Prone Ventilation in Trauma or Surgical Patients With Acute Lung Injury and Adult Respiratory Distress Syndrome: is it Beneficial?

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Background: To compare the effectiveness of supine versus prone kinetic therapy in mechanically ventilated trauma and surgical patients with acute lung injury (ALI) and adult respiratory distress syndrome (ARDS).

Methods: A retrospective review of all patients with ALI/ARDS who were placed on either a supine (roto-rest) or prone (roto-prone) oscillating bed was performed. Data obtained included age, revised trauma score (RTS), base deficit, Injury Severity Score (ISS), head Abbreviated Injury Scale score (AIS), chest (AIS), PaO_2/FiO_2 ratio, FiO_2 requirement, central venous pressure (CVP), days on the bed, ventilator days, use of pressors, complications, mortality, and pulmonary-associated mortality. Data are expressed as mean ± SE with significance attributed to $p < 0.05$.

Results: From March 1, 2004 through May 31, 2006, 4,507 trauma patients were admitted and 221 were identified in the trauma registry as having ALI or ARDS. Of these, 53 met inclusion criteria. Additionally, 8 general surgery patients met inclusion criteria. Of these 61 patients, 44 patients were positioned supine, 13 were placed prone, and 4 patients that were initially placed supine were changed to prone positioning. There was no difference between the groups in age, CVP, ISS, RTS, base deficit, head AIS score, chest AIS score, abdominal AIS score, or probability of survival. The PaO_2/FiO_2 ratios were not different at study entry (149 vs. 153, p = NS), and both groups showed improvement in PaO_2/FiO_2 ratios. However, the prone group had better PaO_2/FiO_2 ratios than the supine group by day 5 (243 vs. 200, $p = 0.066$). The prone group had fewer days on the ventilator (13.6 vs. 24.2, $p = 0.12$), and shorter hospital lengths of stay (22 days vs. 40 days, $p = 0.08$). There were four patients who failed to improve with supine kinetic therapy that were changed to prone kinetic therapy. These patients had significant improvements in PaO_2/FiO_2 ratio, and significantly lower FiO_2 requirements. There were 18 deaths (7 pulmonary related) in the supine group and 1 death in the prone group ($p < 0.01$ by χ^2 test).

Conclusions: ALI/ARDS patients who received prone kinetic therapy had greater improvement in PaO_2/FiO_2 ratio, lower mortality, and less pulmonary-related mortality than did supine positioned patients. The use of a prone-oscillating bed appears advantageous for trauma and surgical patients with ALI/ARDS and a prospective, randomized trial is warranted.

Key Words: Adult respiratory distress syndrome, kinetic therapy, prone ventilation.

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Acute lung injury (ALI) and adult respiratory distress syndrome (ARDS) are serious complications in trauma and surgical patients.[1–4] In spite of improvements in critical care and ventilator management,[5,6] mortality rates have been reported to remain as high as 35% to 40%.[7,8]

Kinetic therapy is defined by the Centers for Disease Control and Prevention as the use of a bed that turns continuously and slowly over greater than 40 degrees along its longitudinal axis.[9] Clinical studies have shown advantages in using kinetic therapy to decrease atelectasis and pneumonia in trauma and surgical patients.[10–12] Additionally, the use of kinetic therapy significantly improved the PaO_2/FiO_2 ratio in mechanically ventilated patients with ALI or ARDS.[13]

The use of prone ventilation has been shown to improve aeration and decrease shunt in an animal model.[14] The use of prone ventilation in a prospective human study demonstrated benefit in improving PaO_2/FiO_2 ratios and decreasing oxygen requirements.[15] However, no study to date has demonstrated a survival advantage to the use of prone positioning in trauma and surgical patients with ALI or ARDS. One prospective trial demonstrated no advantage to prone positioning over continuous lateral rotational therapy (roto-rest) in patients with ARDS.[16]

However, in most of the studies evaluating prone positioning, the patients were placed in the prone position from 4 to 8 hours per day and were not treated with prone kinetic therapy.[17–20]

The purpose of this study was to test the hypothesis that prone kinetic therapy was advantageous in trauma and

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surgical patients with ALI or ARDS and to compare prone to supine kinetic therapy.

PATIENTS AND METHODS

The trauma registry, intensive care unit (ICU) database, and patient medical records were used to identify all patients in the trauma and surgical services from March 1, 2004 through May 31, 2006 with acute lung injury (ALI) or adult respiratory distress syndrome (ARDS). The criteria for ALI were diffuse patchy infiltrates on chest radiograph, noncardiogenic pulmonary edema (central venous pressure <18), and PaO_2/FiO_2 ratio <300. The criteria for ARDS were diffuse patchy infiltrates on chest radiograph, noncardiogenic pulmonary edema, and PaO_2/FiO_2 ratio <200.[21,22] An additional database was queried for use of a kinetic therapy bed (roto-rest or roto-prone, Kinetic Concepts, Inc, San Antonio, TX). Patients were excluded from the study if they were placed on a kinetic therapy bed for prophylaxis against atelectasis or pneumonia, or if they did not tolerate the bed surface. Mechanical ventilation was managed by protocol (ARDS-net[5]), using pressure-regulated volume control and/or pressure-control ventilatory modes and there was no difference between the groups. Patients were placed on the supine oscillating bed (roto-rest) or the prone oscillating bed (roto-prone) at the discretion of the attending physician. Prone positioning was contraindicated in patients with spinal fractures. Patients with head injury and intercranial pressure (ICP) monitors were placed in either group, but patients with higher ICPs were managed in the supine group. Patients with temporary abdominal closure after decompression for intra-abdominal hypertension were managed either prone or supine.

Patients on the supine oscillating bed (roto-rest) were continuously turned to 62 degrees on each side (124 degrees total rotation) and placed level for hemodynamic measurements, hygiene, etc. Patients placed on the prone oscillating bed (roto-prone) were on a 4-hour cycle. During this time, they were prone with continuous 62 degrees per side rotation for 3 hours and 15 minutes, and placed supine and level for 45 minutes for hemodynamic measurements, hygiene, line changes, etc. Patients were taken off the kinetic beds and placed on conventional hospital beds when the FiO_2 was $\leq$0.4 with positive end expiratory pressure of 5 cm H_2O and the PaO_2/FiO_2 ratio had improved by at least 50% over entry.

Data obtained included age, Injury Severity Score (ISS),[23] chest Abbreviated Injury Scale score (AIS), head AIS, Revised Trauma Score (RTS), Glasgow Coma Scale score (GCS), intracranial pressure (when available), abdominal AIS, base deficit, probability of survival, PaO_2/FiO_2 ratio, FiO_2 requirement, dynamic compliance, central venous pressure (CVP), days on the kinetic bed, ventilator days, use of pressors, presence of pneumonia, mortality, and pulmonary-associated mortality. Mortality was attributed to pulmonary causes if the patient died from hypoxemia, hypercarbia, or the death was recorded in the registry as "ARDS" or "ARDS/Multisystem organ failure." Statistical analysis was performed with a commercially available software package (SPSS for Windows, version 12, Chicago, IL) with *t* test and χ^2 analysis. Data are expressed as mean ± SE, with significance attributed to $p < 0.05$. The institutional review board of Community Medical Centers of Central California approved this study.

RESULTS

From March 1, 2004 through May 31, 2006, 4,507 trauma patients were admitted. During that time period, 221 patients were identified in the trauma registry with ARDS or ALI.

Of the patients with ALI or ARDS, 53 patients met the inclusion criteria for this study. Additionally, 8 surgical patients met inclusion criteria for the study. The general surgery patients included five patients with intra-abdominal sepsis (from pancreatitis in 1 and bowel perforations in 4), a patient with a ruptured abdominal aortic aneurysm, and a woman with a resection of retroperitoneal liposarcoma involving the vena cava. Of these 61 patients, 44 patients were placed supine on a roto-rest surface (41 trauma patients and 3 general surgery patients) and 13 patients were placed prone on the roto-prone surface (8 trauma, 5 general surgery patients). Additionally, 4 trauma patients who were initially managed supine on the roto-rest surface and then changed to prone positioning on the roto-prone surface were included in the study group. There were nine patients in the supine group and one patient in the prone group with ALI (p = not significant [NS], χ^2); the remaining patients all had ARDS.

Patients with ARDS were older than the overall trauma patient population (45 years vs. 36 years, $p < 0.001$). There was no difference in age between the ARDS population and either the supine (roto-rest, mean age 45 years) or prone (roto-prone, mean age 49 years) groups. The study group patients were critically injured or ill with vasopressors in use at the time of kinetic therapy surface placement in 51% with 24 of the 53 trauma patients and 7 of the 8 general surgery patients receiving pressor agents. There was no difference in pressor use between the supine and prone groups (54% vs. 46%). There was no difference between the supine and prone groups in CVP, ISS, RTS, base deficit, or probability of survival (Table 1).

There was no difference between the groups in head AIS (Table 1) but the GCS at the time of trauma center admission was significantly lower in the supine versus the prone group (9.8 vs. 13, $p = 0.063$). Intracranial pressure monitors were placed in 12 patients in the supine group and 2 patients in the prone group ($p = 0.2$, χ^2).

There was no difference between the groups in chest AIS (3.7 vs. 4.1) or in ventilator management. Patients were on mechanical ventilation for 4.5 days before being placed on supine kinetic therapy and for 6.3 days before being placed on prone kinetic therapy ($p = 0.12$). There was no difference between the supine and prone groups in positive end expiratory pressure (PEEP; 10.2 vs. 9.6), dynamic compliance (29.8

Table 1 Supine Versus Prone Patient Data (Including Crossover Patients)

	Supine	Prone	*p* Value
n	48	17	
Age	45 ± 2.5	49 ± 4.0	NS
Injury Severity Score	30.1 ± 1.9	26.8 ± 2.6	NS
Revised Trauma Score	8.4 ± 0.6	10.6 ± 0.6	0.07
Base deficit	0.2 ± 0.8	1.2 ± 1.2	NS
Chest AIS	3.7 ± 0.2	4.1 ± 0.2	NS
Head AIS	4.6 ± 0.2	3.8 ± 0.9	0.06
Probability of survival	0.6741 ± 0.0501	0.8373 ± 0.0544	NS
Central venous pressure entry	14 ± 0.5	14 ± 0.7	NS
Bed days	6.2 ± 0.7	5.3 ± 0.5	NS
Ventilator days (survivors)	24.2 ± 4.4	13.6 ± 2.2	0.12
Length of stay, days (survivors)	40 ± 7	22 ± 2	<0.02

vs. 32.8) or $PaCO_2$ (37.5 vs. 39.6) at study entry. The diagnosis of pneumonia was made in 27 patients: 22 in the supine group and 6 in the prone group ($p = 0.8$, χ^2).

There was no difference between the supine and prone groups in abdominal AIS (3.0 vs. 2.8, respectively) although there were 12 patients in the supine group with temporary abdominal closure and 1 patient in the prone group with temporary abdominal closure ($p = 0.086$, χ^2). There were no patients that required renal replacement therapy in either group at the time of kinetic surface placement. Two patients in the supine group eventually received renal replacement therapy, one while on the bed (roto-rest) and one after the kinetic surface was no longer being used.

The PaO_2/FiO_2 ratios were nearly identical at study entry (149 supine vs. 153 prone, NS), and the PaO_2/FiO_2 ratio was significantly increased by day 5 in both groups over entry values ($p < 0.001$; Table 2). The PaO2/FiO2 ratio improved more in the prone group than in the supine group ($p < 0.03$ or 0.06, one or two-tailed *t* test). The FiO_2 requirement decreased in both groups by day 5: in the supine group from 0.63 to 0.45 ($p < 0.001$) and from 0.58 to 0.4 in the prone group ($p < 0.001$). The prone group demonstrated a statistically significant increase in compliance versus the supine group (37 vs. 31, $p < 0.05$) only at day 1. There were no significant differences between the groups in compliance on any other day, or in the other measured respiratory parameters of positive end expiratory pressure (PEEP) and $PaCO_2$.

Ventilator days (13.6 vs. 24.2, $p = 0.06$) and overall hospital stays (22 vs. 40, $p < 0.02$) were less in the prone versus the supine group (Table 1).

There were four patients who were originally placed on the supine kinetic surface and subsequently changed to the prone kinetic bed because of failure to improve. All were trauma patients, with an average age of 56 years and an ISS of 23. They were on supine kinetic therapy for 8 days before being placed prone. These patients showed rapid and significant improvement. There were significant differences in PaO_2/FiO_2 ratios from day 2 through day 5 and in FiO_2 by day 5 (Table 3; Fig. 1).

Table 2 Supine Versus Prone Pulmonary Parameters (Including Crossover Patients)

	Supine	Prone	*p* Value
n	48	17	
PaO_2/FiO_2 ratio entry	149 ± 8	153 ± 9	NS
FiO_2 entry	0.63 ± 0.03	0.58 ± 0.03	NS
PaO_2/FiO_2 ratio day 5	200 ± 14	243 ± 13	0.06
FiO_2 Day 5	0.45 ± 0.02	0.40 ± 0.01	0.12
Mortality	16	0	<0.01
Pulmonary-related mortality	7	0	0.051

Table 3 Pulmonary Parameters in the Four Crossover Patients

	Supine	Prone	*p* Value
PaO_2/FiO_2 ratio entry	156 ± 8	165 ± 9	NS
PaO_2/FiO_2 ratio day 1	176 ± 13	208 ± 10	0.1
PaO_2/FiO_2 ratio day 2	156 ± 19	224 ± 14	<0.03
PaO_2/FiO_2 ratio day 3	176 ± 12	266 ± 23	<0.02
PaO_2/FiO_2 ratio day 5	146 ± 16	238 ± 6	<0.001
FiO_2 entry	0.55 ± 0.02	0.54 ± 0.02	NS
FiO_2 day 5	0.47 ± 0.02	0.4 ± 0.02	0.05

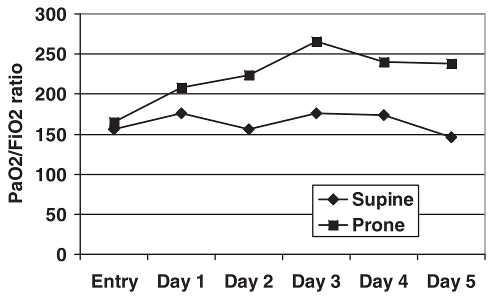

Fig. 1. *PaO_2/FiO_2 ratios on crossover patients. The PaO_2/FiO_2 ratios in the supine versus prone crossover patients. The PaO_2/FiO_2 ratio is shown on the* y*-axis; the days of supine or prone therapy are on the* x*-axis. The differences in PaO_2/FiO_2 ratio were statistically significant from day 2 through day 5.*

A patient not meeting inclusion criteria for this study also responded to prone positioning after not progressing with supine kinetic therapy. This was a 51-year-old man with a 3-day history of a perforated duodenal ulcer who presented with sepsis and ARDS. He had a PaO_2/FiO_2 ratio of 74 on 100% FiO_2 and was placed in a supine oscillating bed immediately postoperatively. His pulmonary function improved slightly (PaO_2/FiO_2 ratio 100 on 60% FiO_2), but did not improve further and by hospital day 13, his PaO_2/FiO_2 ratio was 98 on 70% FiO_2. His prognosis was thought to be grim and he was placed on the prone oscillating bed as a last-ditch effort. He showed slow but steady improvement over time, and eventually met criteria (PaO_2/FiO_2 ratio 355) to be placed on a conventional bed after 30 days of prone oscillation. This patient had the longest duration of prone positioning in our experience, but represented a "proning rescue" from failed supine treatment.

There were 19 deaths in the study patients (31%), all but one occurred in the supine group. The mean length of stay was 15.4 ± 5.4 days before demise. The difference in overall mortality between the prone and supine groups was significant ($p < 0.01$, χ^2). However, nine patients in the supine group died from severe closed head injury. When these patients are excluded, there was no difference between the groups in ISS (28 vs. 26.7), RTS (9.2 vs. 10.6), GCS (11.2 vs. 13), head AIS (3.9 vs. 3.7), or chest AIS (3.5 vs. 3.7). The non-head injury mortality in the study group was 16%. These included deaths secondary to hypoxemia in trauma patients with ARDS (PaO_2/FiO_2 ratios of 54 and 53), a trauma patient with an hypoxic injury, and a PaO_2/FiO_2 ratio of 100 (care withdrawn), a patient with a massive myocardial infarction related to hypoxemia (PaO_2/FiO_2 ratio 118–180), two patients with refractory pulmonary failure that had care withdrawn, and a trauma patient with multiorgan system failure (PaO_2/FiO_2 ratio of 130–240), renal failure, and eventual withdrawal of care for medical futility. The death in the prone group was from intra-abdominal sepsis in a general surgery patient with pancreatitis. The difference in pulmonary related mortality between the supine and prone group (7 versus 0) approached statistical significance ($p = 0.051$).

DISCUSSION

Since West's description of respiratory physiology and ventilation/perfusion zones,[24] position change has been advocated to promote redistribution of gas, recruit alveoli, and redistribute pulmonary blood flow.[25] Kinetic therapy has been postulated to improve pulmonary function by resolving atelectasis, aiding alveolar recruitment, improving mobilization of secretions, improving oxygenation, and improving matching of ventilation and perfusion. Previous studies comparing kinetic therapy to manual turning by the nursing staff have shown improved pulmonary function in patients receiving kinetic therapy with improvements in PaO_2/FiO_2 ratio, decreased days on the ventilator, and shorter ICU lengths of stay.[10,26]

Reports of prone positioning to improve oxygenation in patients with ALI/ARDS date back nearly 30 years.[27] Animal studies have demonstrated improved oxygenation and ventilation perfusion ratios, along with restoring aeration, decreasing shunt, and preserving perfusion.[28,29] In addition, prone positioning has been shown to eliminate compression of the lungs by the heart.[30]

Prospective studies of prone ventilation have shown an improvement in oxygenation of patients with ALI or ARDS, allowing decreases in inspired oxygen concentration.[15,19] Other prospective studies demonstrated improved oxygenation and decreased pneumonia, but prone positioning did not change length of ventilatory support or final outcome.[31–33]

Several prospective studies have suggested little or no benefit with prone positioning. One study found no difference in ventilator duration or mortality, but slight decreases in the frequency of ventilator-associated pneumonia.[20] In another study, there was no difference in PaO_2/FiO_2 ratio, $PaCO_2$, shunt fraction, or outcomes between patients on supine oscillating beds versus patients placed prone on a conventional bed.[16] One retrospective study of ARDS patients demonstrated an improvement in observed versus predicted survival by APACHE II (Acute Physiology and Chronic Health Evaluation) with low pressure ventilation and prone positioning whenever possible.[34]

The use of prone positioning has been limited because of the intensive effort required to actually place patients prone. In most of the previously published studies, the time the patients spent prone was 4 to 8 hours per day.[15,19,20,31,33] The prone oscillating bed used in the current study (roto-prone, Kinetic Concepts, Inc., San Antonio, TX) is relatively new technology. With the use of this bed surface, placing a patient in the prone position is a matter of pushing a button. The patient can subsequently be prone for a longer period of time and derive the benefits of kinetic therapy while prone.

The previously cited studies on prone ventilation have generally shown improvement in PaO_2/FiO_2 ratio, oxygenation, and decreased ventilatory support and ventilator days. The current study also demonstrates improvements in PaO_2/FiO_2 ratio, decreased oxygen requirements, and decreased ventilator days and length of stay. The reported mortality rate for ALI or ARDS is still as high as 35% to 40% in mixed ICU patient populations.[4,6,7] A recent study of ARDS in trauma patients reported a mortality rate of 28%.[35] The overall mortality rate in the present study, with the use of prone or supine kinetic therapy, was 30%, but was only 19% when deaths from head injury were excluded. This study also demonstrated a modest survival benefit to prone versus supine positioning with kinetic therapy.

This study is a small retrospective analysis comparing prone and supine kinetic therapy and it has all the inherent limitations of its type. The study group of patients receiving supine or prone kinetic therapy represented only 28% of the patients with ALI or ARDS treated during the study period. Some of the patients were not treated with kinetic therapy because of unstable spine or pelvis fractures and some had intracranial pressure elevations that could not be managed when the patients were placed on kinetic therapy surfaces.

The supine group had almost three times as many patients. Some of this skewed selection was secondary to patients with spine injury or skeletal injuries requiring traction before definitive orthopedic repair. Additionally, patients with difficult to manage ICPs were placed on supine kinetic surfaces, if they could tolerate kinetic therapy at all. The supine group had higher head AISs and was more likely to have ICP monitors in place, although these differences did not reach statistical significance. The detrimental combined effect of head injury and acute lung injury is well known. However, with all the head injury deaths excluded, there were no differences in head AIS, RTS, GCS, or ISS and the survival benefit persisted. Additionally, as with any new technology, there is commonly resistance to change. One attending championed the use of the prone kinetic bed, which led to some of the disparity in sample size. However, by all other measures except head injury, the prone group was as critically ill and injured as the supine group.

Perhaps the most intriguing and compelling findings in this study were in the crossover patients. These trauma patients failed to progress with supine kinetic therapy after an average of 8 days, but showed rapid and statistically significant improvement within 48 hours of the onset of prone kinetic therapy. It may be that the trauma patients with ARDS or ALI represent a group that are particularly benefited by prone kinetic therapy, particularly when they fail to progress when supine.

The current investigation demonstrates improved oxygenation, PaO_2/FiO_2 ratio, and decreased FiO_2 requirement with continuous rotation in the prone position compared with continuous rotation in the supine position. This study demonstrated a significant reduction in mortality (overall and pulmonary related) with prone kinetic therapy. Additionally, patients who were prone had decreased duration of ventilatory support and length of stay. The use of a prone oscillating bed is advantageous in trauma and surgical patients with ALI or ARDS and was superior to supine kinetic therapy in this study.

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