm Hg with PEEP $\geq$ 5 cm H_2O
Severe	$Pao_2/FIo_2 \leq$ 100 mm Hg with PEEP $\geq$ 5 cm H_2O

Table 1. The Berlin Definition of ARDS

of local ventilation and perfusion. In PP, there are modifications in the thoracic-lung shape as a result of which the intrapleural pressure becomes less negative in nondependent regions and less positive in dependent regions. Computed tomography studies have shown that ventilation is improved in PP relative to the supine position (Figure 2). With PP, the improvement of oxygenation is largely due to the generation of more recruitment in dorsal zones than derecruitment in ventral ones. PP leads to an overall more uniform distribution of alveolar stress, enhanced secretion clearance, and favourable right-ventricular (RV) and systemic hemodynamics. There is improvement in ventilation/perfusion mismatch once in PP.

The acute pulmonary hypertension in ARDS is multifactorial. It could be due to several factors including hypoxemia, hypercapnia, acidosis, or pulmonary vascular obstruction from interstitial oedema and microvascular embolization. The acute cor pulmonale in ARDS is due to increased RV afterload. There are several mechanisms through which PP helps in improving RV function. The proposed mechanisms are reduction in hypoxic pulmonary vasoconstriction leading to a decrease in pulmonary vascular tone and RV afterload and reduction in ventilatory driving pressure, which reduces pulmonary vessel compression and pulmonary vascular resistance. The PP increases the central blood volume which reduces pulmonary vascular resistance and RV afterload and leads to improved pulmonary blood flow by homogenous ventilation and thus improves oxygenation.[6]

The PROSEVA study (PROne ventilation in SEVere acute respiratory distress syndrome) was a multicentre prospective randomised controlled trial which showed that prone positioning decreased 28-day and 90-day mortality and increased the rate

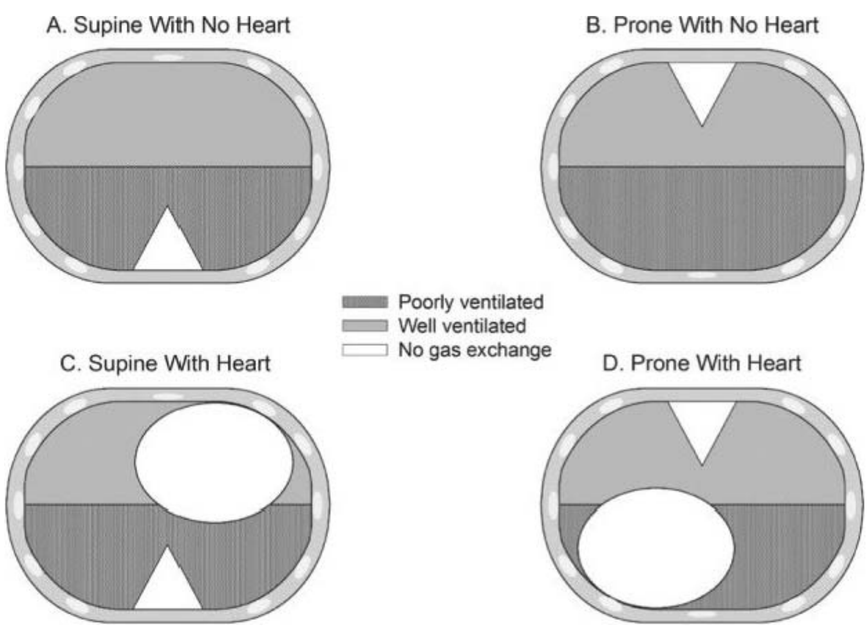

Figure 1. Schematic representation of changes in the volume of ventilated lung between the supine and prone positions. (A and B) In absence of mediastinum and heart and symmetrical lungs, the ventilated tissue is equal to poorly ventilated lung and atelectatic lung. (C and D)In the presence of mediastinum and the heart, the ventilated tissue is less in supine position than in prone position. Image reproduced with permission from Henderson et al.[5]

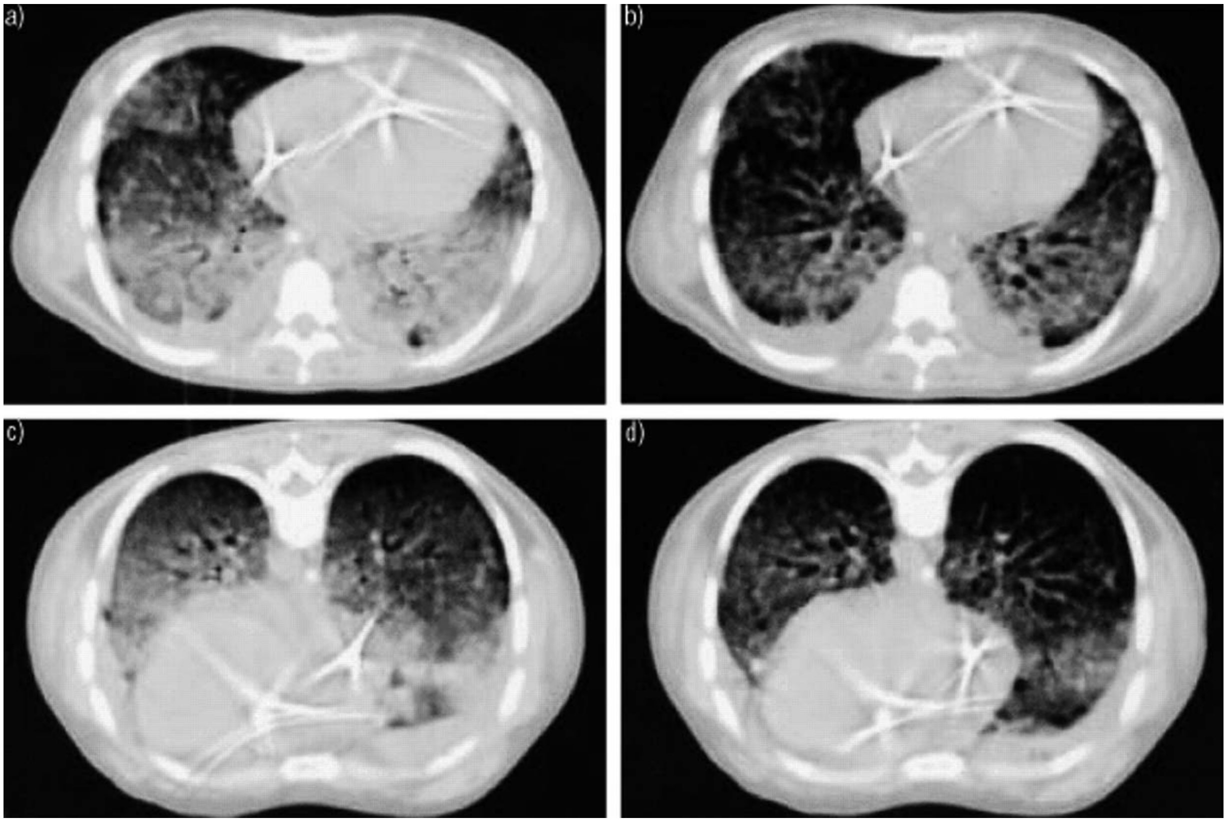

Figure 2. Effects on lung densities of supine positioning at (a) end-expiration and at (b) end-inspiration, and prone positioning at (c) end-expiration and (d) end-inspiration. At end-expiration, densities moved from dorsal to ventral regions. At end-inspiration, ventilation improved in prone compared to supine position. Reproduced with permission of the European Respiratory Society [24] © ERS 2022.

of successful extubation. Other secondary outcomes, such as time to successful extubation, barotrauma, and tracheostomy at days 28 and 90 showed no difference. Based on these data, early ventilation in the prone position is recommended in moderate to severe ARDS patients.[7]

Clinical Aspects

Prone positioning is just one modality used to improve gas exchange in ARDS. Other supportive management, such as positive end-expiratory pressure (PEEP), recruitment manoeuvres, fluid restriction, corticosteroids, and inhaled vasodilators such as nitric oxide can be used in addition and irrespective of patient position.

Based on recent studies, the decision to prone a patient with ARDS should be contemplated once the P/F ratio is less than 150. At least 16 hours of proning is recommended, which can be increased to 24 hours.[8]

As before any potentially complicated airway procedure, preoxygenation with 100% oxygen is advisable. The fraction of inspired oxygen (FIO_2) can be **gradually decreased** after proning has been successfully completed.

Based on the recommendations from the PROSEVA trial, prone positioning can be discontinued once PaO_2/FIO_2 remained $>$ 150 mm Hg 4 hours after supinating (PEEP $<$ 10 cm H_2O and $FIO_2 < 0.6$). For initiating PP in a ventilated patient and later supination from PP, 3 to 5 caregivers are required.[9]

Semiprone Position

When complete prone positioning is logistically impossible or difficult or if there is a relative contraindication (eg, intra-abdominal hypertension or recent laparotomy), a semiprone position can be adopted. TM Schmitz (1991)[10] published an article describing 5 case studies involving ventilation in the semiprone position in patients with ARDS. The semiprone position was easy to adopt and required less personnel to do so. Although there was improvement in oxygenation in this position, it was not substantial when compared to the complete PP.

Use of Neuromuscular Blockers

Use of neuromuscular blocking agents (NMBA) during PP improves oxygenation but not until 48 hours and was associated with lower volutrauma and barotrauma as its use avoids high regional transpulmonary pressures. The ACURASYS (ARDS et Curarisation Systematique) trial demonstrated that rate of pneumothorax was lower in than neuromuscular blocking agent group than placebo.[11] The trial also demonstrated that death at 90 days was less with neuromuscular blocking agent use than with placebo after adjusting for confounding variables like PaO2/FIO2 ratio, SAPS II (Simplified Acute Physiology Score), and end-inspiratory plateau airway pressure levels. The Faculty of Intensive Care Medicine and Intensive Care Society Guideline Development Group suggests use of cisatracurium besylate as an infusion for 48 hours in moderate to severe ARDS and this is recommended during prone ventilation. [12]

Enteral Feeding

Enteral feeding is generally continued safely while the patient is prone, although there are few studies to guide this aspect of care. A systematic review and meta-analysis by Machado et al,[13] suggests that the available evidence for the effect of enteral nutrition administered in the prone position for critically ill patients, in terms of gastrointestinal tolerance and clinical outcomes, is scarce. Therefore, the benefits and safety cannot be commented upon in detail.

Surgical Patients

In a surgical setting, it is traditional to use abdomino-pelvic supports (unrestricted proning) to allow free movement of the abdomen. When such supports are not used, the abdomen and chest rest directly on the mattress (restricted proning) which can increase intra-abdominal pressure and impede abdominal wall excursion.

Logistics of Proning

Tables 2 and 3 summarise the 'algorithm for prone ventilation'. The algorithm has been adapted from the Intensive Care Society and Faculty of Intensive Care Medicine. [14]

OTHER CONSIDERATIONS

Carbon Dioxide Elimination

Although PP improves Pa_{O_2} it does not necessarily improve carbon dioxide clearance despite homogenous aeration. Guérin et al suggested that when Pa_{O_2} increases with the initiation of prone ventilation but Pa_{CO_2} does not simultaneously decrease,

Step	Before Proning	Time Out	Sign Out
1	Confirm members involved	Minimum 5 people	Endotracheal tube length at teeth; capnography
2	Look for contraindications	Role description	Connect monitoring
3	Keep reintubation equipment ready	Appropriate ventilator settings	Review ventilator settings
4	Eye care	Hemodynamic stability	Secure all lines
5	Secure endotracheal tube	Adequate sedation **(Richmond Agitation Sedation Scale-5)**	Unclamp chest tubes
6	Hold nasogastric feed	Muscle relaxation (bolus)	Check pressure areas (lips, eyes, ears, genitals), nasogastric tube, lines, pillow placement
7	Discontinue unimportant infusions and monitoring	Pillow placement (chest, pelvis, knees)	Remove slide sheet and 30-degree reverse Trendelenburg position
8	Clamp chest tubes (if present)	Confirm familiarity with prone position	Recheck nasogastric position and restart feeds
9	Assess and document skin integrity		Availability of postprone care bundle
10	Secure pressure points		
11	Complete oral care, bath, wound dressing		

Table 2. Prone Position Checklist for an Indication of ARDS with P/F Ratio < 150 (adapted from Intensive Care Society and the Faculty of Intensive Care Medicine. [14]

Parameter	Action
Location	
Head/Face	Endotracheal tube mark at teeth/kinking/tracheostomy accessibility
	Ventilator connection to definitive airway
	Cuff pressure
	Compression on lips, if any
	Dermal gel pads between endotracheal tube and skin
	Suctioning postproning
	Eyes taped
	No pressure on the eyes
	Reverse Trendelenburg 30-degree
	Turn head from side to side every 2 h
	Nasogastric tube secure and no pressure on nostril
	Neck
	No hyperextension of lower back and neck
	No compression on the front of neck
	Central line secure
Chest	Chest tube patent and secure
	No pressure and adequate support for the breasts
Abdomen	Abdomen is free
Pelvis	Pelvis support cushion are present
	Male genitals between legs
	Urinary catheter is free and between legs
Arms	Arms by the side, hands free
	No rotation of shoulder
	No compression over elbow
	Wrists in neutral position
	Alternate swimmers' position every 2-4 h
	No peripheral line under the patient
Legs	Pillows under shins to prevent extension
Infusions/ monitoring	Establish all infusions and monitoring as in supine position
	No infusion lines on patient's skin
	Check patency of lines (central line, **continuous renal replacement therapy lines**)
	Place electrocardiogram electrode over back and not underneath
	Adequate sedation and analgesia
	Dynamic mode mattress
	Arterial blood gas 20-30 min after proning

Table 3. Postproning Nursing Checklist for an Indication of ARDS with P/F Ratio $<$ 150 (adapted from Rae[2])

it could be because either cardiac output is lowered or alveolar dead space ventilation is increased by PEEP, which is suggestive of overdistension of the lung. [9] In patients who are Pa_{CO_2} responders, the alveoli are more recruitable than in the patients who are not. Persistent hypercapnia has deleterious effects on right heart function which can correlate with poor outcomes.[15]

PP and Extracorporeal Membrane Oxygenation

In recent years, extracorporeal membrane oxygenation (ECMO) has become an essential tool in the care of adults and children with severe cardiac and pulmonary dysfunction that is refractory to conventional management. Based on the reports of a meta-analysis by Combes et al,[16] the 90-day mortality was significantly lower with the use of ECMO than with conventional management. However, ECMO is an invasive procedure that requires arterial and venous cannulation with large-bore catheters and thereafter needs systemic anticoagulation. ECMO, therefore, carries some significant risks.

In a multicentre retrospective cohort study by Chang et al,[17] the authors concluded that patients with severe influenza pneumonia-related ARDS who received PP had lower mortality rates than did those receiving ECMO at day 60. However, this was a small sample size study (n = 263) and the authors suggested further studies to investigate the superiority of PP versus ECMO. Meanwhile, they recommended considering PP before initiating ECMO.

PP ventilation can be undertaken whilst simultaneously using ECMO. However, care is clearly needed during positioning to reduce complications such as catheter displacement.

Contraindications for PP

Following are the only absolute contraindications for PP in ARDS:[18,19]

- Unstable spine fracture
- Open chest post–cardiac surgery/trauma
- Less than 4 hours post–cardiac surgery
- Central cannulation for veno-arterial ECMO or biventricular assist device support

Prone positioning is not contraindicated in head injury patients. In patients with intracranial pressure of less than 20 mm Hg with hemodynamic stability, prone ventilation can be offered. In the absence of an intracranial pressure monitor, prone ventilation should preferably be deferred.

Following are the relative contraindications of PP:

- Hemodynamic instability; ongoing inotropes/vasopressors
- Open abdominal wounds
- Long-bone fractures
- Morbid obesity
- Late-term pregnancy
- Recent tracheostomy
- Ongoing seizures
- Raised intraocular pressure
- Severe facial fractures

Adverse Events Associated With Prone Ventilation[20,21]

Airway and Breathing

- Facial and airway oedema
- Kinking or displacement of endotracheal tube (accidental extubation or endobronchial intubation)
- Difficulty in endotracheal suctioning
- Barotrauma
- Desaturation (usually transient)

Circulation

- Subconjunctival haemorrhage
- Hypotension
- Arrhythmias
- Difficulty in performing cardiopulmonary resuscitation

Others

- Occlusion or accidental removal of chest tube, nasogastric tube, central lines, urinary catheter, peripheral vascular access
- Deep vein thrombosis
- Peripheral nerve injuries
- Enteral feed intolerance
- Pressure sores on the face, chest wall, and abdomen (utilisation of wound and skin care nurses has shown to reduce the incidence of pressure sores by 97%)

AWAKE PP

Traditionally, PP is employed in patients with moderate to severe ARDS who are mechanically ventilated. However, during the COVID19 pandemic, awake prone positioning was used by many clinicians in patients with moderate ARDS. Many of these patients showed marked improvement in P/F ratio and Spo_2 with improvement in clinical symptoms and a reduced rate of intubation. These patients received either high-flow nasal oxygenation or noninvasive ventilation.[22]

These patients were able to tolerate the position well, could pronate and supinate themselves, and could continue oral intake as tolerated. Awake PP is cost effective, requires minimal numbers of caregivers, is easy to perform, can be performed in high-dependency units, and is associated with fewer of the adverse effects mentioned earlier.[23]

SUMMARY

Based on the current evidence, it is prudent to consider early PP in patients with refractory hypoxemia if not responding in the initial 48 hours in patients with moderate or severe ARDS. The duration of PP should be at least 16 hours followed by a period of supination for 4 hours. Other than improvement in oxygenation, PP can improve secretion clearance, leads to a homogeneous distribution of transpulmonary pressures, and improves right heart function.

References

1. ARDS Definition Task Force, Ranieri VM, Rubenfeld GD, et al. Acute respiratory distress syndrome: the Berlin Definition. *JAMA*. 2012;307(23):2526-2533. doi:10.1001/jama.2012.5669
2. Rae J. Acute respiratory distress syndrome. Accessed November 2, 2022. https://resources.wfsahq.org/atotw/acute-respiratory-distress-syndrome/
3. Bryan AC. Conference on the scientific basis of respiratory therapy. Pulmonary physiotherapy in the pediatric age group. Comments of a devil's advocate. *Am Rev Respir Dis*. 1974;110(6 Pt 2):143-144. doi:10.1164/arrd.1974.110.6P2.143
4. Douglas WW, Rehder K, Beynen FM, Sessler AD, Marsh HM. Improved oxygenation in patients with acute respiratory failure: the prone position. *Am Rev Respir Dis*. 1977;115(4):559-566. doi:10.1164/arrd.1977.115.4.559
5. Henderson WR, Griesdale DE, Dominelli P, Ronco JJ. Does prone positioning improve oxygenation and reduce mortality in patients with acute respiratory distress syndrome? *Can Respir J*. 2014;21(4):213-215. doi:10.1155/2014/472136
6. Zochios V, Parhar K, Vieillard-Baron A. Protecting the right ventricle in ARDS: the role of prone ventilation. *J Cardiothorac Vasc Anesth*. 2018;32(5):2248-2251. doi:10.1053/j.jvca.2018.01.007
7. Guérin C, Reignier J, Richard JC,. Prone positioning in severe acute respiratory distress syndrome. *N Engl J Med*. 2013;368(23):2159-2168. doi:10.1056/NEJMoa1214103
8. Gattinoni L, Taccone P, Carlesso E, Marini JJ. Prone position in acute respiratory distress syndrome. Rationale, indications, and limits. *Am J Respir Crit Care Med*. 2013;188(11):1286-1293. doi:10.1164/rccm.201308-1532CI
9. Guérin C, Albert RK, Beitler J, et al. Prone position in ARDS patients: why, when, how and for whom. *Intensive Care Med*. 2020;46(12):2385-2396. doi:10.1007/s00134-020-06306-w
10. Schmitz TM. The semi-prone position in ARDS: five case studies. *Crit Care Nurse*. 1991;11(5):22, 25-26, 28-30 passim. doi:10.4037/ccn1991.11.5.22
11. Papazian L, Forel JM, Gacouin A, et al. Neuromuscular blockers in early acute respiratory distress syndrome. *N Engl J Med*. 2010;363(12):1107-1116. doi:10.1056/NEJMoa1005372
12. Griffiths MJD, McAuley DF, Perkins GD, et al. Guidelines on the management of acute respiratory distress syndrome. BMJ Open Respir Res. 2019; 6(1):e000420. doi: 10.1136/bmjresp-2019-000420.
13. Machado LS, Rizzi P, Silva FM. Administration of enteral nutrition in the prone position, gastric residual volume and other clinical outcomes in critically ill patients: a systematic review. *Rev Bras Ter Intensiva*. 2020;32(1):133-142. doi:10.5935/0103-507x.20200019.0
14. Intensive Care Society, Faculty of Intensive Care Medicine. New guidance for prone positioning in adult critical care. Accessed on November 8th, 2022.. https://ics.ac.uk/resource/new-guidance-for-prone-positioning-in-adult-critical-care.html
15. Gattinoni L, Vagginelli F, Carlesso E, et al. Decrease in $PaCO_2$ with prone position is predictive of improved outcome in acute respiratory distress syndrome. *Crit Care Med*. 2003;31(12):2727-2733. doi:10.1097/01.CCM.0000098032.34052.F9
16. Combes A, Hajage D, Capellier G, et al. Extracorporeal membrane oxygenation for severe acute respiratory distress syndrome. *N Engl J Med*. 2018;378(21):1965-1975. doi:10.1056/NEJMoa1800385
17. Chang KW, Hu HC, Chiu LC, et al. Comparison of prone positioning and extracorporeal membrane oxygenation in acute respiratory distress syndrome: a multicenter cohort study and propensity-matched analysis. *J Formos Med Assoc*. 2022;121(6):1149-1158. doi: 10.1016/j.jfma.2021.10.007
18. Bruni A, Garofalo E, Longhini F. Avoiding complications during prone position ventilation. Intensive Crit Care Nurs. 2021; 66:103064. doi: 10.1016/j.iccn.2021.103064.
19. Reinprecht A, Greher M, Wolfsberger S, Dietrich W, Illievich UM, Gruber A. Prone position in subarachnoid hemorrhage patients with acute respiratory distress syndrome: effects on cerebral tissue oxygenation and intracranial pressure. *Crit Care Med*. 2003;31(6):1831-1838. doi: 10.1097/01.CCM.0000063453.93855.0A

20. González-Seguel F, Pinto-Concha JJ, Aranis N, Leppe J. Adverse events of prone positioning in mechanically ventilated adults with ARDS. *Respir Care*. 2021;66(12):1898-1911. doi:10.4187/respcare.09194
21. Johnson C, Giordano NA, Patel L, et al. Pressure injury outcomes of a prone-positioning protocol in patients with COVID and ARDS. *Am J Crit Care*. 2022;31(1):34-41.
22. Dhrmann S, Li J, Ibarra-Estrada M, et al. Awake prone positioning for COVID-19 acute hypoxaemic respiratory failure: a randomised, controlled, multinational, open-label meta-trial. *Lancet Respir Med*. 2021;9(12):1387-1395. doi:10.1016/S2213-2600(21)00356-8
23. Singh P, Jain P, Deewan H. Awake prone positioning in COVID-19 Patients. *Indian J Crit Care Med*. 2020;24(10):914-918. doi:10.5005/jp-journals-10071-23546
24. Pelosi P, Brazzi L, Gattinoni L. Prone position in acute respiratory distress syndrome. Eur Respir J. 2002; 20(4):1017-28. doi: 10.1183/09031936.02.00401702.