Prone positioning ventilation for treatment of acute lung injury and acute respiratory distress syndrome

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Patients who are diagnosed with acute lung injury/acute respiratory distress syndrome (ALI/ARDS) usually have ventilation-perfusion mismatch, severe decrease in lung capacity, and gas exchange abnormalities. Health care workers have implemented various strategies in an attempt to compensate for these pathological alterations. By rotating patients with ALI/ARDS between the supine and prone position, it is possible to achieve a significant improvement in PaO$_2$/FiO$_2$, decrease shunting and therefore improve oxygenation without use of expensive, invasive and experimental procedures. Prone positioning is a safe and effective way to improve ventilation when conventional strategies fail to initiate a patient response. Because a specific cure for ARDS is not available, the goal is to support the patients with therapies that cause the least amount of injury while the lungs have an opportunity to heal. Based on current data, a trial of prone positioning ventilation should be offered to the patients who have ALI/ARDS in the early course of the disease. Published studies exhibit substantial heterogeneity in clinical results, suggesting that an adequately sized study optimizing the duration of proning ventilation strategy is warranted to enable definitive conclusions to be drawn.

Key words: Prone position; Ventilators, mechanical; Acute lung injury; Respiratory distress syndrome, acute

Physiologic effects of prone positioning ventilation on patients with ALI/ARDS

In the 1970s, an improvement in arterial oxygenation was observed when patients receiving mechani-
cal ventilation were placed in the prone position. More studies afterwards have shown that changes in patients’ position improve gas exchange of patients with ALI/ARDS. Continuous lateral and prone positions can improve oxygenation, raise PaO\textsubscript{2} by 20-69 mmHg, improve alveolar ventilation and perfusion, and prevent complications of mechanical ventilation. Some researchers reported that oxygenation was improved within 30 minutes after patients were turned to the prone position. However, the reason why the prone position is better than the supine position for most patients with severe hypoxemia is not clear. Based on the physiologic principles of intrapulmonary ventilation and perfusion distribution, we can easily understand the beneficial effects of position change on oxygenation for patients with ALI /ARDS. On the basis of many animal and clinical studies, researchers proposed several theories on the relationship between ventilation and perfusion on the condition of position change in patients with healthy and diseased lungs. These findings may help to explain why the prone position is effective: (1) increased functional residual volume, (2) changes in diaphragm motion, (3) shifting of water and exudates, (4) accelerated removal of secretions, (5) redistribution of perfusion and (6) improved ventilation.

Placing a patient in a prone position can provide an opportunity to correct lung capacities. Galvin believed that the improvement in oxygenation while the patient was in a prone position was not only a result of a regional redistribution of the blood flow but also due to an increased number of recruited alveoli that caused a decrease in right-to-left shunt and an increased area of the lung where a normal ventilation-perfusion relationship is. The rationale is that the gravitational distribution of pleural pressure is more uniform in a prone position. Wolfson et al studied the effects of position on the mechanical interaction between the rib cage and abdomen in pre-term infants recovering from respiratory distress syndrome. They found that patients in a prone position exhibited an increase in tidal volume and in the thoracic mobility compared with those in a supine position. There were no significant differences in the abdominal mobility in these two positions. They proposed that the gravity in a prone position “flattens” the diaphragm resulting from a shortened muscle fibre length. This change ameliorated the contractility of the diaphragm, improved thoracic mobility and therefore, contributed to better synchrony between the abdominal and rib cage movement during inspiration. Mure et al presumed that the improvement in oxygenation that occurred while patients were placed prone might be due to the shifting of water and exudates from dependent to nondependent regions of the lung. Drainage of bronchial secretions via gravity is another proposed explanation for improvement in oxygenation. Although drainage of bronchial secretions is improved in prone patients, it may only play an integrating role, not a major factor during the course of the dramatic improvement in oxygenation. Vollman et al proposed that improvement in oxygenation in prone patients was due to redistribution of blood flow along gravitational gradient toward the less injured lung regions. Richter et al, using an animal model of lung injury, found that prone position is beneficial because it generates a transpulmonary pressure sufficient to exceed airway opening pressure in dorsal lung regions where atelectasis, shunt, and ventilation-perfusion imbalance occur.

### Systematic hemodynamic changes in prone position

ALI/ARDS patients are characterized as systemic hypotension and decreased cardiac output. Früdl et al reported that cardiac index (CI) of patients increased when they changed supine position to prone one and afterwards returned to baseline. The initial increase in cardiac output is accompanied by an increase in the mean arterial pressure. When CI increases, there is an increase in pulmonary capillary ventilation and thereby a decrease in the physiological dead space ventilation, resulting in improved oxygenation. Toyota et al studied hemodynamic changes in ARDS patients and found no differences in these parameters when turning the patients from the supine to the prone position. However, Sudheer et al observed a decrease in the CI of patients with prone position. They concluded that the change in CI was due to increased intrathoracic pressure, which caused a decrease in the venous return and left ventricular volume. The discrepancy of CI among the studies may be due to the use of different modes of mechanical ventilation, position-supporting devices, and the time-phase by which the measurements are obtained. Differences in CI values may also be due to the use of different techniques in CI measurements, such as thermodilution or transoesophageal echocardiography. Thus, careful monitoring of hemodynamic variables is necessary when moving a patient to the prone position.
Clinical guidelines for the use of prone position ventilation in ALI/ARDS patients

Prone position may be considered for patients with a PaO₂/FiO₂ less than 300, or progressively increased PiO₂ and PEEP in order to maintain individually accepted oxygenation values. The above selection criteria are used to trigger a multidisciplinary team discussion on the patient’s suitability for prone position; meanwhile all exclusion criteria, specialists’ opinions and risk assessment should also be considered. Risk assessment includes evaluation of the patient’s need for improved oxygenation and individual factors that may outweigh the use of prone position. However, the following exclusion criteria derived from critical appraisal of several draft proposals should be considered as potential contraindications: (1) hemodynamic instability or shock, (2) asthma, (3) head injury (raised intracranial pressure), (4) seizures history, (5) spinal injury, spinal column instability and osteoporosis, (6) abdominal operation or colostomy, (7) pregnancy, (8) open chest, left or right ventricular assist device, (9) recent cardiovascular surgery or unstable mediastinum, (10) cardiopulmonary arrest, (11) tracheostomy, (12) multiple trauma, external pelvic fixation, (13) maxillofacial operation, (14) recent pelvic or chest fractures, (15) acute bleeding, (16) traction, (17) advanced osteoarthritis and rheumatoid arthritis, (18) increased intraocular pressure, (19) poor tolerance to prone position, (20) body weight > 90 kg, and (21) scoliosis.

If patients are suitable for prone position after considering the above exclusion criteria and risk assessment, the following measures should be undertaken: (1) calculate risks of the pressure area and assess the use of special mattress, (2) maintain eyes closed by using adhesive tape or bandage to avoid corneal abrasion, (3) suck all secretion from the mouth and oropharynx, (4) check PERLA (pupils equal and reacting to light accommodation) before and after position change, (5) put wound drainage on the anterior aspect of the body, (6) check endotracheal tube and tracheostomy tube to ensure security, (7) record the depth of endotracheal tube to the teeth by which to ensure correct placement of the endotracheal tube after position change, (8) assess and record patient’s level of sedation, whether need analgesia and muscle relaxants, (9) aspirate nasogastric tube, stop nasogastric feed during position change, and check placement of tube before recommencing feed, (10) don’t clamp thoracic catheter and keep it below the level of the chest drain, ensure any drains und-clamped and keep it at a horizontal position after position change, (11) adjust position control settings or alternatively place pillows under the chest and hip if abdominal disension exists, (12) disconnect any non-essential venous channels and reconnect them after position adjustment, (13) a sufficient length of venous tubing ready for transfusion, (14) remove ECG electrodes from anterior chest wall and reconnect them after position change, (15) don’t disconnect ventilator from the patient as position change.

Once the patient is in a prone position, several routine nursing cares need to be given to reduce potential complications. Proper anatomic support and keeping the body straight are necessary to prevent skin damage and reduce the complications of nerves and joints. Pillows or foam supports are placed to prevent overextension or flexion of the cervical spine. Full weight-bearing on bony prominences and bowing of the back should be avoided. In order to prevent foot drop, the thigh support is needed to avoid external rotation or shortening of the Achilles tendon, which can be accomplished by placing a pillow under the shins to flex the knees and keep the ankle at 90°. Willems et al. described two shoulder injuries resulting from permanent contractures as a result of the arm abduction for 26 and 56 days in a prone position. They recommend the position in which one arm was upwards and another was along one side of the body while turning the patient’s head towards the direction of the upper arm. In addition, they recommend altering the arm positions every 2 hours and providing physiotherapy. When the arm is upwards, be careful to keep the shoulder in neutral position and the elbow at 90° so as to prevent hyperextension of the shoulder. In emergent situation, quickly and safely returning the patient to a supine position is probably the best strategy.

Other nursing measures, such as assessment of patient’s response to the treatment, hemodynamic monitoring, nasogastric feeding, suctioning, and oral care should be performed in both the prone and supine positions. Instant changes in oxygenation are assessed by monitoring pulse oximetry, mixed venous oxygenation saturation or mixed central venous oxygen saturation. To determine the effect of the position change on oxygenation, arterial blood gases analysis should be implemented within 1 hour after position change. Hemodynamic monitoring includes cardiac output/car-
Frequency and duration of the prone position ventilation

Doctors generally decide whether or when to return to a supine position according to patient’s response to treatment. Researches on the duration and frequency of the prone position ventilation are limited. The duration varies but tends to be shortened since year 2000, ranging from 30 minutes to 20 hours, the mean between 6 to 12 hours sequentially. McAuley et al tried to identify the optimal duration of the prone position ventilation and found a progressive improvement in P/F ratio within 12 hours; thereafter, it declined.

The decision to cut down or prolong prone position ventilation depends on several factors. First, the longer a patient remains a stationary position, the more challenging the cardiovascular system endures. Second, the potential skin injury and edema formation can be minimized following the pressure relief. Longer time is allowed if better support is guaranteed. At last, if patients maintain a positive response to supine position, they can be placed in a lateral position for 6 to 12 hours or till the oxygenation starts to decline. At this point patients should be placed to a prone position again. For those who immediately lose the oxygenation improvement when returned to the supine position, measures should be taken to provide necessary care and return them to the prone position as soon as possible. Position changes in turn are essential to reduce corresponding complications.

Controversy on prone position ventilation in treatment of ALI/ARDS

Prone position was advocated 30 years ago to improve oxygenation for patients with hypoxemic acute respiratory failure receiving mechanical ventilation. Although dramatic oxygenation improvement was reported in severely hypoxemic patients, some recent trials showed that prone position ventilation failed to raise the survival rate of patients with ALI. Similar results were reported from a multicenter, randomized, controlled clinical trial in which prone position ventilation did not significantly decrease ventilator-dependent days or improve other clinical outcomes for pediatric patients with ALI. Abroug et al studied the effects of ventilation in prone and supine positions on 1372 patients with ALI/ARDS by meta-analysis of randomized controlled trials. It showed a substantial increase in the $\text{PaO}_2/\text{FiO}_2$ ratio in prone position compared with that in supine position, as well as a 3% and 23% reduction in mortality and pneumonia respectively.

Summary

Patients with ALI/ARDS are usually afflicted with ventilation-perfusion imbalance, marked decrease in lung capacity, and gas exchange abnormality. Various measures have been taken to try to rectify these pathological changes. By changing position (between the supine and prone), it is possible to achieve a significant improvement in P/F, decrease shunting and therefore improve oxygenation and meanwhile avoid using expensive and invasive procedures. Prone position ventilation is a safe and effective way to improve oxygenation when conventional measures fail to initiate a patient response. Since there is no special therapy for ARDS, this method, bringing about minimal injury to the lung, is confirmed to promote healing of injured lungs. Based on current data, we prefer that prone position ventilation should be given to patients with ALI/ARDS at the early stage. Considering controversy in clinical results, more studies are needed to optimize the prone ventilation strategy and refine on its curative effect.

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