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Rachel Culbreth  
*Georgia State University, rculbreth@student.gsu.edu*

Lynda T. Goodfellow  
*Georgia State University, ltgoodfellow@gsu.edu*

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Complications of Prone Positioning During Extracorporeal Membrane Oxygenation for Respiratory Failure: A Systematic Review

Rachel E Culbreth MPH RRT and Lynda T Goodfellow EdD RRT AE-C FAARC

BACKGROUND: Extracorporeal membrane oxygenation (ECMO) is often used in patients with severe respiratory failure to improve oxygenation and survival. ECMO gives the lungs an opportunity to rest and recover. The addition of prone positioning therapy used concurrently with ECMO can further aid in optimizing alveolar recruitment and reducing ventilator-induced lung injury, ultimately resulting in fewer ICU admission days and improved overall survival. The objective of this review is to perform a systematic analysis of the complications reported with prone positioning and ECMO in the adult population and to briefly report on the patient outcomes in the studies.

METHODS: PubMed, MEDLINE, Cochrane Library, and CINAHL were searched from January 1, 1960 to September 14, 2014. Studies were included if they examined both extracorporeal membrane oxygenation and prone positioning simultaneously for the treatment of respiratory failure in the adult population. RESULTS: Seven studies fit the study inclusion criteria (1 prospective cohort study, 3 retrospective cohort studies, and 3 case series). All of the studies in this review reported no occurrence of ECMO cannula dislodgment, and 2 studies reported cannula site bleeding. Chest tube dislodgment and airway dislodgment did not occur in any of the studies included. Bleeding from the chest tube site was reported in 13.5% of prone positioning maneuvers in 1 study, and the rest of the studies reported no evidence of chest tube site bleeding. Of the 2 studies that reported hemodynamic instability during the prone positioning maneuvers, very few adverse hemodynamic episodes were reported. The authors who reported adverse effects stated that the episodes were quickly and successfully reversible. CONCLUSIONS: This review highlights the limited complications documented during prone positioning and ECMO. More studies are needed to assess the clinical efficacy of the addition of prone positioning therapy to ECMO for patients in severe respiratory failure. Key words: extracorporeal membrane oxygenation; prone position; respiratory insufficiency; acute lung injury; respiratory distress syndrome; adult; anoxia. [Respir Care 2016;61(2):249–254. © 2016 Daedalus Enterprises]

Introduction

Respiratory failure leading to acute lung injury and ARDS occasionally requires a combination of interventions to improve oxygenation and ultimately survival for the patient. Extracorporeal membrane oxygenation (ECMO) may be offered to provide the lungs an opportunity to rest and recover. Since the first trial of ECMO in the 1960s, this life support mechanism has transitioned over the years from primarily being used in neonates with cardiac diseases and irregularities to use in adults with a variety of life-threatening conditions, including ARDS. Veno-venous ECMO is primarily used in patients with respiratory failure, where a large-bore cannula is typically inserted into the right internal jugular vein, providing a blood infusion pathway, and a large-bore cannula inserted into the femoral vein provides the drainage pathway. The blood is filtered through a membrane oxygenator, providing oxygen-rich blood to be infused into the body. Patients treated with ECMO are typically on the device anywhere between several days to weeks, depending on the disease process and how early the intervention was implemented.

The addition of prone positioning therapy concurrently with ECMO can aid in optimizing alveolar recruitment.
and reducing ventilator-induced lung injury, therefore hope-
fully reducing ICU admission days and improving overall
survival.1–3 The Guidelines for Adult Respiratory Failure
from the Extracorporeal Life Support Organization4 rec-
ommend the consideration of adding prone positioning
therapy to patients receiving ECMO if there is posterior
consolidation of the lung fields with some lung fields open
anteriorly. The guidelines recommend exercising caution
to prevent the dislodgment of the ECMO cannulas.4 Adding
prone positioning therapy can also help reduce the risk
of memory and other cognitive impairments associated
with hypoxemia.2–5 However, severe complications can po-
tentially result from prone positioning ECMO pa-
tients.2,3,6–11 Prone positioning alone can pose serious risks.
Among a study examining prone positioning in subjects
without ECMO, a high incidence, 10.7%, of unintended
extubations was reported.12 In addition to unplanned ex-
tubations, complications from prone positioning alone in-
clude accidental removal of lines, kinks in various tubing,
and potential injuries to health-care workers. However, the
overwhelming literature supports prone positioning as a
treatment option for patients in severe respiratory failure.13
To reduce the risks of potential complications, trained crit-
cal care staff and strict protocol implementation are rec-
commended.13
ECMO alone can result in several serious complica-
tions. The most common complication of ECMO is bleed-
ing, commonly due to anticoagulation therapy.4 Other
complications can include cannula site infection, throm-
bocytopenia, and heparin-induced thrombotic thrombocy-
topenia. Severe neurological injuries can occur as a com-
plication of ECMO, including subarachnoid hemorrhage,
encephalopathy, and brain death.14
The aim of our review is to perform a systematic anal-
ysis of the complications that have been reported with
prone positioning and ECMO in the adult population with
respiratory failure and to briefly report on the subject out-
comes in the studies. The purpose of this review is to
provide clinicians with an overview of documented and
potential complications from using prone positioning and
ECMO to assess the feasibility of adding prone position-
ning therapy to patients receiving ECMO.

Methods

Search Strategy

Databases searched included PubMed, MEDLINE, Co-
chrane Library, and CINAHL. The terms “prone position”
AND “extracorporeal membrane oxygenation” were used
as well as “ECMO” AND “respiratory failure.” Alternate
word searches were performed for prone positioning, such
as “kinetic therapy” and “positioning therapy.” The data-
bases were searched from January 1960 to September 2014.

Results

Using specified search terms, 71 articles from PubMed,
10 articles from MEDLINE, 4 articles from CINAHL, and
0 articles from Cochrane library were found. A total of 7
articles met the study inclusion criteria (3 retrospective
cohort studies, 1 prospective cohort study, and 3 case se-
ries) (Table 1). The case series were included due to the
<table>
<thead>
<tr>
<th>Study</th>
<th>Sample Size</th>
<th>Patient Positioning</th>
<th>ECMO Type/Equipment</th>
<th>Complications Reported Related to Prone Positioning, ( n (%) )*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goettler7, 2002</td>
<td>Total ( N = 50 )</td>
<td>Manual vs Mechanical</td>
<td>VV ECMO/prone positioning</td>
<td>No complications reported: cannula dislodgment due to gradual dislodgment, replaced with no further complications</td>
</tr>
<tr>
<td>Litmathe6, 2011</td>
<td>( N = 3 )</td>
<td>Manual</td>
<td>VV ECMO, equipment unspecified</td>
<td>No complications reported</td>
</tr>
<tr>
<td>Otterspoor3, 2012</td>
<td>( N = 3 )</td>
<td>Manual</td>
<td>Single sites cannulas</td>
<td>No complications reported</td>
</tr>
<tr>
<td>Kipping2, 2013</td>
<td>Retrospective Cohort</td>
<td>Manual</td>
<td>Multisite large bore cannulas</td>
<td>Of 74 total prone positions for 12 subjects: bleeding cannula site = 10 (13.5%); bleeding central venous catheter site = 11 (14.6%); bleeding chest tube site = 10 (13.5%); chest tube obstruction = 1 (1.4%); tracheal tube obstruction = 2 (2.7%); acute pulmonary embolism = 1 (1.4%); hypotension = 3 (4.1%); pneumothorax = 1 (1.4%); no significant hemodynamic variations; cannula dislodgment, bleeding/dislodgment tracheal tube, corneal abrasion</td>
</tr>
<tr>
<td>Masuda9, 2014</td>
<td>( N = 4 )</td>
<td>Manual</td>
<td>Single sites, 19 French catheters</td>
<td>No complications reported: bleeding cannula site, no significant hemodynamic variations, cannula dislodgment, bleeding/dislodgment tracheal tube, corneal abrasion</td>
</tr>
<tr>
<td>Guervilly10, 2014</td>
<td>Prospective Cohort</td>
<td>Manual</td>
<td>Single sites, 20 French catheters</td>
<td>No complications reported: cannula dislodgment, central venous catheter dislodgment, sutures dislodgment, catheter and arterial pressure sites, chest tube dislodgment</td>
</tr>
</tbody>
</table>

*Percentages indicate the percentage of patients who experienced complications out of the total number of patients within each study.
study sample consisting of >1 patient. Complications resulting from prone positioning during ECMO therapy were assessed in all included studies. A total of 49 subjects from 7 articles were included in this review, and all subjects were receiving veno-venous ECMO. The majority of the subjects experienced no complications from concurrent ECMO and prone positioning therapy.\(^2,3,6,7,9-11\) However, the most common complications included bleeding from the ECMO cannula site. One study reported 11 prone positioning maneuvers, of a total of 74 maneuvers among 12 subjects, resulting in bleeding from the cannula site.\(^2\) In addition, Otterspoor et al\(^1\) reported 1 subject who experienced bleeding from the cannula site; however, the majority of all subjects (94.3%) did not experience this complication. Other documented complications observed while subjects were receiving concurrent ECMO and prone positioning therapy included pneumothorax (2.0%),\(^10\) edema (12.2%),\(^11\) and entrance of air into the ECMO circuit (2.0%).\(^11\)

**ECMO Cannula Complications**

Dislodgment of ECMO cannulas has been recognized as potentially the most serious complication resulting from prone positioning during ECMO.\(^8,9\) All of the studies included in this review reported no occurrence of ECMO cannula dislodgment.\(^2,3,6,7,9-11\) Two of 7 studies indicated cannula site bleeding as a complication.\(^2,3\) Bleeding from the ECMO cannula site was also noted in 11 episodes of prone positioning out of a total of 74 prone positions among 12 subjects in 1 study,\(^2\) and bleeding from the cannula site was observed in 1 subject by Otterspoor et al.\(^3\) Although cannula site bleeding was common among these studies, cannula site bleeding is a frequent occurrence of subjects receiving ECMO due to anticoagulation therapy.\(^9\) Although common, this complication is not to be minimized or dismissed, because cannula site bleeding can pose many risks for patients receiving ECMO.\(^3\) It is important to note that this complication cannot be completely attributed to the addition of prone positioning to ECMO.

**Central Venous and Arterial Catheter Complications**

Only 1 study\(^2\) reported catheter complications. No central venous or arterial catheters were reported dislodged among all studies.\(^2,3,6,7,9-11\) In the study with one of the largest sample sizes, bleeding from the central catheter was noted in 10.8% of a total of 74 prone position maneuvers among 12 subjects.\(^2\)

**Chest Tube Complications**

None of the adult studies reported chest tube dislodgement in this review.\(^2,3,6,7,9-11\) Kipping et al\(^2\) reported bleeding from the chest tube site in 13.5% of prone positioning maneuvers. The rest of the studies reported no chest tube site bleeding.\(^3,6,7,9-11\)

**Airway Dislodgment and Obstruction**

Airway dislodgment has been reported as a common complication in prone positioning patients,\(^12\) but among the studies selected, no episodes of tracheal or endotracheal tube dislodgment was found.\(^2,3,6,7,9-11\) Kipping et al\(^2\) reported 1 incident of an endotracheal tube obstruction during the prone positioning maneuver, in which the subject was placed back in a supine position for an emergent bronchoscopy and change of endotracheal tube. Kipping et al\(^2\) was the only study to report obstructions of airways; however, the authors rationalized that patients receiving ECMO were less at risk for severe hypoxemia compared with patients without ECMO. Therefore, airway obstruction or dislodgment would have less severe implications for subjects receiving ECMO compared with subjects not receiving ECMO.\(^2\)

**Hemodynamic Instability During Positioning**

Only 2 studies reported episodes of hemodynamic instability.\(^2,10\) Guervilly et al\(^10\) reported no significant hemodynamic variations during the prone positioning maneuvers. Bradycardia (<60 beats/min or drop in heart rate by 50%) was reported by Kipping et al\(^2\) in 3 subjects during the prone positioning maneuver. A 20% decrease in systolic blood pressure was experienced in 7 of the 74 prone positioning maneuvers. The hemodynamic episodes were all quickly treated with success, and the overall rates of the episodes were considered low by the authors.\(^2\)

Kipping et al\(^2\) also reported 1 subject who experienced a pulmonary embolism during the prone positioning maneuver requiring immediate resuscitation; however, the authors did not consider this complication attributable to prone positioning. Patients receiving ECMO are required to be repositioned frequently, and the pulmonary embolism would have probably occurred during routine positioning as well.\(^2\)

Several studies have reported hemodynamic instability during prone positioning without ECMO\(^12,15\); however, 1 randomized control trial reported no difference in bradycardia and hypotension episodes between subjects receiving prone positioning and subjects not receiving prone positioning.\(^1\)

**Miscellaneous Non-Life-Threatening Complications**

Cutaneous pressure sores are considered a potential complication of prone positioning and/or ECMO. None of the studies in this review reported cutaneous pressure sores.\(^2,3,6,7,9-11\)
Facial edema was reported in 66.7% of subjects in 1 study but was reversible.11 Also, this study reported complications related to ECMO (entrance of air in the circuit and pump failure), but these were deemed unrelated to the prone positioning.11

Prone Positioning Maneuver Type: Mechanical Versus Manual

Only 1 study11 reported the use of automated, rotating beds to perform prone positioning of subjects. Among the remainder of the studies that reported on the type of prone positioning maneuver used, all studies utilized manual prone positioning techniques.2,6,7,9

ECMO Equipment and Cannula Site

Multiple sites for cannulation were used in several studies. Goettler et al7 suggest that the location of high-flow catheters does not affect the number of complications or malfunctions. All cannulas were heparin-coated, or, if the cannulas were not specified as heparin-coated, subjects were placed on heparin therapy while receiving ECMO.2,3,6,7,9-11 Among the studies that reported the type of ECMO equipment used, all studies reported using either a centrifugal pump system3,9-11 or an occlusive pump system.2 Only 1 of the studies3 reported on the amount of circuit changes required while patients were receiving ECMO. Otterspoor et al3 reported that 1 subject required a total of 4 circuit changes over a 45-d period receiving ECMO.

Outcomes: Oxygenation and Survival

Four studies in this review reported oxygenation measures before and after prone positioning maneuvers.2,9-11 Of these studies, 3 found a significant difference between the \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio before and after prone positioning.2,9,10 Kipping et al2 reported that 58% of subjects experienced an improvement in \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio of >20% post-prone positioning compared with pre-prone positioning. A significant increase in \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio was found post-prone positioning compared with pre-prone positioning using the non-parametric Wilcoxon test for pairwise comparisons in the second prone positioning maneuver (\( P = .009 \)).2 Guervilly et al10 found significant improvements in \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratios after 12 h of prone positioning (\( P = .007 \)). A significant increase in \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio was also found by Masuda et al9 with a prior median \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio of 143 ± 38.1 to a post-median \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio of 235.5 ± 87.1 (\( P < .05 \)).

Survival was reported in all studies.2,3,6,7,9-11 Among these studies, 30 of 49 subjects (61.2%) survived. One subject, 6 y in age, was excluded from the survival analysis due to not meeting the age criterion of 15–75 y.9 The overall survival proportion for adults receiving ECMO for respiratory failure is 65% (n = 7,008).4 The national survival proportion is not only higher than the survival from our review (65% vs 61.2%), respectively), but there is no statistical significance between survival proportions (\( P = .54 \)). The overall impact of prone positioning and ECMO on long-term oxygenation as well as survival is limited in the literature.2

Discussion

This review highlights the limited number of complications experienced when implementing prone positioning and ECMO concurrently. The survival percentage among the subjects included in this study is lower than the national survival percentage; however, this could be attributed to the severity of the conditions of subjects who are receiving both prone positioning and ECMO compared with ECMO alone.

Limitations

Several limitations are noted in this review. First, there is a lack of randomized control trials and prospective studies analyzing the concurrent use of ECMO and prone positioning. The small sample size of the total number of studies also limits the statistical power, which could be generated with larger sample sizes to determine the efficacy of adding prone positioning to ECMO in terms of survival. Only 1 study10 was a prospective, 2-y cohort study. Three of the studies were retrospective cohort studies, whereas the remaining 3 were case series. Due to the nature of retrospective chart reviews, some complications could have been missed, therefore underestimating the complications documented.7,11 A multi-center, randomized control trial would be beneficial in evaluating the intervention of prone positioning for adult patients receiving ECMO for respiratory failure. Due to the retrospective nature of the studies, adequate \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratio comparisons before and after prone positioning are difficult due to other factors that could influence \( P_{\text{aO}_2}/F_{\text{I}0_2} \) ratios, including pump flow rate and ventilator settings. Keeping these factors constant would allow adequate comparison of adding prone positioning to ECMO patients compared with patients receiving ECMO alone.

Second, some of the studies lacked documentation on the equipment they used for ECMO and prone positioning (manual vs automated). This leads to inadequate conclusions regarding which equipment would best be utilized during prone positioning. Only 1 study3 reported on the number of ECMO circuit changes that were performed. Documentation of the number of circuit changes would
help in determining the effects of prone positioning on the circuit longevity.

Third, 6 of the 7 studies utilized manual prone positioning techniques. More studies including prone positioning where automated beds were used would be beneficial in assessing complications.

Last, analyzing overall survival and days spent in the critical care units would be more beneficial to clinicians’ decisions than $P_{aO_2}/F_I_{O_2}$ ratios alone. Future studies should include survival analyses as well as the total number of days spent in the critical care unit to determine the overall efficacy of prone positioning and ECMO for respiratory failure.

**Recommendations**

All of the studies in this review documented a sufficient number of hospital personnel to assist in the prone positioning maneuver. The authors recommended highly trained personnel to monitor all catheters and lines as well as vital signs to reduce the risk of appliance dislodgment. One study specifically recommended experienced personnel to be responsible for observing the airway (respiratory therapist) and ECMO cannula position (ECMO specialist) to reduce complications caused by these devices.

Automated, rotating beds have emerged in critical care units, and the use of these beds results in a reduced burden on staff. Taccone et al. reported fewer tube and catheter dislodgments with the use of automated, rotating beds. More studies are needed to assess the complications among automated, rotating beds versus manual prone positioning maneuvers to adequately inform clinicians. Clinicians should weigh the benefits of prone positioning against the complications noted in this study as well as anticipated complications. The awareness of potential complications and documented complications can lead to safety improvement of the addition of prone positioning therapy to ECMO.

**Conclusions**

This review highlights the limited number of complications documented during the addition of prone positioning therapy to ECMO. More studies are needed to assess the clinical efficacy of the addition of prone positioning to adult patients receiving ECMO for respiratory failure. Prospective and randomized control trials are necessary to assess the long-term impact of prone positioning and ECMO on survival as well as the effects on ICU stay and complications. Due to the limited sample size of studies included in this review, the current available literature is unable to fully answer the question of whether concurrent use of ECMO and prone positioning is completely safe. However, the studies included in this review have reported that concurrent use of prone positioning and ECMO is safe. Thus, our review has presented the current literature on the limited complications investigators have found when implementing both interventions simultaneously on adult subjects.

**References**


