Prone position in therapy-refractory hypoxaemia

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The prone position is used for mechanically ventilated patients with acute respiratory failure to improve oxygenation. Clinical studies have shown that although some patients may benefit from prone position (responders), others show no improvement in oxygenation (non-responders). The probable mechanism that increases the PaO_2 in the patients is the improvement of regional ventilation, redistribution of ventilation and relatively unchanged perfusion in dorsal lung regions, resulting in improved regional ventilation–perfusion matching and reduction of shunt perfusion. The difficulty in turning critically ill patients and the potential complications of the prone position can be significantly reduced by the use of air-fluidized beds.

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Abbreviations

ARDS	adult respiratory distress syndrome
FRC	functional residual capacity
CT	computerized tomography
PaO_2	arterial PO_2
PEEP	positive end-expiratory pressure
FiO_2	fraction of inspired oxygen

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Introduction

The prone position is recommended to improve oxygenation in patients with acute respiratory failure [1]. It was first suggested in 1974 by Bryan [2] for patients requiring mechanical ventilation in order to enhance the expansion and ventilation of the dorsal lung units. During the past 2 decades clinical studies have shown an improvement of oxygenation in some patients (responders) but not in others (non-responders) [3–7]. In one study [5], no significant baseline differences between responders and non-responders could be found. Despite existing evidence of the beneficial effects of the prone position, in need of further clarification are the exact mechanism of the improvement of oxygenation, the reason for the difference in response between patients, the indication for prone position, the timing and duration.

The aim of this review is to summarize the potential beneficial effects of the prone position, such as improved oxygenation in patients with acute respiratory failure. The use of air-fluidized beds for turning the patients into the prone position will also be described.

Mechanism of the effect of prone position

Changes in functional residual capacity and regional diaphragmatic movement

The improvement of arterial PO_2 (PaO_2) when patients with adult respiratory distress syndrome (ARDS) were turned prone was thought to be related to the possible increase in functional residual capacity (FRC) or to the change in regional diaphragmatic movement [4]. The increase in FRC is shown to occur in humans turned prone especially when thorax and abdomen are suspended [8,9]. However, in other clinical studies, oxygenation could be improved without particular support for abdomen and upper chest [3,5,6]. Furthermore, in an animal model of ARDS, Albert *et al.* [10] could not find any relationship between improvement of PaO_2 on prone position and the changes in FRC or the regional diaphragmatic motion.

Drainage of secretions

A gravitational advantage to the drainage of secretions from peripheral airways of diseased dorsal lung segments is thought to improve ventilation [4]. Piehl and Brown [3] reported copious amounts of secretions obtained in some of their patients. In contrast, Langer *et al.* [5] observed a transient increase in bronchial secretions in the prone position. However, this increase was seen both in responders and non-responders, suggesting that this may not be the only reason of improvement in PaO_2.

Redistribution of perfusion

Redistribution of perfusion to previously non-dependent and less damaged lung zones is another suggested explanation of improved PaO_2 [3]. Gattinoni and colleagues [11] found that changes in density on computerized tomography (CT) scan from dorsal to ventral areas in the prone position were too great to be explained by only pulmonary blood redistribution. No data are available on the effect of the prone position of the distribution of pulmonary blood flow in ARDS patients. In dogs with oleic acid-induced lung injury, perfusion was preferentially distributed to dorsal lung regions regardless of whether this region was dependent or not [12–14]. The gravitational distribution of perfusion is markedly reduced in the prone position [12], confirming earlier animal and human studies [15–19]. Reviewing these studies, Albert [20•] stated that a constant lung density did not equate to there being a constant shunt or a low ratio of alveolar volume to perfusion.

Changes of regional ventilation and redistribution of ventilation

The use of CT scanning in ARDS patients showed that most of the lung density was distributed to dorsal lung regions [21,22]. In normal lungs in supine position, an increase in density in the dependent areas is seen because of a decreased regional gas volume or an increased tissue volume. A decrease in regional gas volume may be caused by a decrease in transpulmonary pressure as a result of a regional decrease (pressure becoming less negative) in pleural pressure along the vertical gradient [23–26]. This situation may reduce the alveolar size in normal patients. However, patients with acute respiratory failure have greater gravitational gradients of pleural pressure and decreased transpulmonary pressure, which causes atelectasis of dependent lung levels. Gattinoni and colleagues [11] observed that turning a patient from supine to prone changed the direction of the gravitational force from dorsal to ventral, causing re-opening of dorsal units and compression atelectasis of the ventral lung units. The ventral atelectases explain the lack of overall improvement of PaO_2 in the prone position in their study. However, in one article [1], the decrease of regional gas volume in the dependent lung region was greater in the supine than in the prone position. In other words, regional inflation was more homogeneously distributed in the prone position in patients showing improvement of PaO_2. Animal studies [27–30] showed that the gravitational pleural pressure gradient was less in the prone position compared with supine. Therefore, ventilation would be diminished or absent relative to perfusion in the dorsal lung regions when the animals were supine but would increase on turning prone without decreasing ventilation perfusion ratios in ventral regions [27].

Pappert *et al.* [7] investigated the influence of the prone position on the ventilation–perfusion distribution in ARDS patients with a multiple inert gas elimination technique. In responders, a reduction of shunt perfusion and an increase of normal ventilation–perfusion ratios was found. The authors concluded that ventilation–perfusion ratios improved because of alveolar recruitment in previously atelectatic but well-perfused lung regions.

Lamm *et al.* [14] measured regional ventilation and perfusion in supine and prone dogs with oleic acid-induced lung injury, by using single photon emission CT scanning. The authors observed improvement in oxygenation, in median ventilation–perfusion ratio, in regional ventilation–perfusion heterogeneity and in gravitational ventilation–perfusion gradients when the animals were in the prone position with a generally unchanged regional distribution of perfusion. They related these to a reduction in the amount of lung affected by shunt and low regional ventilation–perfusion ratios. Furthermore, their data supported the importance of regional pleural and transpulmonary pressure in determining regional ventilation, degree of shunting and ventilation–perfusion heterogeneity.

In most studies the study period is limited to 2 h, and little information is available on changes in ventilation–perfusion ratios when patients are kept longer in the prone position. In a CT scan study in ARDS patients, Pelosi *et al.* [31] reported that the lung deflation seen along the vertical gradient is most probably caused by an increased hydrostatic pressure in each level of the lung. If this is the main reason for the improved oxygenation in prone position, then new oedema formation may be expected at the new dependent areas with subsequent deterioration of oxygenation when a patient remains in the prone position for a prolonged period.

Timing of prone position

The improvement in oxygenation

The studies performed in ARDS patients showed an overall response of improvement in oxygenation of approximately 65% (Table 1). Gattinoni *et al.* [1] stated that the effects of positioning on oxygenation would wear off with time because of the evolving underlying pathology of the diseased lung. Albert [20•] stated that most of the responders were turned within 24–36 h of developing ARDS. Most of the non-responders had ARDS for at least several weeks before the prone position was attempted.

Table 1. Clinical studies showing the effect of prone position in increasing PaO_2 in patients with acute respiratory failure

	Number of patients	Responders	%
Piehl *et al.* [3]	5	5	100
Douglas *et al.* [4]	6	6	100
Langer *et al.* [5]	13	8	61
Albert [6]	11	7	64
Pappert *et al.* [7]	12	8	67
Gattinoni *et al.* [11]	10	3	30
Total	57	37	65 (mean)

The author suggested that, in non-responders, pleural pressure in dependent regions may increase to the point that the decrease of pleural pressure in the prone position may not be enough to permit airspace opening.

The results of the recently completed study in ARDS patients performed in our department (unpublished data) confirmed the observations of Albert [20•]. In ARDS patients in whom the prone position was applied when the positive end-expiratory pressure (PEEP) was greater than or equal to $10 cmH_2O$, the fraction of inspired oxygen (FiO_2) greater than or equal to 0.6 and the PaO_2/FiO_2 ratio less than or equal to 100 mmHg, the response rate was above 90%. Turning prone 1–2 weeks after the onset of ARDS caused the rate of response to reduce below 50%. These observations suggest that the prone position should be applied as early as possible for patients with ARDS.

The duration of the prone position

The duration of the prone position remains empirical. Clinical studies, case reports and abstracts show a range in the duration of the prone position of 45 min to 136 h [3–5,7,11,32–35]. Clinical studies designed to investigate the mechanism of prone position are all limited to a maximum duration of 2 h [5,7,11]. Changes of PaO_2 have been the only parameter so far indicating the need for repositioning. Piehl and Brown [3] reported an intial improvement of PaO_2 values and a deterioration after between 4 and 8 h in the prone position. Douglas *et al.* [4] observed a decrease in oxygenation in one patient after 33 h in the prone position. These results show a great variability between responses of individual patients. Furthermore, the duration of each application of the prone position in an individual patient shows great variations [4] and seems to be dependent on the extent of the pathological changes in the lungs.

In our yet unpublished clinical study, patients were turned every 6 h as long as the PaO_2/FiO_2 ratio was greater than 100 mmHg. If in supine position the PaO_2/FiO_2 ratio was between 60–100 mmHg, the patient was turned prone after 4 h and remained in that position for 8 h. If the PaO_2/FiO_2 ratio was less than 60 mmHg in supine position, the patient was immediately turned prone. In the acute stage of ARDS, approximately 20% of patients needed to stay in prone position for more than 8 h (maximum 72 h). Turning of the patient to the prone position continued until an improvement of chest radiograph or CT scan was seen in addition to the following criteria: pressure support ventilation less than or equal to $15 cmH_2O$, PEEP between 5 and $7.5 cmH_2O$ and FiO_2 at 0.4.

Recently, in our intensive care unit, we have started to use the prone position in early respiratory failure even before ARDS was established. Whether this concept may play a preventive role in ARDS by improving the physiopathology of the lungs and ventilation–perfusion ratios needs further evaluation.

Mechanical ventilation in prone position

Lachman [36] suggested the importance of opening up the lungs and keeping them open to achieve improved oxygenation with low intrapulmonary pressure swings and to prevent the depletion of surfactant. In an experimental model of ARDS, ventilation at low end-expiratory lung volumes augmented lung injury [37]. Amato *et al.* [38] reported improved lung function in ARDS patients when the lungs were kept open, increasing the chances of early weaning and lung recovery. Application of high inflation pressures was described as a measure to open the collapsed alveoli during pressure-controlled ventilation [39,40].

In our unpublished clinical study, pressure-controlled inverse ratio ventilation was applied when peak inspiration pressure reached $40 cmH_2O$ with conventional volume-controlled ventilation. At every repositioning of the patient either higher insufflation pressures up to $50 cmH_2O$ were used for approximately 5 min or sustained inflations were applied manually with a Mapleson C breathing system. When insufflation pressure was reduced to the previous value or the patient reconnected to the ventilator, a significant increase in tidal volume was observed in patients in the prone position compared with supine, indicating improved ventilation and re-opening of the dorsal collapsed lung regions. The opening of the lung was confirmed by auscultation as well as by increased PaO_2. When a Mapleson C set was used, during the reconnection to the ventilator, the intubation tube was clamped at end inspiration to avoid the collapse of the lungs. In spite of an improved PaO_2, the total PEEP was not reduced in the prone position in order to keep the lungs open. PEEP was only reduced when a dramatic improvement in chest radiograph or CT scan was observed.

As a result of the changes in pleural pressure gradients in the supine and prone position, it is logical that the 'open up the lung and keep the lung open' concept of Lachmann [36] has to be especially applied to patients in the prone position in early ARDS when the lungs are recruitable. This procedure seems to be a potential determinant of the percentage of success of the prone position.

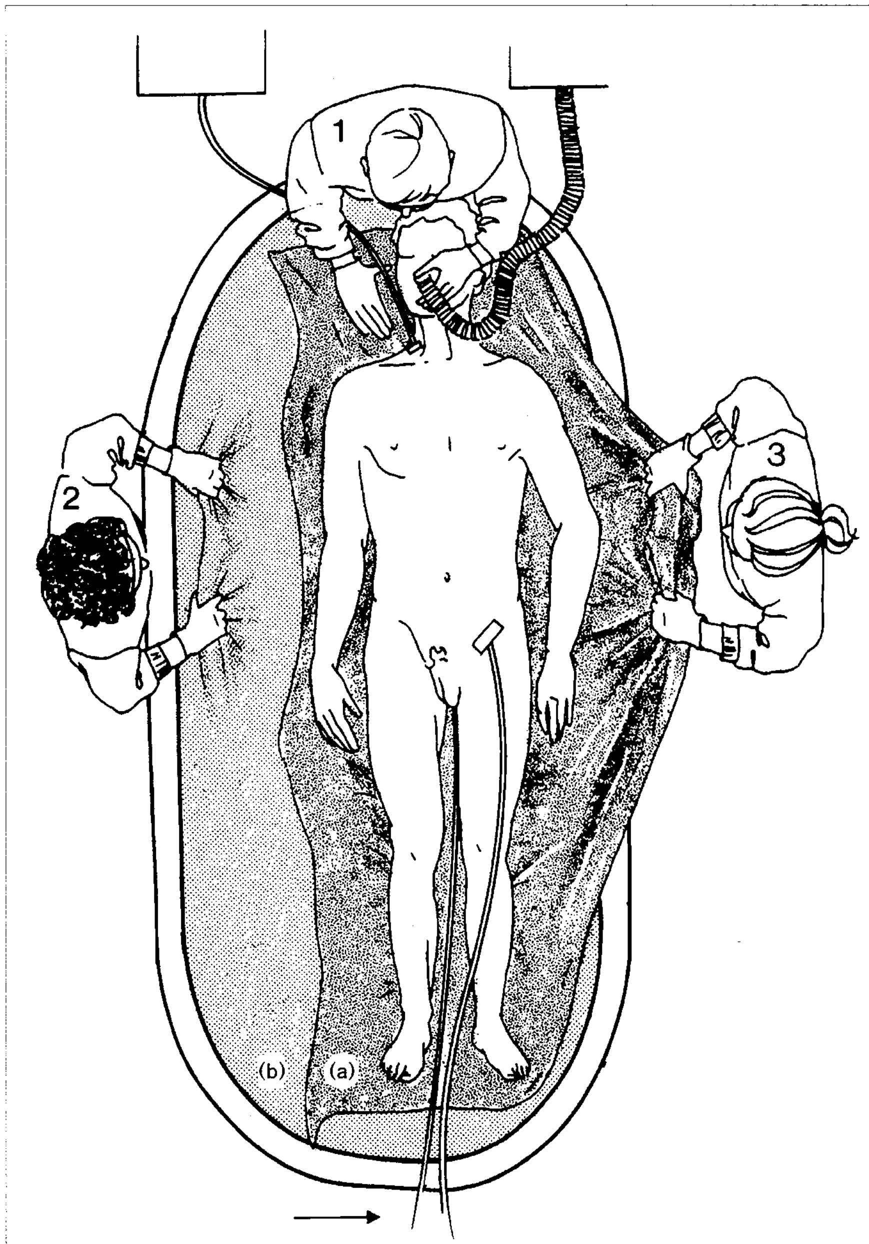
Other indications of prone position

Severe hypoxaemia in acute respiratory failure has so far been the primary indication for the use of the prone position. One additional beneficial effect of the prone position is the easy drainage of secretions [3,5], in particular, for patients with pneumonia and lung abcesses. This situation may be helpful in the re-opening of atelectatic lung units caused by sputum retention.

Bilateral lower lung lobe atelectasis and respiratory failure caused by the compression of the lungs by the abdominal contents after major intra-abdominal surgery is another potential indication of prone position.

Figure 1

Artist's view of the use of air-fluidized bed in turning the patients. The intensive care physician fixes the endotracheal tube and the central venous lines. The patient is pulled to the side of the bed. 1, intensive care physician; 2, nurse; 3, nurse; (**a**), old sheet; (**b**), nylon sheet of air-fluidized bed.



Potential complications of prone position

The prone position is not without hazards. The increased abdominal pressure caused by the weight of the torso may cause either hypotension by compressing the inferior vena cava or, if the patient is not properly supported, may prevent the descent of the diaphragm at end expiration, decreasing the FRC. This situation may even result in a further decrease of PaO_2.

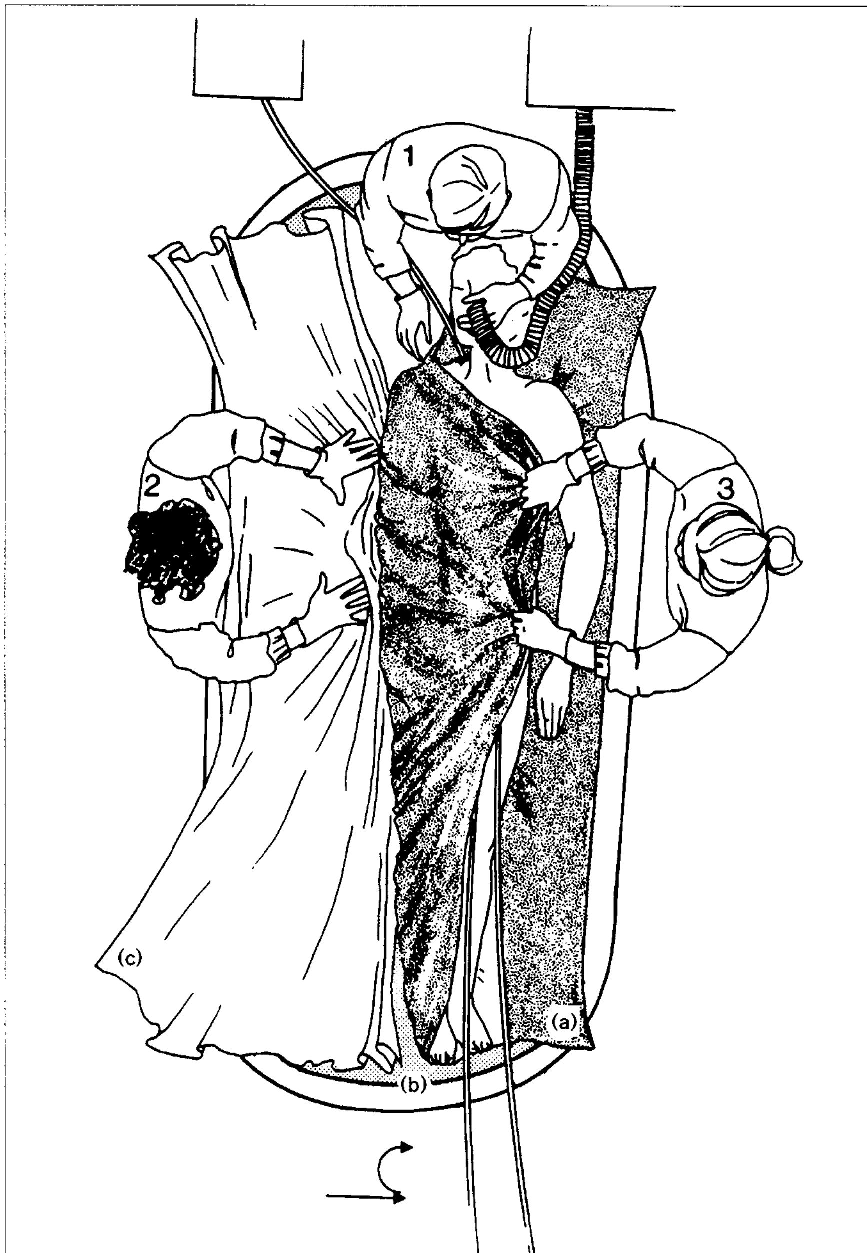
To avoid peripheral nerve injury or dislocation of a joint, the arms must be positioned carefully at the sides of the deeply sedated patient. Damage to the cornea must be prevented by covering the eyes with eyepads and avoiding pressure and direct contact on the eyes. Peri-orbital and conjunctival oedema is a potential complication if the head of the patient is lower than the body.

Special care must be taken to avoid accidental extubation or removal of the central catheters. Production of thick mucus secretions in the prone position may cause partial or total obstruction of the endotracheal tube.

Turning a severely ill patient may result in cardiocirculatory deterioration especially if a patient is hypovolaemic. Patients fed enterally have a risk of regurgitation and aspiration in the prone position. Therefore, feeding by a duodenal tube is

Figure 2

Artist's view of the use of air-fluidized bed in turning the patients. A clean bedsheet is laid on the bed, under the patient. 1, intensive care physician; 2, nurse; 3, nurse; (**a**), old sheet; (**b**), nylon sheet of air-fluidized bed (**c**), new sheet.



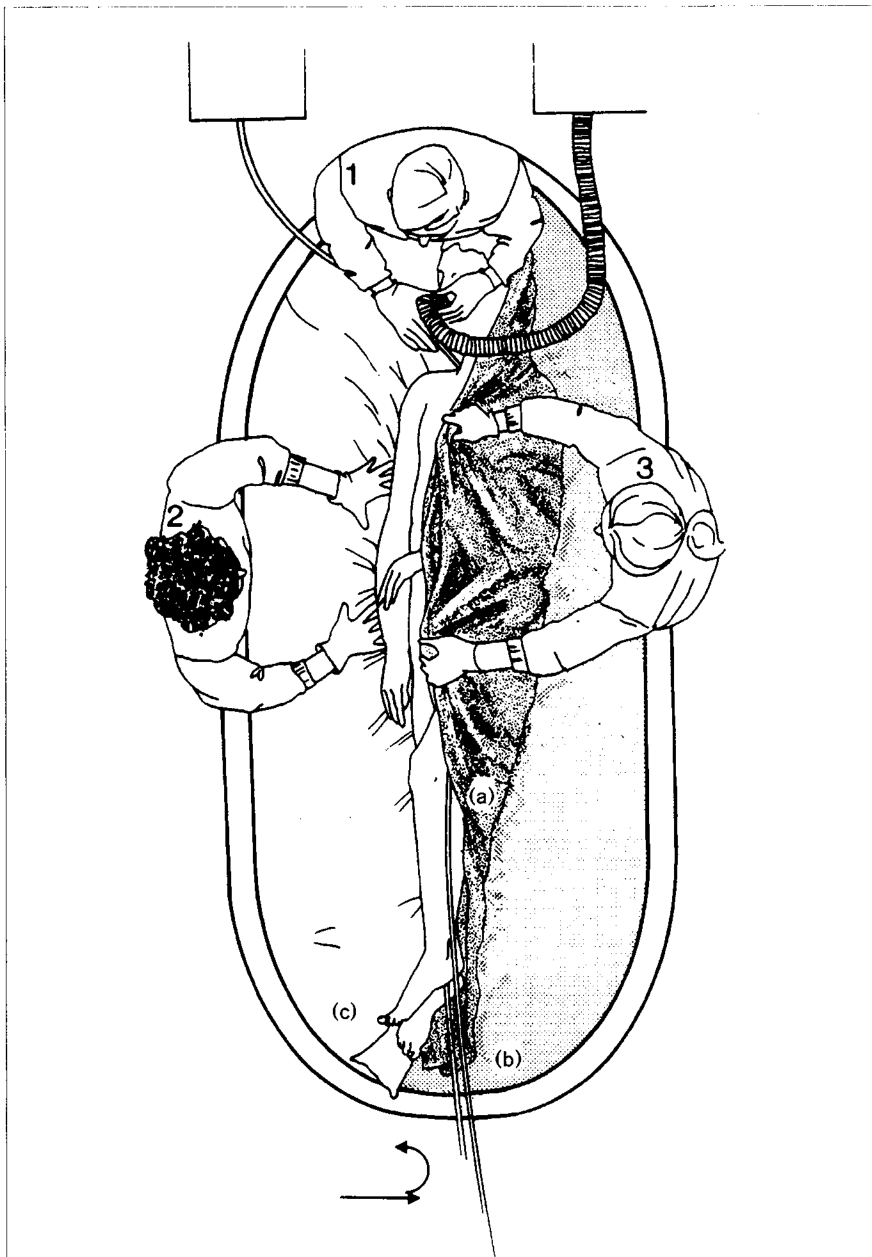
appropriate for this patient group. Decubitus ulcers of the skin may develop on sites where a patient is supported in the prone position, especially if kept for a long time in this position. Moreover, frequent positioning of the patient on a conventional hospital bed may need substantial support of the nursing and medical staff.

The use of an air-fluidized bed in prone positioning

In our institution, we have recently started to use an air-fluidized bed for all patients who need to be turned prone. This allows easy turning and prevents some of the major complications of the prone position. To turn a patient, all lines are redirected in the axis of the body, the eyes are covered with a protective ointment and an eyepad, an intensive care physician fixes the endotracheal tube and the central venous lines. The patient is then first pulled, in supine or prone position, to the side of the air-fluidized bed by pulling at the bedsheet while a nurse standing at the opposite side of the bed pulls the nylon sheet of the air-fluidized bed in the opposite direction. Next, a clean bedsheet is laid on the bed and approximately one-quarter of its width is put under the patient, underneath the old bedsheet. A nurse easily rolls

Figure 3

Artist's view of the use of air-fluidized bed in turning the patients. A nurse rolls the patient to prone or supine position on the new sheet by lifting up the old sheet. 1, intensive care physician; 2, nurse; 3, nurse; (**a**), old sheet; (**b**), nylon sheet of air-fluidized bed (**c**), new sheet.

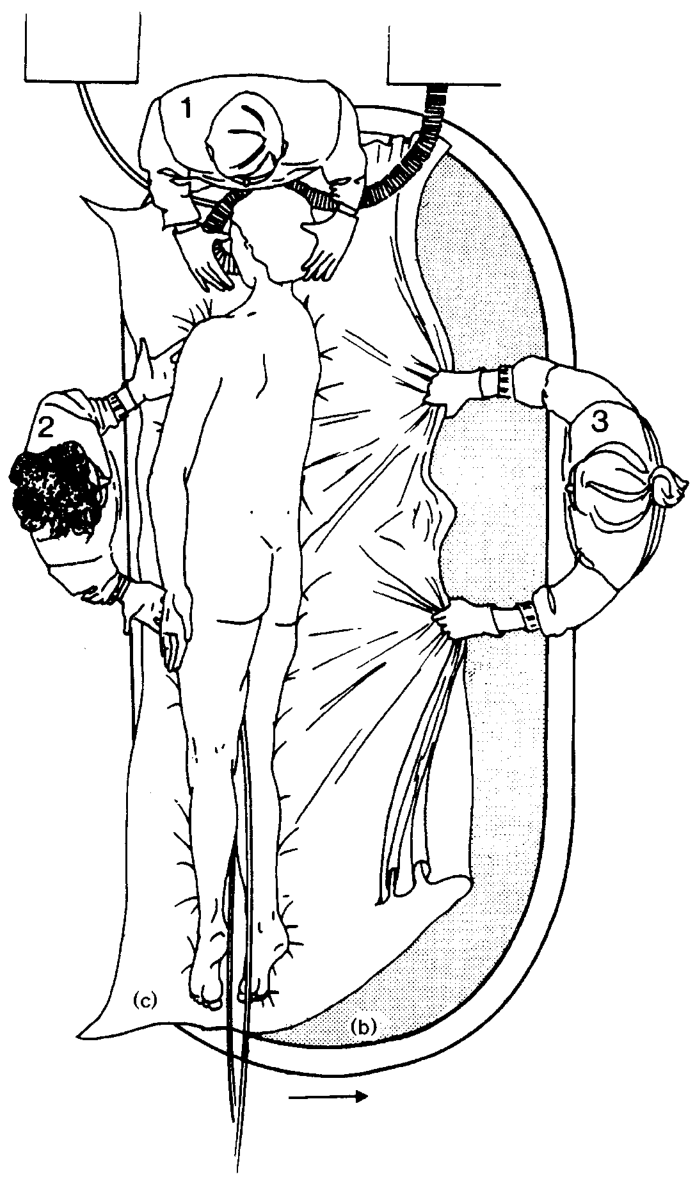


the patient to the prone or supine position on the new sheet by lifting up the old sheet (Figs. 1–4). The whole procedure can be performed in less than 5 min by a physician at the head and one nurse at each side of the bed.

As a result of the low resistance of the bed, the weight of the torso does not cause abdominal compression. Pressure sores are uncommon. In our unpublished study, one patient developed a pressure sore on his nose and chin (approximately 3%). No injuries of the cornea were observed when the eyes were covered with a pad. No dislocation of joints or peripheral nerve injury occurred in any of these patients. The low resistance of the bed means that the heavier parts of the body (head and torso) are slightly lower than the legs. This results in a minimal head-down position when the patients are in prone position causing facial and conjunctival oedema in some patients. However, this is reversible once the patient is turned back to the supine position. It was possible to perform continuous veno-venous haemofiltration

Figure 4

Artist's view of the use of air-fluidized bed in turning the patients. The patient is pulled to the middle of the bed by pulling the new sheet. 1, intensive care physician; 2, nurse; 3, nurse; (**b**), nylon sheet of air-fluidized bed (**c**), new sheet.



and to use an intra-aortic balloon pump without interruption when the patient was turned prone.

Conclusion

Ventilating hypoxaemic patients with ARDS in the prone position is an old but still developing concept. The mechanism of the increase in PaO_2 is most probably the result of a more uniform distribution of ventilation, improvement of regional ventilation and relatively unchanged regional perfusion at dorsal lung regions, resulting in a reduction of low regional ventilation–perfusion ratios and shunt perfusion. According to the existing data, oxygenation improves in approximately two-thirds of the patients when ventilated in prone position. However, it is observed to be more succesful early in the course of ARDS when the lungs are opened and kept open in prone position. Fewer responders are seen when it is applied at a later stage, probably because of too high a pleural pressure in dependent lung regions to permit airspace opening in the prone position.

The prone position can be applied easily and frequently with minimal effort and complications when an air-fluidized bed is used. The indication of prone position should not be restricted only to life-threatening hypoxaemia in ARDS but should also be extended to pulmonary infiltrations or consolidation, aiming to open the lung, even in the absence of a low PaO_2. Furthermore, it can be used to avoid sputum retention or compression of the diaphragm after a major abdominal surgical procedure, both of which may cause atelectasis of the lung.

The improved physiology of the lung as a result of the improved ventilation and recruitment of alveoli in the prone position is suggestive of a more homogeneous ventilation and a potential reduction of mechanical ventilation-related complications in ARDS patients. However, further studies are needed to investigate the preventive role of ventilation in the prone position on the development of barotrauma and of ARDS.

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