Prone Positioning of Pediatric Patients With ARDS Results in Improvement in Oxygenation if Maintained > 12 h Daily*

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Objectives: To evaluate changes in oxygenation index (OI) in pediatric patients with ARDS during the first 24 h of prone positioning (PP), and to determine whether or not longer periods of PP (>12 h) result in a more pronounced improvement in oxygenation.

Design: A retrospective chart review of patients with ARDS who had been placed in PP for their management.

Setting: Pediatric ICU of a children’s hospital.

Measurements and main results: We retrieved the charts of patients with ARDS who had been admitted to our pediatric ICU over a 3-year period and placed in PP for their management. The patients received conventional mechanical ventilation, were sedated and pharmacologically paralyzed, and underwent arterial blood gas analysis, with concomitant documentation of ventilator settings, at a frequency of once every 4 h or more often. We divided the first 24 h of PP into two periods, brief and prolonged. The brief period was defined as duration of PP between 6 h and 10 h, and the prolonged period was between 18 h and 24 h. We compared pre-PP OI values to values after brief periods and prolonged periods of PP. Values of the PaO2/fraction of inspired oxygen (P/F) ratio and the mean airway pressure (MAP) were similarly evaluated. We also evaluated the degree of OI fluctuations during 24 h of PP by identifying the time points at which the best OI and the worst OI were observed. Data from a total of 40 pediatric patients with ARDS were evaluated. Twenty-one of the patients were male, and 19 were female; their ages ranged from 1 month to 18 years (mean ± SD, 6.22 ± 6.27 years). Thirty-two patients received conventional mechanical ventilation, and 8 patients received high-frequency oscillatory ventilation. Thirty-three patients survived, and 7 patients (21%) died. The mean duration of PP was 67 ± 64 h (2.8 ± 2.7 days), the mean number of ventilator days was 32 ± 32, and the mean interval between endotracheal intubation and placing the patients in PP was 107 ± 108 h (4.5 ± 4.5 days). Thirty-seven patients completed 20 h of PP or more. The mean post-PP time points at which OI values were actually evaluated for these patients were 8 ± 2 h (brief) and 21 ± 4 h (prolonged), respectively. Overall, the OI decreased from a pre-PP value of 24.8 ± 13.0 to 16.7 ± 13.7 after a brief period of PP (p < 0.05 when compared to baseline) and 11.4 ± 6.3 after prolonged period (p < 0.05 when compared to baseline and brief period values). This improvement in OI followed the improvement seen in the P/F ratio, whereas the MAP remained unchanged. The best mean OI value, with patients in PP, was 11 ± 9 (p < 0.05 when compared to baseline) that occurred at 16 ± 6 h, and the worst was 22 ± 15 (p = not significant when compared to baseline) that occurred at 9 ± 7 h.

Conclusions: PP of pediatric patients with ARDS for prolonged periods (18 to 24 h) results in a more pronounced and more stable reduction in their OI values than those observed after brief periods (6 to 10 h). This improvement in OI was not associated with changes in MAP during the first 24 h of mechanical ventilation. OI values tend to fluctuate more during the first 12 h of PP then they do during the subsequent 12 h.

Key words: ARDS; mechanical ventilation; oxygenation index; pediatric; prone positioning

Abbreviations: MAP = mean airway pressure; OI = oxygenation index; P/F = PaO2/fraction of inspired oxygen; PP = prone positioning; SP = supine positioning

Prone positioning (PP) of patients with ARDS has been shown to improve lung compliance1 and gas exchange2–7 during mechanical ventilation. However, the published protocols for PP have been inconsistent (Table 1). While in some reports the patients were placed in the PP for very brief periods,5,8,9 in others the duration of PP ranged from 6 to 24 h. This variation in the duration of PP makes it difficult to determine whether or not longer periods of PP (>12 h) result in a more pronounced improvement in oxygenation.

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269
The question whether or not a longer duration of PP is more beneficial for patients with ARDS than a shorter one, or vice versa, has not been clearly answered. To the best of our knowledge, there has not been a "dose (duration) response curve" published for PP; therefore, some of the protocols used may be less advantageous to patients than others.

Our protocol is based on an algorithm that frequently enables us to keep patients in PP for periods of >12 h, and very often for >20 h at a time. As per our algorithm, as long as an ongoing improvement in gas exchange is observed, no complications occur, and specific medical or nursing procedures do not require placement in supine positioning (SP), the patient is allowed to remain in PP (Fig 1). Thus, some of our patients with ARDS may end up staying in PP for a few days. This enabled us to retrospectively evaluate changes in the oxygenation index (OI)

![Figure 1. A practice algorithm for PP of pediatric patients with ARDS.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21996/ on 04/02/2017)
during the first 24 h of PP. Our goal was to test the hypothesis that keeping patients in PP > 12 h at a time results in a more pronounced beneficial effect on their oxygenation than with shorter periods.

**Patients and Methods**

We retrieved the charts of patients with ARDS who had been admitted to our pediatric ICU over a 3-year period and placed in PP according to our practice algorithm (Fig 1). The diagnosis of ARDS in all studied patients was based on the following criteria: radiographic findings of bilateral pulmonary infiltrates and PaO2/ fraction of inspired oxygen ratio (P/F) ratio < 200. The repositioning technique entailed several ICU personnel and followed an established protocol (see Appendix). All patients received mechanical ventilation, were sedated and pharmacologically paralyzed, and underwent arterial blood gas analysis, with concomitant documentation of ventilator settings, at a frequency of once every 4 h or more often. Data of patients who had completed a minimum of 20 h of PP during the first 24 h of their management were statistically tested.

The pre-PP OI values were calculated based on the latest arterial blood gas results and ventilator settings documented, but no earlier than 4 h, prior to placement of patients in PP. The following formula was used to calculate the OI: 

\[
\text{OI} = \frac{\text{MAP} \times \text{FiO}_2}{\text{PaO}_2}
\]

where MAP = mean airway pressure, and \(\text{FiO}_2\) = fraction of inspired oxygen. We divided the first 24 h of PP into two periods, brief and prolonged. The brief period was defined as duration of PP between 6 h and 10 h, and the prolonged period was between 18 h and 24 h. We compared pre-PP OI values to values after brief periods and prolonged periods of PP. Values of the P/F ratio and the MAP were similarly evaluated. We defined a beneficial response to PP as a reduction in OI of ≥ 20% of baseline values. We also evaluated the degree of OI fluctuations during PP by identifying the time points at which the best OI and the worst OI were observed. We considered the first hour after PP as a period required for patient stabilization and, therefore, used only data that were documented after the first hour of PP.

Analysis of variance for repeated measures was used to identify whether significant changes in OI, P/F ratio, and MAP values occurred. Baseline values of OI, P/F ratio, and MAP were then compared with subsequent values using the Newman-Keuls test. Data are presented as mean ± SD. We rejected the null hypothesis at a p < 0.05.

**Results**

Data from 40 pediatric patients with ARDS were evaluated (Table 2). Twenty-one of the patients were male, and 19 were female; their ages ranged from 1 month to 18 years (mean, 6.22 ± 6.27 years). Thirty-two patients received conventional mechanical ventilation, and 8 patients received high-frequency oscillatory ventilation. Thirty-three patients survived, and 7 patients (21%) died. The mean duration of PP was 67 ± 64 h (2.8 ± 2.7 days), the mean number of ventilator days was 32 ± 32, and the mean interval between endotracheal intubation and placing the patients in PP was 107 ± 108 h (4.5 ± 4.5 days). Three patients (7%) did not complete a 20-h period of PP for the following reasons: one patient did not respond and required extracorporeal membrane oxygenation, withdrawal of treatment was requested by the parents of another patient and approved by the hospital bioethics committee, and the third patient required placement of a chest tube for pneumothorax. No other major adverse events occurred.

In the 37 patients who completed ≥ 20 h of PP, the pre-PP OI values were compared to OI values measured at 8 ± 2 h after PP (brief period) and 21 ± 4 h after PP (prolonged period). Overall, the OI values were 24.8 ± 13.0, 16.7 ± 13.7 (33% decrease from the pre-PP mean value), and 11.4 ± 6.3 (54% decrease from the pre-PP mean value), respectively (p < 0.05 when pre-PP values were compared to subsequent values and when brief period values were compared to prolonged period values; Fig 2). Values of the P/F ratio were 91 ± 36, 157 ± 75 (72% increase from the pre-PP mean value), and 202 ± 84 (121% increase from the pre-PP mean value), respectively (p < 0.05 as described for OI values). The best mean OI value, while in PP, was 11 ± 9 (52% decrease from the pre-PP OI, p < 0.05) and the worst was 22 ± 15 (5% decrease from the pre-PP OI, p = not significant). These changes in OI occurred at mean time points of 16 ± 6 h after PP and 9 ± 7 h after PP, respectively (Fig 3).

<table>
<thead>
<tr>
<th>Table 2—Baseline Patient Characteristics*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics</strong></td>
</tr>
<tr>
<td>Demographics</td>
</tr>
<tr>
<td>Age range (mean ± SD)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Gender</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Causes of ARDS</td>
</tr>
<tr>
<td>Pneumonia</td>
</tr>
<tr>
<td>Aspiration</td>
</tr>
<tr>
<td>Respiratory tract infection after surgery</td>
</tr>
<tr>
<td>Other types of respiratory disease</td>
</tr>
<tr>
<td>Sepsis</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>Type of mechanical ventilation</td>
</tr>
<tr>
<td>Conventional</td>
</tr>
<tr>
<td>High-frequency oscillatory ventilation</td>
</tr>
<tr>
<td>Outcome</td>
</tr>
<tr>
<td>Survived</td>
</tr>
<tr>
<td>Died</td>
</tr>
<tr>
<td>Reason for failure to complete 20 h of PP</td>
</tr>
<tr>
<td>No. of patients</td>
</tr>
<tr>
<td>Extracorporeal membrane oxygenation</td>
</tr>
<tr>
<td>Withdrawal of support</td>
</tr>
<tr>
<td>Tube thoracostomy</td>
</tr>
</tbody>
</table>

*Data are presented as % unless otherwise indicated.
Discussion

Placement of patients with ARDS in PP has been shown to improve oxygenation. The proposed mechanism by which PP improves oxygenation is multifactorial and includes better diaphragmatic movement, recruitment of formerly collapsed dependent lung regions, rerouting of pulmonary blood flow to better ventilated regions, enhanced drainage of airway secretions, and increased negative pleural pressure.

Similarly, repositioning these patients back to SP has often been associated with a noticeable deterioration in gas exchange. Thus, alternating periods of PP and SP result in swings in the P/F ratio, as well as in OI. When the P/F ratios are plotted across time, a typical zigzag pattern of the graph is noted due to the alternating periods of patient positions. There are no clinical studies that provide guidelines as to the recommended length of time patients should remain in PP. It is also unclear whether or not periods of PP should be longer than, equal to, or shorter than periods of SP when repeatedly performed. It appears that until a duration-response curve is investigated for PP, these questions will remain unanswered.

We advocate long periods of PP for our patients with ARDS; however, the goal of our study was not to prove that the algorithm used in our practice is better than any other published protocols. Nonetheless, the fact that most of our patients stay in PP for extended periods of time enabled us to evaluate their oxygenation status as it relates to the duration of PP. Despite the fact that most of our patients had been in PP for periods > 24 h at a time, we elected to investigate the first 24 h only, as it would have been hard to link changes in OI to longer durations of PP when changes in fluid balance, nutrition, antibiotic regimen, and hemodynamic support may also affect oxygenation and may be difficult to sort out. We also elected to focus on changes in OI, as opposed to P/F ratio, as OI takes into account the MAP, and the concentration of inspired oxygen and oxygen tension in the blood, and, therefore, provides indirect information about lung compliance as well. Assessing trends in oxygenation during mechanical ventilation through changes in P/F ratio only may occasionally be misleading, as a higher P/F ratio following an increase in the MAP may not coincide with an improved OI.

Our results indicate that OI values after a brief period of PP (8 ± 2 h) and after a prolonged period...
of PP (21 ± 4 h) were significantly lower (better) than the pre-PP values. The OI values after a prolonged period of PP were significantly better than those after a brief period. The fact that the P/F ratio improved in a similar manner to the OI while the MAP remained unchanged indicates that the observed improvement in oxygenation in our patients was unrelated to changes in mechanical ventilation settings. Moreover, the worst OI values were commonly observed during the first 12 h of PP (at 9 ± 7 h), while the best OI values were commonly seen in the second half of the 24-h period of PP (at 16 ± 6 h). Curley et al similarly found that the OI decreased much more significantly after 20 h of PP than after 1 h; however, their study does not provide information regarding OI fluctuations between 1 h and 20 h. Our results suggest that despite an observed improvement in oxygenation during the first 12 h of PP, OI values tend to fluctuate during that period, with an average worst OI being very close to baseline (5% lower than pre-PP values). This degree of fluctuations was less commonly observed in the second half of the 24-h period of PP.

Fridrich et al and Jolliet et al described PP of patients for periods of 20 h and 12 h, respectively. However, while in the study by Fridrich et al, an increasing improvement in oxygenation is observed over a period of 20 h, Jolliet et al found that the P/F ratio was not significantly different at 2 h of PP from that at 12 h of PP. They suggested that a 30- to 120-min trial of PP should be sufficient to determine whether or not a patient is a responder. Chatte et al and Vollman and Bander arrived at similar conclusions. Why did some studies show an overall cumulative improvement in oxygenation across a 20-h period of PP while other studies failed to demonstrate the same trend across a shorter period? It is feasible that the answer to this question relates to the time points at which data were collected. Namely, data collected at or before 12 h of PP, much like the data observed in our study approximately 9 ± 7 h after PP, may include significant fluctuations in oxygenation parameters and, therefore, may not be reflective of true improvement.

More recently,Gattinoni et al published their study with regard to PP of adult patients with ARDS, and concluded that PP improves oxygenation but not survival. The mean period of PP in their study group was 7.0 ± 1.8 h daily. Using our results, we postulate that had the researchers used PP for ≥ 20 h, the response in oxygenation could have been different and perhaps would have resulted in a different outcome. We do not dispute that Gattinoni et al did indeed find that an average of 7 h of PP did not affect outcome from ARDS. Yet, the mention of “7 h” is missing from their concluding statement.

A general statement that PP does not improve survival can only be made after the right “dose” of PP has been established.

In summary, PP improves oxygenation in patients with ARDS receiving mechanical ventilation. Keeping these patients in PP for >12 h appears to be associated with a more pronounced and more stable improvement in the OI than shorter periods. The observed improvement in oxygenation seems to be unrelated to changes in MAP. Our retrospective study evaluated changes in OI within 24 h of PP only. However, future prospective studies may be more appropriate for this purpose and for studying longer periods of PP. This will provide the necessary evidence as to the right approach regarding PP of critically ill patients with ARDS.

APPENDIX: Procedure for PP

Preparing the Patient

1. Obtain a chest radiograph and verify that the endotracheal tube is appropriately positioned in the trachea.
2. Ensure security of endotracheal tube, pulse oximeter probe, and all indwelling catheters.
3. Move ECG electrodes to the lateral aspects of the upper arms and hips.
4. Consider capping nonessential vascular catheters and the nasogastric tube.
5. Suction the oropharynx.
6. Apply spongy dressing to pressure point areas (knees).
7. Assess the need for a special-care bed.
8. Assign responsibilities to each and every member of the PP team (the airway should be assigned to the pediatric intensivist).

Placing the Patient in PP

1. Turn the head and body in unison halfway toward the ventilator, and then turn prone. Smaller patients can be elevated first and then turned. The head should be laterally rotated to face the ventilator.
2. Immediately reassess the security and patency of the endotracheal tube and other indwelling catheters.
3. Assess the need for suctioning the endotracheal tube.
4. Insert bolsters under the shoulders and pelvis (use jell pillow, foam pad, egg crates, etc.), so that the abdomen protrudes off the mattress.
5. Flex the arms and position the knees and feet off the bed using an appropriate-sized roll. Cushion the forehead. Pressure points over knees and ears should be protected with control gel formula dressing.
6. Adjust the sedation/analgesia infusion to achieve adequate patient comfort. Chemical paralysis may be necessary although not mandatory.
7. Position ECG leads to obtain a clear monitor wave form.
8. Obtain a chest radiograph to ascertain an adequate endotracheal tube position within the thoracic trachea.
9. Patients may be slightly repositioned every 2 h to alleviate pressure points.
10. Leave in prone position for at least 20 h.

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Placing the Patient in SP

1. Follow similar steps for placing the patient in PP.
2. Once supine, assess the skin for existing wounds or ulcers.
3. Obtain a chest radiograph to verify that the endotracheal tube is within the thoracic trachea and above the carina.
4. Obtain the patient’s weight.
5. If the patient deteriorates, consider using PP again and follow the steps described.

Contraindications for PP

1. Increased intracranial pressure
2. Hemodynamic instability despite the administration of adequate vasoactive agents.
3. Unstable spinal cord injuries.
4. Recent abdominal or thoracic surgery.
5. Open thorax or a flail chest.
6. Inability to tolerate PP (eg, pelvic fracture, unstable long bone fracture).

References