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## INTRODUCTION

Invasive mechanical ventilation is traditionally delivered with the patient in the supine position. Prone ventilation is ventilation that is delivered with the patient lying in the prone position. Prone ventilation may be used for the treatment of acute respiratory distress syndrome (ARDS) mostly as a strategy to improve oxygenation when more traditional modes of ventilation fail (eg, lung protective ventilation).

The physiologic effects of, selection of patients for, and the outcomes associated with prone ventilation are reviewed here. Approaches to mechanical ventilation and supportive care for patients with ARDS are described separately. (See "[Ventilator management strategies for adults with acute respiratory distress syndrome](#)" and "[Acute respiratory distress syndrome: Supportive care and oxygenation in adults](#)".)

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## DEFINITION

Prone ventilation refers to the delivery of mechanical ventilation with the patient lying in the prone position. Prone ventilation is NOT considered a mode of mechanical ventilation. Volume-controlled and pressure-controlled modes of ventilation are the typical modes of ventilation that are delivered in the prone position. Other modes of ventilation including high frequency

ventilation and other methods of improving gas exchange (eg, extracorporeal membrane oxygenation [ECMO]) are not generally administered in the prone position but may be used in conjunction with prone positioning. Modes of mechanical ventilation are discussed separately. (See "[Modes of mechanical ventilation](#)" and "[Extracorporeal membrane oxygenation \(ECMO\) in adults](#)" and "[High-frequency ventilation in adults](#)".)

## PHYSIOLOGIC EFFECTS ON OXYGENATION

The prone position alters the mechanics and physiology of gas exchange to result consistently in improved oxygenation. The improvement of oxygenation during prone ventilation is multifactorial ([table 1](#)). Prone positioning improves gas exchange by ameliorating the ventral-dorsal transpulmonary pressure difference, reducing dorsal lung compression, and improving lung perfusion ([figure 1](#) and [figure 2](#)).

Increased functional residual capacity (FRC) has also been proposed, but changes in FRC have not been a dominant finding in most studies of prone ventilation [[1-3](#)]. Changes in the distribution of extravascular lung water and secretions may also play a role.

**Reducing ventral-dorsal transpulmonary pressure difference** — The distending pressure across the lung is estimated by the transpulmonary pressure (Ptp), which is defined as the difference between the airway pressure (Paw) and pleural pressure (Ppl);  $P_{tp} = P_{aw} - P_{pl}$ . The difference between ventral and dorsal Ptp appears to be favorably affected by prone positioning.

- **The effects of supine positioning** – When an individual is supine, the dorsal Ppl is greater than ventral Ppl. As a result, the ventral Ptp exceeds the dorsal Ptp and there is greater expansion of the ventral alveoli than the dorsal alveoli. This effect is exaggerated in supine patients with acute respiratory distress syndrome (ARDS), probably because the difference between the dorsal and ventral pleural pressures is increased by the excess lung weight. The result is a tendency towards overinflation of the ventral alveoli and atelectasis of the dorsal alveoli ([image 1](#)) [[4,5](#)].
- **The effects of prone positioning** – Prone positioning reduces the difference between the dorsal and ventral Ptp, making ventilation more homogeneous [[6](#)], leading to a decrease in ventral alveolar overinflation and dorsal alveolar collapse [[7](#)]. As a result, reduced alveolar distension limits ventilator-associated lung injury from overdistention and cyclic atelectasis. Prone ventilation also recruits (ie, opens) alveoli that had collapsed during the supine ventilation, a process that may continue over time when the patient is lying prone while receiving appropriate positive end expiratory pressure (PEEP). The result is improved

ventilation and oxygenation, which many patients sustain even after they return to the supine position [1,7-9]. (See "[Ventilator management strategies for adults with acute respiratory distress syndrome](#)".)

**Reduced lung compression** — Lung compression by both the heart and the diaphragm can be favorably affected by prone positioning.

- **The effects of supine positioning** – When an individual with ARDS is supine, the heart compresses the medial posterior lung parenchyma and the diaphragm compresses the posterior-caudal lung parenchyma. The latter is caused by the abdominal contents displacing the diaphragm cranially, which can be exacerbated by a loss of diaphragmatic tone due to sedation and/or paralysis or increased abdominal pressure [10]. Compression by either the heart and/or the diaphragm may exaggerate dependent lung collapse in the supine position, increasing hypoxemia (ie, worsening shunt) and ventilator-associated lung injury [11].
- **The effects of prone positioning** – During prone ventilation, the heart becomes dependent, lying on the sternum, potentially decreasing medial posterior lung compression. In addition, the diaphragm is displaced caudally (especially in obese patients and when the abdomen is left unsupported), decreasing compression of the posterior-caudal lung parenchyma [12]. These effects improve ventilation and oxygenation [13].

**Improved lung perfusion** — Improved perfusion of the dependent portions of the lung is thought to be partially responsible for the improved oxygenation seen with prone ventilation.

- **The effects of supine position** – In ARDS, there is substantial ventilation-perfusion mismatch in the supine position, since blood flow and alveolar collapse are both greatest in the dependent portions of the lung.
- **The effects of prone positioning** – Ventilation/perfusion match improves when the patient is moved into the prone position as the previously dependent lung continues to receive the majority of the blood flow (independent of the gravitational gradient) as alveoli reopen, while the newly dependent lung continues to receive the minority of the blood flow as alveoli begin to collapse [14]. In addition, increases in cardiac output have been observed and thought to be due to the effect of increased lung recruitment and reduction in hypoxic pulmonary vasoconstriction resulting in increases in right ventricular preload and decreased right ventricular afterload and a decrease in pulmonary vascular resistance [6,15-19].

It was previously hypothesized that prone ventilation permits the redistribution of blood flow based on gravitational gradient. However, there is little evidence to support this belief, with most

studies indicating that the blood flow pattern changes only modestly upon turning prone [20-22]. Even with similar degrees of dependent atelectatic alveoli, the shunt fraction is decreased and oxygen tension will generally be higher in the prone patient.

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## EFFICACY

Consistently, most trials demonstrate improved oxygenation with ventilation in the prone position. One randomized trial and several meta-analyses also suggest a mortality benefit in those with severe ARDS. Data that report the efficacy of prone ventilation are discussed below.

**Oxygenation** — Trials have consistently shown that in most patients with ARDS (up to 70 percent), prone ventilation increases PaO<sub>2</sub> allowing a reduction in the FiO<sub>2</sub> [2,23-26]. Among patients whose oxygenation improves during prone ventilation, some continue to have improved oxygenation for hours after they return to the supine position and many improve each time prone ventilation is repeated (figure 3) [8,9,27].

Most patients who demonstrate a response do so within the first hour but delayed responses beyond that have been observed.

For example, in an uncontrolled trial of 13 patients with moderate to severe ARDS, two-thirds of patients had a sustained response defined as a 10 mmHg increase in PaO<sub>2</sub> over the first 30 minutes of prone ventilation that predicted a sustained increase in PaO<sub>2</sub> over the next two hours [28]. In contrast, in the remaining one-third of patients whose PaO<sub>2</sub> did not increase during the first 30 minutes of prone ventilation, no subsequent improvement in oxygenation was noted.

Although poorly studied, the following patient-related factors may also predict improved oxygenation during prone ventilation:

- Patients with diffuse pulmonary edema and dependent alveolar collapse appear more likely to improve their PaO<sub>2</sub> during prone ventilation than patients with predominantly anterior abnormalities, marked consolidation, and/or fibrosis [29].
- Patients with an extrapulmonary cause for their ARDS seem more likely to increase their PaO<sub>2</sub> during prone ventilation than patients with a pulmonary cause at least in some studies [30].
- Patients with elevated intra-abdominal pressure appear more likely to increase their PaO<sub>2</sub> during prone ventilation than patients with normal intraabdominal pressure [31].
- Patients whose chest wall compliance decreases when moving from the supine to the prone

position are likely to improve their PaO<sub>2</sub> during prone ventilation [2].

**Mortality** — While a mortality benefit with prone ventilation in patients with severe ARDS has been reported in some studies, important study limitations preclude a definite conclusion. Early randomized trials and meta-analyses initially reported no mortality benefit with prone positioning for patients with ARDS in general [32-39]. Since then, one large randomized trial (PROSEVA) and several meta-analyses (some of which included PROSEVA and some of which did not) have reported mortality benefits from early, high-dose prone ventilation in the subpopulation of patients with severe ARDS (defined by them as PaO<sub>2</sub>:FiO<sub>2</sub> <150 mmHg) [26,40-45]. Separate meta-analyses that included PROSEVA additionally suggested that the improved survival from prone ventilation is only observed in those who concomitantly receive low, but not high, tidal volume ventilation [37,44]. While encouraging, a second randomized trial will be needed to validate this mortality benefit.

The benefit of prone ventilation in the subpopulation with severe ARDS who are mechanically ventilated with low tidal volumes is best supported by a single large randomized trial of early (within 33 hours of intubation), high-dose (17 consecutive hours) prone ventilation (PROSEVA) [26]. This trial of 466 patients receiving low tidal volume mechanical ventilation for severe ARDS (PaO<sub>2</sub>:FiO<sub>2</sub> <150 mmHg, FiO<sub>2</sub> ≥0.6, PEEP ≥5 cm H<sub>2</sub>O), reported that, compared with patients ventilated in the supine position, patients receiving prone ventilation (average time spent prone: 73 percent) had a reduction in 28-day mortality (16 versus 33 percent; hazard ratio [HR], 0.39; 95% CI, 0.25-0.63) and 90-day mortality (24 versus 41 percent; HR, 0.44; 95% CI, 0.29-0.67, respectively). The mortality benefit occurred without excess risk of complications. In addition, patients in the prone group needed less rescue therapy including ECMO (1 versus 2.6 percent) or inhaled [nitric oxide](#) (10 versus 16 percent). (See '[Prone procedure](#)' below.)

Important limitations in this trial (PROSEVA) that may have affected the outcome or limit its generalizability are the following [26]:

- The intervention was applied to a highly selective group of patients that represent only a minority of patients with ARDS. Of the 1434 patients with severe ARDS screened, 858 were not eligible on the basis of exclusion criteria alone ([table 2](#)). An additional 107 patients were excluded prior to randomization due to improvement after a predefined 12 to 24 hour window, organizational issues, or withdrawal by their physician. Thus, the mortality benefit likely applies to a small select group of patient with ARDS. (See '[Contraindications](#)' below.)
- The list of exclusion criteria was lengthy and included elevated intracranial pressure, spinal or other fracture instability, massive hemoptysis, deep venous thrombosis treated for less than two days, a mean arterial pressure less than 65 mmHg, anterior chest tube with leaks,

chronic oxygen-dependent respiratory failure, use of noninvasive ventilation (NIV), inhaled [nitric oxide](#) or almitrine bismesylate, or ECMO before inclusion ([table 2](#)). Thus, patient selection for prone positioning appears to be important in determining a good outcome.

- Despite randomization, patient groups were not matched. Patients ventilated in the supine position had higher sequential organ failure assessment (SOFA) scores and were receiving more pressors, suggesting they were a sicker population of patients that may have biased the outcome. In addition, more patients in the prone group received neuromuscular blocking agents, which may have favorably affected the outcome. (See "[Predictive scoring systems in the intensive care unit](#)", section on '[Sequential \(sepsis-related\) Organ Failure Assessment \(SOFA\)](#)' and "[Neuromuscular blocking agents in critically ill patients: Use, agent selection, administration, and adverse effects](#)".)
- Study site staff had extensive experience (five years) with prone ventilation so that the same benefits may not apply to facilities with untrained staff.
- At the time of randomization patients had on average PEEP of <10 cm H<sub>2</sub>O. Based on the ARDSnet tables ([table 3](#)), PEEP in these patients was not adequately optimized prior to proning.

Several meta-analyses that include PROSEVA confirm similar benefits [\[42-45\]](#). As an example, one meta-analysis of eight randomized trials reported lower mortality in patients severe ARDS and particularly in those with 12 hours or more of proning (risk ratio 0.74) [\[45\]](#). Another network meta-analysis of 25 trials that examined several ventilatory interventions in patients with moderate to severe ARDS on low tidal volume ventilation reported that prone positioning was associated with a lower 28-day mortality (risk ratio [RR] 0.69, 95% CI 0.48-0.99) [\[46\]](#).

**Other Outcomes** — There is no evidence that prone ventilation prevents organ system dysfunction [\[34\]](#) or reduces the intensive care unit (ICU) length of stay [\[32,35\]](#). Prior studies suggested that it does not shorten the duration of mechanical ventilation [\[32,33\]](#). However, the large randomized PROSEVA trial suggested improvement in ventilator-free days (14 versus 10 ventilator-free days at day 28) and time to extubation (85 versus 65 percent successful extubations at day 90) in the prone position group [\[26\]](#).

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## INDICATIONS

**Severe acute respiratory distress syndrome** — For most patients with acute respiratory distress syndrome (ARDS), we recommend using lung protective strategies (ie, low tidal volume

ventilation and plateau pressure <30 cm H<sub>2</sub>O) in the supine position rather than prone position as the initial ventilation strategy (see "[Ventilator management strategies for adults with acute respiratory distress syndrome](#)", section on '[Low tidal volume ventilation \(LTVV\): Initial settings](#)'). However, for patients with severe ARDS who fail to improve despite use of such ventilatory strategies, we suggest a trial of prone ventilation, provided there is no contraindication ([table 2](#)) [[47](#)]. Prone ventilation may also be used on a trial basis in patients with ARDS who have refractory hypoxemia that is unresponsive to multiple attempts at optimizing ventilator settings (eg, lung protection plus permissive hypercapnia) or as a bridge to extracorporeal membrane oxygenation (ECMO). Prone positioning does not appear to consistently benefit those with mild or moderate ARDS.

Our view that prone ventilation be reserved as a rescue therapy in this population is based upon one randomized trial that showed a mortality benefit (PROSEVA), where there was a 12 to 24 hour stabilization period using a supine lung protective strategy before the initiation of prone ventilation in patients with severe ARDS [[26](#)] (see '[Efficacy](#)' above). In keeping with the observation that this strategy is appropriate in only a select proportion of ARDS patients, one multicenter, international study reported that prone positioning was used by experts in 16 percent of patients with severe ARDS [[48](#)].

The degree of hypoxemia and severity of ARDS that warrants prone ventilation has been variably defined:

- Severe ARDS – PROSEVA defined severe ARDS as those having a partial pressure of arterial oxygen:fraction of inspired oxygen (PaO<sub>2</sub>:FiO<sub>2</sub>) ratio <150 mmHg with a FiO<sub>2</sub> ≥0.6 and PEEP ≥5 cm H<sub>2</sub>O; at study entry, the median PaO<sub>2</sub> was 80 mmHg (range 62 to 98 mmHg; 8.3 to 13 kPa), fraction of inspired oxygen was 0.8 (range 0.75 to 0.95), and PaO<sub>2</sub>:FiO<sub>2</sub> ratio was 100 mmHg [[26](#)]. This definition deviates from the Berlin definition where severe ARDS is defined as a PaO<sub>2</sub>:FiO<sub>2</sub> ratio <100 mmHg. (See "[Acute respiratory distress syndrome: Clinical features, diagnosis, and complications in adults](#)", section on '[Clinical diagnosis \(Berlin definition\)](#)'.)
- Refractory hypoxemia due to ARDS – An alternative reasonable definition is a PaO<sub>2</sub>:FiO<sub>2</sub> of ≤100 mmHg with a PaO<sub>2</sub> ≤60 mmHg despite optimization of the ventilator settings on FiO<sub>2</sub> of 1 (ie refractory hypoxemia) [[26,32,40](#)]. (See "[Acute respiratory distress syndrome: Supportive care and oxygenation in adults](#)", section on '[Management of hypoxemia](#)'.)

For patients with ARDS who have hypoxemia that is immediately life-threatening in whom an increase in oxygenation is urgently required or who are rapidly progressive despite optimizing ventilator settings, strategies other than proning such as ECMO or pulmonary vasodilators may

be more appropriate, if available. (See "[Extracorporeal membrane oxygenation \(ECMO\) in adults](#)" and "[Acute respiratory distress syndrome: Supportive care and oxygenation in adults](#)", section on 'Management of hypoxemia'.)

In rare circumstances, prone ventilation has been used as a bridge to ECMO [49].

The benefits appear to be consistent among those with ARDS from many etiologies as well as ARDS occurring in those with underlying lung disease or obesity [50-54].

The use of prone ventilation has not been studied in non-ARDS populations and the rationale for it is limited.

Practical aspects of prone positioning including the contraindications are discussed separately. (See '[Prone procedure](#)' below.)

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## CONTRAINDICATIONS

Absolute contraindications to prone ventilation include spinal instability, patients at risk of spinal instability (eg, rheumatoid arthritis), unstable fractures (especially facial and pelvic), anterior burns, chest tubes, and open wounds, shock, pregnancy, recent tracheal surgery, and raised intracranial pressure ([table 2](#)). For patients whose spine has been stabilized with surgery, close consultation with the operating surgeon is recommended before prone positioning is instituted. Relative contraindications include hemodynamic instability (eg, mean arterial pressure [MAP] <65 mmHg) and cardiac abnormalities (eg, freshly placed pacemaker, life threatening arrhythmias, ventricular assist devices, balloon pumps); devices may be dislodged or immediate access for cardiopulmonary resuscitation may be needed urgently. Thoracic and abdominal surgeries are also considered relative contraindications, although prone ventilation has been accomplished safely during the early postoperative period. Other relative contraindications include difficult airway or difficult intubation and massive hemoptysis.

Exclusion criteria in PROSEVA, included many of the contraindications listed above and also massive hemoptysis, deep venous thrombosis treated for less than two days, a mean arterial pressure less than 65 mmHg, anterior chest tube with leaks, chronic oxygen-dependent respiratory failure, use of noninvasive ventilation (NIV), inhaled [nitric oxide](#) or almitrine bismesylate, use of extracorporeal membrane oxygenation (ECMO), and burns [26].

Prone ventilation is not contraindicated in those who require vasopressors provided patients have a stable MAP  $\geq$ 65 mmHg. Similarly, receiving renal replacement therapy through femoral, jugular, or subclavian catheters is not considered a contraindication, with the exception of



peritoneal dialysis. It is unknown whether prone positioning should be avoided in those who require continuous renal replacement therapy.

Obesity is not is not generally considered a contraindication. In one randomized trial that demonstrated a mortality benefit, the median body mass index was 28, ranging from 21 to 36 [26]. However, turning patients with massive obesity may pose more procedural challenges.

While not advised, some case reports suggest successful use in patients with chest wall trauma and traumatic brain injury [55].

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## PRONE PROCEDURE

Despite evidence in favor of prone ventilation, adoption of this strategy has been slow in the United States, compared with Europe, likely due to the perceived operational barriers to performing it. Nonetheless, most large academic centers in both continents have policies in the practice of prone ventilation so that it can be provided safely, when needed. For patients who meet the criteria for prone ventilation (see '[Indications](#)' above), the strategy for implementing it is described in the following sections.

**Timing of initiation** — After a 12 to 24 hour stabilization period of supine ventilation, we maintain a low threshold for initiating prone ventilation early (up to 36 hours) in the course of mechanical ventilation for severe acute respiratory distress syndrome (ARDS). This is based on the observation from PROSEVA and additional trials that early initiation of prone ventilation was most effective, as well as the physiologic rationale that collapsed lung units are likely to be opened (ie, recruited) most easily during the acute exudative phase of ARDS [26,35]. (See '[Efficacy](#)' above.)

**Positioning** — There is no standard method for moving a patient from the supine to the prone position. Our intensive care unit uses a log roll, which is described step-by-step in the table ([table 4](#)). We suggest that facilities that want to offer prone ventilation, be educated in its use and have a readily accessible policy describing all aspects of the procedure. [This video](#) is freely available while another video is available at [this site](#) for those with login access.

Commercially available beds can initiate, maintain, and facilitate prone positioning, may minimize risk during turning, and some provide continuous rotation, if desired [56,57]. One retrospective cohort study of 61 surgical and trauma patients with ARDS reported that compared with supine positioning, use of a commercially available proning bed resulted in improved oxygenation and mortality [41]. However, no comparisons were made with manual prone positioning protocols to

justify widespread use of commercially available beds that have proning function.

Regardless of the technique, moving the patient into the prone position is labor-intensive requiring a coordinated effort among respiratory therapists and nurses for each turn [56]. The respiratory therapist ensures the stability of the endotracheal tube, one nurse protects the vascular access lines, and at least two other staff members turn the patient. An experienced clinician who can reintubate the patient if necessary should also be present.

All involved staff should know how to quickly put the patient back into the supine position, if necessary, since this is required if cardiopulmonary resuscitation becomes necessary.

Transient hemodynamic instability and oxyhemoglobin desaturation related to turning the patient is frequent and can be minimized by providing adequate sedation and preoxygenating with a fraction of inspired oxygen (FiO<sub>2</sub>) of 1 prior to moving the patient [8].

**Ventilatory strategies** — The delivery of invasive mechanical ventilation in the prone position is similar to that employed when the patient is supine. For patients with ARDS, this is typically a ventilation strategy that incorporates low tidal volumes and similar to patients with ARDS who are ventilated supine, the optimal PEEP setting is unknown [26,37,58]. Data that support low tidal volume ventilation in the prone position are discussed above. (See '[Mortality](#)' above and '[Ventilator management strategies for adults with acute respiratory distress syndrome](#)'.)

Prone positioning is rarely combined with other modes of ventilation (eg, noninvasive ventilation, high frequency ventilation) or therapies for improving oxygenation (eg, inhaled [nitric oxide](#), extra corporeal membrane oxygenation), although rare case reports suggest success [59-61]. (See '[High-frequency ventilation in adults](#)' and '[Noninvasive ventilation in acute respiratory failure in adults](#)' and '[Acute respiratory distress syndrome: Supportive care and oxygenation in adults](#)', section on '[Management of hypoxemia](#)'.)

Peak and plateau airway pressures may increase immediately after a patient is placed in the prone position, but typically decline with time. The initial increase is likely related to decreased chest wall compliance and the mobilization of secretions, while the subsequent decrease is probably due to progressive alveolar recruitment [62].

**Monitoring** — Prone ventilation does not require additional monitoring, although the need for endotracheal suctioning should be assessed with increased frequency after the patient is placed prone because large quantities of pulmonary secretions may drain into the endotracheal tube; in some patients this effect may be quite dramatic.

Electrocardiographic leads should be placed on the back.

All other forms of monitoring are routine (eg, central venous pressure).

**Feeding** — Once prone, enteral tube feeds and usual mouth and skin care can be resumed. However, enteral feeding during prone ventilation can be complicated by emesis and/or increased residual gastric volumes [63,64]. In order to minimize such complications, we prefer a cautious approach to enteral feeding in the prone position, with proper positioning (head of the patient slightly elevated), monitoring, and judicious use of prokinetic agents. One study evaluated the use of a protocol consisting of continuous feeding with rate increased by 25 cc every six hours, 25 degree head elevation and prophylactic [erythromycin](#) (250 mg IV every six hours) in 69 patients ventilated in the prone position. This strategy allowed faster titration to nutrition target without increased gastric residuals, vomiting, or ventilator-associated pneumonia [65]. Tube feeds should be temporarily switched off and the stomach emptied before repositioning back to the supine position. (See "[Nutrition support in critically ill patients: Enteral nutrition](#)".)

**Sedation** — All patients in whom prone ventilation is performed require increased sedation and some require neuromuscular blockade. In a major randomized trial (PROSEVA), more patients in the prone ventilation group received neuromuscular blockade than in the supine groups (91 versus 82 percent) [26]. (See "[Sedative-analgesic medications in critically ill adults: Selection, initiation, maintenance, and withdrawal](#)" and "[Sedative-analgesic medications in critically ill adults: Properties, dosage regimens, and adverse effects](#)" and "[Neuromuscular blocking agents in critically ill patients: Use, agent selection, administration, and adverse effects](#)".)

**Procedures** — Most procedures are performed in the supine position, although some experts have successfully performed bronchoscopy during prone ventilation [66]. Similarly, the patients should be supine for planned transport to imaging suites and to other units.

**Duration** — The optimal duration of prone positioning is unknown. Most studies have used either repeated sessions of prone ventilation lasting six to eight hours per day [33,34] or prolonged prone ventilation lasting 17 to 20 hours per day ([figure 3](#)) [9,26,32,35], with similar results. In the one randomized study that showed a mortality benefit for prone positioning in severe ARDS (PROSEVA), the mean duration of time in the prone position was 17 hours per day with an average of four sessions in total per patient [26]. Prone ventilation was continued for the study period for up to 28 days. It was stopped for continued improvement in oxygenation ( $\text{PaO}_2:\text{FiO}_2 \geq 150$  mmHg,  $\text{FiO}_2 \leq 0.6$ ,  $\text{PEEP} \leq 10$  cm  $\text{H}_2\text{O}$ ) maintained for at least four hours after the end of the last prone session.

We believe that minimizing the frequency of turning severely ill patients decreases the likelihood of complications. Supported by data from PROSEVA, we prefer to maintain prone ventilation for longer periods (18 to 20 hours per day), with position changes as needed for interim nursing care

and interventions. Cessation of proning is appropriate after signs of improved oxygenation or for acute emergencies, prolonged interventions, or surgical procedures.

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## ASSESSING THE RESPONSE

We consider a response as a sustained improvement in gas exchange (eg, >10 mmHg PaO<sub>2</sub> on stable ventilator settings) or evidence of alveolar recruitment (eg, increase in lung compliance based on a fall in plateau pressure for a given tidal volume) that does not increase the risk of ventilator induced lung injury. Usually a response is noted during the first hour of the initial trial but longer periods (eg, 12 to 18 hours) are appropriate to ensure a response, provided no life-threatening hypoxemia is present. Importantly, if prone ventilation fails (eg, no change in the patient's gas exchange or lung mechanics, a worsening of gas exchange or cardiovascular status), the patient should be returned to the supine position and alternate strategies for improving oxygenation (eg, extracorporeal membrane oxygenation) should be pursued. (See ["Acute respiratory distress syndrome: Supportive care and oxygenation in adults"](#), section on ["Management of hypoxemia"](#) and ["Extracorporeal membrane oxygenation \(ECMO\) in adults"](#).)

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## COMPLICATIONS

Prone positioning increases the risk of certain complications listed in the table ([table 2](#)). However, estimates of the frequency of such complications have been variable [[26,32,67](#)]:

- In a randomized trial of 342 patients, the following adverse events were more likely among patients undergoing prone ventilation than among patients undergoing conventional supine ventilation: Increased need for sedation or paralysis (80 versus 56 percent), hypotension or arrhythmias (72 versus 55 percent), transient oxyhemoglobin desaturation (64 versus 51 percent), airway obstruction (51 versus 34 percent), vomiting (29 versus 13 percent), loss of venous access (16 versus 4 percent), and displacement of the endotracheal tube (11 versus 5 percent) [[32](#)].
- In contrast, a review of 240 patients who underwent prone ventilation (>746 prone cycles) reported far fewer adverse events: Hemodynamic instability (1.1 percent per prone cycle), inadvertent extubation (0.4 percent per prone cycle), decreased oxyhemoglobin saturation (0.3 percent per prone cycle), and apical atelectasis (0.3 percent per prone cycle) [[67](#)]. In addition, each of the following events occurred with an incidence of only 0.1 percent per prone cycle: obstructed endotracheal tube, kinked endotracheal tube, obstructed chest tube, dislodged central venous catheter, dislodged femoral hemodialysis catheter, compressed

tubing infusing vasoactive medications, and transient episodes of supraventricular tachycardia.

Pressure point-related adverse effects such as skin breakdown, dependent facial and ocular edema, and brachial plexus neuropathy have been reported but can be minimized by frequent repositioning, soft padding, and increased awareness of caregivers regarding these complications [68]. The frequency of pressure ulcers does not appear to be different with prone ventilation but rather occurs in different locations such as the anterior shoulder and chest, knee, and face. Risk factors for pressure ulcers mostly relate to time spent prone but male gender, age  $\geq 60$  years, and body mass index  $< 28.4$  may also increase the risk [68]. Similarly, dependent pressure on the brachial plexus may induce neuropathy. One case of ischemic optic neuropathy was reported in a patient who underwent extended prone positioning for 22 days, although it was unclear whether this complication was directly due to prone positioning or to severe hypoxemia [69].

Although not proven, centers experienced in prone positioning may have fewer complications. The only randomized controlled trial (PROSEVA) to show benefit of prone positioning for severe acute respiratory distress syndrome (ARDS) was performed in 25 centers by staff with five years of experience in prone positioning [26]. In that trial, the rate of expected complications (eg, unplanned extubation, endotracheal tube obstruction, hemoptysis, arterial desaturations, bradycardia and severe hypotension) was no different between the groups. Supine patients had a higher rate of cardiac arrest, which could be explained by the higher sequential organ failure assessment (SOFA) scores in this group. However, the lack of difference in other complications suggests that intensive care units (ICUs) experienced in turning patients frequently may protect against complications.

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## SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "[Society guideline links: Adult respiratory distress syndrome](#)" and "[Society guideline links: Assessment of oxygenation and gas exchange](#)".)

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## SUMMARY AND RECOMMENDATIONS

- Prone ventilation refers to the delivery of mechanical ventilation with the patient lying in the prone position. The prone position alters the mechanics and physiology of gas exchange to consistently result in improved oxygenation ([table 1](#)) and may result in improved mortality in

a select population of patients with severe acute respiratory distress syndrome (ARDS).

(See ['Definition'](#) above and ['Physiologic effects on oxygenation'](#) above.)

- For most patients with ARDS, we recommend using low tidal volume ventilation in the supine position rather than prone ventilation as the initial ventilation strategy. For patients who fail this strategy who have severe ARDS (partial pressure of arterial oxygen: fraction of inspired oxygen [ $\text{PaO}_2:\text{FiO}_2$ ] ratio  $<150$  mmHg with a  $\text{FiO}_2 \geq 0.6$  and positive end expiratory pressure [PEEP]  $\geq 5$  cm  $\text{H}_2\text{O}$ ) or refractory hypoxemia ( $\text{PaO}_2:\text{FiO}_2 \leq 100$  mmHg with a  $\text{PaO}_2 \leq 60$  mmHg despite optimization of the ventilator settings on  $\text{FiO}_2$  of 1) from ARDS, we suggest a trial of prone ventilation, provided there is no contraindication (**Grade 2B**). (See ['Indications'](#) above.)
- We prefer to implement prone ventilation early in the course of ARDS (within the first 36 hours) and maintain the prone position for 18 to 20 consecutive hours, with position changes as needed for interim nursing care and interventions. Low tidal volume ventilation strategies are typically concurrently employed. Cessation of proning is appropriate after signs of improved oxygenation or for acute emergencies, prolonged interventions, or surgical procedures. (See ['Prone procedure'](#) above.)
- Absolute contraindications to prone ventilation include patients with spinal instability or at risk of spinal instability, unstable fractures (especially facial and pelvic), anterior burns and open wounds, shock, pregnancy, recent tracheal surgery, and raised intracranial pressure. Other contraindications include hemodynamic instability, life-sustaining cardiac hardware (eg, ventricular assist device) and/or abdominal surgery. These and others are listed in the table ([table 2](#)). (See ['Contraindications'](#) above.)
- Prone positioning increases the risk of certain complications listed in the table ([table 2](#)). Reported rates vary but common complications include transient desaturations and dislodgement of catheters and endotracheal tubes as well as vomiting, facial and ocular edema, ischemic neuropathy and decubitus ulcers of the face, knee, and shoulders. (See ['Complications'](#) above.)

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