CME article

Prone Ventilation in ARDS

Lakshmikanthcharan S, Sivakumar MN

Email: drcharan01@gmail.com

Abstract

ARDS is a clinical syndrome characterised by severe refractory hypoxaemia associated with significant mortality and morbidity. Low tidal volume ventilation and restricting plateau pressure has got maximum survival benefit. Various others measures to tackle refractory hypoxaemia in patients with ARDS have been studied. Prone ventilation is one such rescue therapy which has shown promising results. This article is intended to discuss the benefits of prone ventilation and to clarify some of the common queries one has in practising prone ventilation.

Keywords: ARDS, prone ventilation, severe hypoxaemia.

Introduction

Ashbaugh *et al* in 1967 first described Acute Respiratory Distress Syndrome (ARDS) in a group of adult patients with severe respiratory failure and bilateral infiltrates on chest radiograph.[1] Since then ARDS has been one of the most common and challenging case group we come across in critical care management. ARDS is characterised by life-threatening hypoxaemia and methods to tackle hypoxaemia were extensively researched over years. The difficulty is that ARDS is not a single disease entity but is a syndrome due to numerous diseases both of pulmonary and extrapulmonary origin that result in injury to capillary endothelium, leakage of fluid into the interstitium and noncardiogenic pulmonary oedema. The only strong evidence is that high tidal volumes with high plateau pressures can promote the systemic inflammatory response and cause further injury to lungs. Low tidal volume strategy with lower plateau pressure is associated with lesser mortality.[2]

Lakshmikanthcharan S, MD., IDCCM., EDIC
Consultant Intensivist, Department of Critical Care Medicine, Kovai Medical Center and Hospitals, Coimbatore – 641014.

Sivakumar MN, DA., DNB., IDCCM., EDIC
Consultant Intensivist and Head, Department of critical care medicine, Kovai Medical Center and Hospitals, Coimbatore – 641014.

Mechanical ventilation in the prone position was first proposed in 1974 by Bryan,[3] who suggested that the procedure would result in better expansion of the dorsal lung regions, thus improving oxygenation. For last three decades, prone ventilation has been used in many ARDS patients with clear benefit in oxygenation but without survival benefit.[4,5] Only recently a randomised controlled trial by Guerin *et al* has demonstrated a significant reduction in mortality, the reason for which is not clear but probably due to reduction in ventilator-induced lung injury in prone ventilation.[6]

This article is intended to answer some of the common queries one has in practising prone ventilation with available evidences as of now.

Pathophysiology – Why do we prone?

The physiological effect of prone positioning in patients with severe lung injury improves oxygenation and respiratory mechanics. Prone position may be advantageous because of the following factors:

- Regional ventilation is more uniform and ventilation-perfusion relationship is better.[7,8]
- The anatomy of diaphragm in prone position, improvement in chest wall mechanics with change in posture, less compression by the heart and the mediastinum improves gas exchange.[4,9]

How to cite this article: Laxmikanthcharan S, Sivakumar MN. Prone ventilation in ARDS. Ind J Resp Care 2015; 4(2): 624-31.

- The effect of recruitment manoeuvre on oxygenation is both increased and prolonged.[10]
- Ventilator-induced lung injury (VILI) may be reduced.[11]
- More efficient drainage of secretions.[12]

Alveolar distending pressure estimated as the transpulmonary pressure, which is the difference in pressure between the alveolar pressure (P_A) and the pleural pressure (Ppl) determines the size of the alveoli. In supine position, Ppl is more in the dorsal than the ventral region. The ventral transpulmonary pressure exceeds that of the dorsal region causing a greater expansion in the ventral alveoli. The transpulmonary pressure gradient is affected by several factors such as lung weight, cephalic displacement of the diaphragm, weight of the heart, the mechanical properties and regional shape of the chest wall and lungs. In ARDS, the effect of this gradient is further increased causing atelectasis of dorsal alveoli and overdistension of the ventral alveoli.[13,14] In ARDS patients, there is increased compression of the lungs and increased alveolar collapse by the enlarged heart.[15] The tone of the diaphragm is lost or reduced due to sedation and muscle relaxants used while ventilating patients with ARDS. Hence, the diaphragm cannot oppose the weight of the abdominal contents and its posterior part gets displaced cephalad worsening the dorsal atelectasis.[16]

Prone positioning causes a more homogeneous distribution of ventilation compared to the supine position decreasing the ventral alveolar overinflation and dorsal alveolar collapse.[17]

In prone position, ventilation of dorsal regions improves due to removal of compression of heart and abdominal contents over the lung. Atelectatic dorsal lung regions are recruited in the prone position, without equivalent compression and derecruitment in ventral regions. Although chest wall compliance is reduced, the reduction is largely due to the constraint to the ventral chest wall. This makes chest wall compliance and chest wall expansion in response to positive-pressure ventilation more uniform.

Perfusion depends on gravity and in supine position it is maximal to the dependent parts of the lung. Since these are the regions with maximal collapse in ARDS it leads to ventilation perfusion mismatch and increase in shunt. So when the patient is turned prone and densities remain in the dorsal part, perfusion following a gravitational gradient is increased ventrally to the alveoli that are opened up. This causes an improvement in oxygenation due to better ventilation-perfusion matching and decrease in shunt fraction.[21]

In a homogeneous lung, the transpulmonary pressure is equally distributed in the entire lung. In a nonhomogeneous lung, the collapsed or consolidated regions are minimally stretched, whereas the normal fibres experience excessive strain leading to ventilator induced lung injury through release of cytokines and mechanical rupture. Prone position may attenuate ventilator-induced lung injury by increasing homogeneity of transpulmonary pressure distribution and minimising the stress and strain on the alveoli.[22]

Also prone ventilation promotes homogenous recruitment of alveoli that had collapsed during initial supine ventilation without causing overdistension of nondependent areas. Prone ventilation results in improved ventilation and oxygenation which may sustain even after they return to the supine position. This makes recruitment in prone position more safe and effective.[10]

Whom to Prone - Indications

Existing evidence clearly indicates prone ventilation is beneficial for 'severe' ARDS patients. But till the introduction of Berlin definition,[23] the criteria for 'severe' ARDS were not well defined. In clinical practice the severity of ARDS has been graded according to PaO_2/FiO_2 ratio, although it may vary according to the level of PEEP and the FiO_2 in use. Current available evidences clearly show that the use of long-term prone positioning in severe ARDS ($PaO_2/FiO_2 < 100$ mm Hg according to the Berlin criteria) is highly recommended, whereas its use is not encouraged in mild ARDS (PaO_2/FiO_2 – 200 to 300 mm Hg).[24] Coming to the intermediate group of moderate ARDS (PaO_2/FiO_2 – 100 to 200 mm Hg) the pooled analysis of all the major trials including the PROSEVA trial suggest that prone positioning should be strongly considered in patients in whom PaO_2/FiO_2 is lower than 150 mm Hg when assessed at a PEEP > 5 cm H_2O and an FiO_2 equal > 0.6.[6]

Patients with primary ARDS are characterised by consolidation and appear to be less responsive to recruitment and application of PEEP. Secondary ARDS are those whose lungs are diffusely injured by a process that originates elsewhere and is characterised by diffuse atelectasis which is more responsive to recruitment and PEEP.[25] Since the response in oxygenation with prone positioning seems to depend on the presence of recruitable lung, it is likely that prone positioning is more effective in patients with secondary ARDS.

When to prone

The timing of prone positioning in relation to the course of ARDS has been examined widely and the data are more favourable during the early stage. During this early phase, conditions that favour effectiveness of proning are oedema, reversible collapse, and absence of structural lung alterations. The risk of ventilator-induced lung injury is also reduced by adoption of prone position in early than in late-stage ARDS, during which the damage has already occurred. Pulmonary fibrosis and remodelling of pulmonary vessels occur in late ARDS and the radiological opacities become more homogeneous,[26] all of which decrease the responsiveness to prone ventilation.

Whom not to Prone –Contraindications

Although no absolute contraindications have been defined to prone positioning, it is suggested that proning should be deferred in following patients:

- Life-threatening hypotension or cardiac arrhythmias
- Spinal instability
- Increased intracranial pressure
- Burns or open wounds on the face or ventral body surface
- Pelvic fractures
- Polytrauma with unstable fractures

How to prone protocol

The decision to prone a patient is to be taken by the intensivist and should be planned in discussion with the other team members. It is highly recommended to have a protocol drafted as per the facilities available in every setup. Here I have given you below what we practice in our institution *(Figure 1 and 2)*.

To consider before proning

- Does the patient fulfil criteria for proning?
- Does the patient need any line/tube changes?
- Does the patient need any investigations/ procedures (USG, X-ray, ECHO)?
- Is there history of neck/spinal injury or instability?
- Is the patient haemodynamically stable / has only minimal vasopressor requirement?
- Check movement of head and neck (90 degrees both sides)
- Whenever possible, explain the manoeuvre and complications to the patient and/or their family.

Prior to proning

- Ensure sufficient number of experienced staff are available
- Ensure adequate sedation and complete neuromuscular blockade
- Disconnect nonessential infusions, discontinue nasogastric (N/G) feed (perform N/G suction)
- Ensure essential lines have adequate length
- Ensure endotracheal tube and nasogastric tube are in position and secured well
- Use inline suctioning if possible
- Assemble all needed pillows, foam pads, or other types of supports that might be needed to support the head, neck and body after turning prone
- Preoxygenate adequately.

Staff requirements

- At least 6 experienced staff are required to turn a patient prone (that includes a doctor, respiratory therapist, physiotherapist, staff nurses and support staff)
- 1 supports head and controls airway (usually the respiratory therapist)
- 3 move trunk and limbs in toto
- 1-2 additional staff to look after lines, chest drains and monitors
- The doctor supervises the process.

The turn

- Ensure body is in alignment and move patient to edge of bed
- Place a rolled up clean sheet ready for patient to be turned onto
- Remove pillow from under head
- Place 2 pillows on the new sheet for shoulders and pelvis to be rolled onto (this will allow downward displacement of the abdomen)
- All commands should come from co-ordinator (at head end)
- Turn the patient to the lateral decubitus position with the dependent arm tucked slightly under the thorax. As the turning progresses the nondependent arm can be raised over the patient's head. Alternatively, the turn can be performed using a log-rolling procedure.

After Turning Prone

- Turn his/her face toward the ventilator. Ensure that the airway is not kinked and has not been displaced during the turning process. Suction the airway if necessary
- Ensure all lines are accessible and essential infusions are running
- Ensure pillows are in place (abdomen must be free-hanging to free dorsal diaphragm)
- Ensure no pressure on genitalia, eyes, nose and superficial nerves
- Recommence IV and nasogastric infusions after confirming the position
- Support the face and shoulders appropriately avoiding any contact of the supporting padding with the orbits or the eyes
- Use some padding for the elbow, knee and ankle joint. We usually use water filled gloves for this purpose.

General Care of Prone Patient (in addition to normal care)

- Frequent arterial blood gas analysis (ABG) (initially after 30-60 min)
- Frequent endotracheal (ET) suction (prone position increases drainage of secretions)
- Ensure adequate sedation and muscle relaxation (as required)
- Tilt bed to 10 degrees head up (prevents facial oedema and gastric regurgitation)
- Adequate eye care and oral suction (increased saliva production, skin maceration)
- Change arm and leg positions 2nd hourly
- Always aim to keep elbows at 90° (this ensures correct shoulder position)
- Confirm correct nasogastric tube placement before each feed.

Continuing Care

- Reassess the need for prone ventilation every 24 hours
- Patient to be turned supine routinely every 24 hours. It should be planned during daytime in such a way that maximum resources are available
- After turning supine check for facial oedema, pressure sores, tubes position and plan for x-ray and ECHO
- When patient is supine any requirements for vascular access is to be considered
- After reassessing the patient, decision about continuing prone positioning should be taken
- Monitor closely areas at risk for pressure sores in every shift and document
- Same protocol and precautions must be followed every time the patient is turned supine or prone.
- The team needs to be ready at all times to turn the patient supine in emergencies such as cardiac arrest or tube dislodgement.

Figures 1 and ***2***: Patients in prone position.

Is abdominal suspension must?

Though it was thought that turning prone from supine increases the functional residual capacity and this can be further increased by suspending the abdomen,[27] most reports showing improved oxygenation by prone ventilation have not employed it. Whether further increases can be obtained by doing so has not been investigated. In our setup we do not use bolsters under the chest and pelvis to keep the abdomen suspended and our results have been fair till date. Abdominal suspension can be considered in obese patients, with gross ascites, or other pathologies causing abdominal distension.

Is proning effective?

Once patient is turned prone we need to know whether it has been effective. Many studies were done to determine if there are factors that can help predict success with prone ventilation. In a study done by Jolliet *et al*,[28] among 19 patients nursed in the prone position for up to 12 hours, they declared the patient a responder if there was an increase in PaO_2 of > 10 mm Hg or an increase in PaO_2/ FiO_2 ratio of > 20. By these criteria, 57% of patients responded on the first proning. Nine patients (responders and nonresponders) subsequently were placed in prone position again and they found that failure to respond on the first attempt seemed to correlate with failure on subsequent trials (one of four episodes), but the numbers were small. Responders had a 71% success rate with further trials. Later an uncontrolled trial on 13 patients with moderate to severe ARDS, showed that a 10 mmHg increase in PaO_2 over the first 30 minutes of prone ventilation predicted a sustained increase in PaO_2 over the next two hours.[29] Thus the best predictor of a sustained increase in PaO_2 during prone ventilation is improved oxygenation during a brief trial.

How long to prone and when to stop

For long, the optimal duration of prone positioning was unknown. Some studies used repeated sessions of prone ventilation lasting six to eight hours per day[30,31] while others used prolonged prone ventilation lasting 17 to 20 hours,[6,32,33,34] with similar results. The mean duration of time in the prone position in the PROSEVA trial,[6] only randomised study that showed a mortality benefit for prone positioning in severe ARDS was 17 hours per day. Proning was done with an average of four sessions per patient and was continued for up to 28 days until there was a continued improvement in oxygenation (PaO_2:FiO_2 $\geq$150 mmHg with FiO_2 $\leq$0.6 and PEEP $\leq$10 cm H_2O) maintained for at least four hours after the end of the last prone session. In that study, proning sessions were stopped once improvement was achieved, which was defined by 1 major (relative improvement of PaO_2/FiO_2 $\geq$30% relative to randomisation, with $FiO_2$$\leq$60%) and at least 1 minor criterion (PEEP $\leq$ 8 cm H_2O, no sepsis, and cause of respiratory failure under control. Based on the results of this study, it is preferable to maintain prone ventilation for longer periods (12 - 18 h) and to stop proning only after improvement in oxygenation is seen. This minimises the frequency of turning a critically ill patient which in turn will reduce the likelihood of complications.

Complications

During the process of proning:

- Worsening hypoxaemia
- Hypotension
- Accidental extubation
- ET tube malposition or kinking
- Accidental removal of central lines and Foley's catheter.

During the maintenance of proning

- Pressure ulcers and facial oedema
- Complications related to increased need for sedation and prolonged neuromuscular blocker usage
- ET tube malposition
- Compression of superficial nerves
- Ocular injuries
- The incidence of these problems gradually decreases as the team starts routinely using this intervention and gain experience.

PROSEVA trial[6] for the first time found the rate of serious complications to be similar between the supine and prone groups. This is probably due to the expertise and skills of the centres involved in the trial that performed the procedure safely. Following this finding and the significant survival benefit of PROSEVA trial, the risk/benefit ratio has greatly improved for prone ventilation.

What evidence do we have

Two of the major studies on prone ventilation have helped to conclude that prone ventilation improves oxygenation and permits earlier use of a lower, safer

Table 1 : Characteristics of the five largest randomised controlled trials testing the role of prone positioning in patient survival

	GATTINONI (28)	GUERIN (27)	MANCEBO (31)	TACONNE (30)	GUERIN (6)
PaO_2/FiO_2 at inclusion (mm Hg)	127	150	147	113	100
Tidal volme at inclusion (ml/ kg^{-1})	10.3	8	8.4	8	6.1
PEEP at inclusion (cm H_2O)	10	8	12	10	10
Prone position average duration per session (h)	7	8	17	18	17
Mortality % - Supine positon	25	31.5	58	32.8	32.8
Prone position	21.1	32.4	43	31	16

level of inspired fraction of oxygen by ventilating at lower pressures, earlier liberation from ventilator and improved survival.

- Gattinoni and colleagues found no improvement in survival in a randomised trial of prone ventilation applied in the course of ARDS or acute lung injury for an average of 7 hours/ day for 10 days.[31] On *post hoc* analysis, however, 10-day mortality was found to be significantly lower in the prone group as compared with the supine group in the quartile with the lowest $PaO_2:FiO_2$ ratio (<88 mm Hg), the quartile with the highest V_T (>12 ml/kg), and the quartile with the highest (>49) simplified acute physiology score II (SAPS II).
- After a long wait for survival benefit, a recent randomised controlled trial was performed in ARDS patients by Guerin *et al* after a 12–24 h stabilisation period and severity criteria (with $PaO_2:FiO_2$ ratio <150 mmHg with a $FiO_2 \geq 0.6$ and PEEP ≥5 cm H_2O).[6] This trial has demonstrated a significant reduction in mortality from 32.8% in the supine group to 16% in the prone group ($p < 0.001$).

To consider the evolution of study designs over the years on prone ventilation, the five major trials in Table 1 can be compared and the following trends are seen:

- The patients enrolled had progressively more severe disease (at least as assessed by PaO_2/FIO_2 level)
- The daily duration of prone positioning was increased from 7-9 hours to 17-18 hours
- Lung-protective strategies were applied more strictly (like Guerin *et al*[6] employing protective PEEP selection and muscle relaxation in early phases.[35]

These refinements in the research methodology over all these years continued:

- Initially suggested benefit in patients with more severe disease
- Following meta-analysis proved that in patients with severe disease, prone positioning reduced mortality risk
- Recently concluded randomised clinical trial confirmed that prone position along with strict adherence to lung-protective ventilation by an experienced team significantly improved survival.

Conclusion

Prone positioning earlier was considered as a short term rescue therapy for those patients requiring potentially injurious levels of FiO_2 (*i.e.*, >60%) or plateau pressure (*i.e.*, >30 cm H_2O). But now with the available evidences, it is judicious to recommend the use of lung protective ventilation in supine position as the initial ventilation strategy for severe ARDS patients. In severe ARDS ($PaO_2:FiO_2$ ratio <150 mmHg with a $FiO_2 \geq 0.6$ and PEEP ≥5 cm H_2O) with refractory hypoxaemia despite use of lung protective ventilatory strategies, a trial of prone ventilation should be strongly considered. When prone ventilation is considered, it should be done early and patient should be maintained in prone ventilation for at least 12 to 18 hours per day. With the current evidences, it is prudent to conclude that in severe ARDS prone ventilation when used early, in relatively long sessions, by experienced team will have a positive impact on the patient outcome.

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