Prone position*

KELLY CRISTINA DE ALBUQUERQUE PAIVA[1], OSVALDO SHIGUEOMI BEPPU[2]

ABSTRACT

The prone position is a maneuver used to combat hypoxemia in patients with acute respiratory distress syndrome. Despite the fact that this is currently considered an efficient way to improve oxygenation, the physiological mechanisms that bring about improvements in respiratory function are not yet fully understood. The aim of this review is to discuss the physiological and clinical aspects of the prone position in patients with acute respiratory distress syndrome.

Keywords: Prone position/physiology; Respiratory distress syndrome, adult; Lung/injuries; Posture/physiology; Supine position/physiology; Anoxemia; Pulmonary gas exchange; Hemodynamic processes

INTRODUCTION

Strategies that use body positioning as a form of treatment and prevention of various diseases that affect the locomotor system of bedridden, critically ill patients are widely known and routinely used in the majority of intensive care units around the world. In view of the increasing interest in the possible physiological effects that changing positions may have on these patients, studies aiming to find other benefits in other organs and systems have been carried out, resulting in new findings, especially regarding the cardiorespiratory system. In a study published in 1999, Drakulovic et al. showed that elevating the position of recumbent patients from 35º to 45º can effectively reduce the occurrence of nosocomial pneumonia.[1]

Other studies have proven the efficacy of moving patients out of the lateral decubitus position as a way of improving oxygenation in unilateral lesions and preventing other complications related to immobilization. Such complications include atelectasis, accumulation of secretions and prolonged intubation.[2-3] More recently, the prone position has also shown its usefulness in improving oxygenation in patients with acute respiratory distress syndrome (ARDS). New studies investigating this position have been carried out, and this technique has proven to be a simple and safe method of increasing oxygenation in ARDS patients.

* Study conducted in the Pulmonology Department of the Universidade Federal de São Paulo (UNIFESP, Federal University of São Paulo), São Paulo, (SP), Brazil.
1. Doctoral student of Respiratory Sciences at the Universidade Federal de São Paulo (UNIFESP, Federal University of São Paulo), São Paulo, (SP), Brazil.
2. Adjunct Professor in the Pulmonology Department of the Universidade Federal de São Paulo (UNIFESP, Federal University of São Paulo), São Paulo, (SP), Brazil.
Correspondence to: Kelly C A Paiva. Disciplina de Pneumologia, Universidade Federal de São Paulo - Escola Paulista de Medicina. Rua Botucatu, 740, 3º andar, São Paulo, SP. CEP: 04023-062. Tel: 55 11 5549-1830. E-mail: kc.paiva@uol.com.br.
Submitted: 23 January 2004. Accepted, after review: 21 December 2004.

BACKGROUND

The beneficial effects of using the prone position were first described in 1974, when Bryan suggested that patients who were anesthetized and paralyzed presented better expansion of the dorsal region of the lung and a consequent improvement in oxygenation when placed in the prone position.[4] In 1976, Piehl and Brown conducted a retrospective study and showed that the prone position increased oxygenation in five ARDS patients without causing any deleterious effects.[5] A year later, Douglas et al. carried out a prospective study and confirmed the findings of Piehl and Brown. The authors demonstrated an improvement in arterial oxygen tension (PaO_2) in all six of the patients studied, including one who continued to present spontaneous respiration, making it possible to reduce the fraction of inspired oxygen (FiO_2) and the positive end-expiratory pressure (PEEP).[6]

Although these studies had already demonstrated that the prone position could improve oxygenation in ARDS patients, no experimental studies investigating the mechanism by which the prone positioning could lead to this improvement had been conducted. Suggestions that the improvement in PaO_2 was due to the change in the regional motion of the diaphragm or to increased functional residual capacity inspired further studies. For example, in 1987, Albert et al. carried out a study of eleven dogs in which ARDS was induced through intravenous administration of oleic-acid.[7] The authors observed diaphragm motion, functional residual capacity, heterogeneity of the ventilation/perfusion ratio, hemodynamic behavior, pulmonary shunt, dead space and gas exchange. The protocol consisted of changing patient position from prone to supine five times and monitoring the behavior of the variables. Although they found a significant improvement in PaO_2, this improvement could not be attributed to changes in functional residual capacity, regional motion of the diaphragm, cardiac index, or any change in vascular pressures. However, to the authors found a correlation between the prone position and a significant decrease in intrapulmonary shunt.

Despite these promising initial results, the physiological mechanism responsible for the improved oxygenation in the prone position remained in question, which led to the publication of several studies. The controversy continues, especially regarding mortality, since randomized studies have not demonstrated lower mortality rates. However, the protocols of these studies presented various contested points, and, consequently, this remains an open question. Therefore, additional randomized studies are warranted.

PHYSIOLOGICAL EFFECTS OF THE PRONE POSITION

The most significant physiological effect of the prone position is improved oxygenation, which is seen in approximately 70% to 80% of ARDS patients placed in this position[6,8-17] (Chart 1). This improvement in oxygenation can be attributed to several mechanisms that may occur in isolation or in combination. Among these are the reduced numbers of factors that contribute to alveolar collapse, alveolar ventilation redistribution and perfusion redistribution, as well as an increase in the compression effects that promote alveolar collapse (atelectasis).

Whatever the positioning of an individual, alveolar expansion is always dependent on transpulmonary pressure, which is the difference between alveolar pressure and pleural pressure. Regardless of whether the lung presents injury or not, pleural pressure is always greater (less negative) in the dependent regions of the lung, causing alveolar expansion to be reduced in this region. However, in the presence of pulmonary edema, pleural pressure becomes more positive in

Chart 1 - Synopsis of studies and their respective number of patients responsive to the prone position

	Total N	Responders (%)
Douglas,1977[6]	6	83
Langer,1988[8]	13	62
Beppu,1989[9]	14	78,5
Pappert,1994[10]	12	68
Blanch,1997[11]	23	70
Servillo,1997[12]	12	83
Chatte,1997[13]	32	78
Pelosi,1998[14]	16	75
Rosseti,1998[15]	41	75
Flatten,1998[16]	11	73
McAuley,2002[17]	11	73
TOTAL	191	74,4

the dependent portion, which aggravates the difference in transpulmonary pressure between the dependent and the nondependent regions. Since the variation in pleural pressure between the dependent and the nondependent regions is less significant in the prone position, the distribution of transpulmonary pressure is also more homogeneous than in the supine position.[18]

Although the reason that the gradient of transpulmonary pressure behaves in this manner in the different pulmonary regions has yet to be further clarified, it may be attributed to several factors:

Lung weight. The pathological process of ARDS is uniform throughout the lung. Pulmonary edema increases lung weight, which, together with the effects of gravity, causes the dependent region to collapse. Consequently, in the supine position, the dorsal region collapses to a greater degree than do the other regions. When the patient is placed in the prone position, the dorsal region is no longer submitted to the effect of lung weight, thereby becoming more expanded.[19-20]

Cardiac Mass. In normal individuals, the weight of the heart on the dependent regions of the lung decreases the gradient of transpulmonary pressure, exerting considerable influence on the aeration of these regions, which facilitates their collapse. In ARDS patients, this effect may be even more pronounced due to increased right cardiac chamber size secondary to pulmonary hypertension resulting from hypoxic vasoconstriction, release of vasoconstrictors and remodeling of the pulmonary circulation. In studies involving tomography scans made in the prone and the supine positions, the pulmonary areas that were under cardiac compression were compared.[21-22] The authors showed that, in the supine position, considerable portions of both lungs were affected by cardiac weight, whereas, in the prone position, only small fractions of the lungs were thus affected.

Alteration of diaphragmatic motion and cephalic deviation of the abdominal content. In the supine position, the motion of the human diaphragm is uniform, whereas, in the prone position, there is greater movement in the dorsal region.[23] This probably occurs due to decreased compression of the diaphragm by the abdominal organs. In the supine position, sedation and paralysis of patients on mechanical ventilation depress the diaphragmatic muscular tonus, causing the abdominal content to induce a cephalic deviation of the most posterior regions of the diaphragm, contributing to the collapse of these regions.[24] In the prone position, the weight of the abdominal content rests on the surface of the bed, diminishing the deviation of the diaphragm.

Configuration of the chest cavity. The configuration of the chest cavity may influence the transpulmonary pressure of the different pulmonary regions. In the supine position, its shape is triangular (apex up), which propitiates the formation of more extensive atelectases in the dorsal region. In the prone position, it assumes a more rectangular shape, thereby decreasing atelectasis formation.[18]

In conclusion, in the supine position, there is less pulmonary expansion in the dependent portions due to the weight of the lung, the weight of the cardiac mass, diaphragmatic motion and the shape of the chest cavity. The effects of these factors are minimized in the prone position, which propitiates better aeration of these regions. This was clearly demonstrated in studies carried out by Gattinonni et al. in 1991,[25] in which the authors compared computed tomography scans of the chest made in the prone position with those made in the supine position.

PERFUSION REDISTRIBUTION

In normal individuals, perfusion increases progressively from the nondependent to the dependent regions (ventral to dorsal in the supine position), according to the effects of gravity.(26) Although other factors (hypoxic vasoconstriction, vascular obliteration and extrinsic venous compression) may interfere with the perfusion distribution in individuals with acute lung injury or ARDS, perfusion in the supine position continues to follow the gravitational gradient. In 1991, Glenny et al. showed that, in contrast to what was believed at the time, perfusion in the prone position does not follow the gravitational gradient, remaining greater in the (nondependent) dorsal region.[27] Although further studies are necessary in order to explain the correlation between lung perfusion behavior and position changes, it has been speculated that the vascular conductance of the more dorsal regions of the lung may be greater due to its anatomy, counteracting the gravitational effects when in the prone position.[28-29]

In summary, the decreased size of the areas of atelectasis propitiates better distribution of ventilation, reducing the pulmonary shunt, which, together with better distribution of perfusion, leads to a more homogeneous ventilation/perfusion ratio, thereby explaining the fact that the prone position successfully improves oxygenation.

Another mechanism that may contribute to reducing arterial hypoxemia is the drainage of secretions, which is much greater in the prone position. This is easily observed in intensive care units.

EFFECTS ON THE RESPIRATORY MECHANICS

Alterations in respiratory mechanics would be expected in patients placed in the prone position. However, the exact nature of such alterations is not well known.

Most studies comparing the respiratory mechanics parameters in the prone position to those seen in the supine position have failed to demonstrate differences in respiratory system compliance. However, some authors have found a reduction in thoracoabdominal compliance. This could be explained by the limited expansion of the anterior region of the chest cavity, which is more compliant (less rigid) than the posterior region. However, other studies have demonstrated greater respiratory system compliance when an individual was moved in the supine position, showing some beneficial effect is brought on the pulmonary structure. Somehow, via a mechanism yet to be elucidated, the prone position also increases abdominal compliance. In 1998, Mure et al. showed that, using the same model of abdominal distention, the increase in gastric pressure was significantly smaller and oxygenation was better in the prone position than in the supine position.[30] This leads us to explore a new field, in which the use of the prone position and its benefits may be extrapolated to treating patients other than those with acute lung injury or ARDS, such as patients with ascites.

OTHER EFFECTS OF THE PRONE POSITION

Effects of the prone position on pulmonary lesions induced by mechanical ventilation.

Although improved oxygenation is the main benefit brought by the prone position, other benefits have also been explored.

Since it limits alveolar cyclic opening and closing, a process that has been identified as a causative agent of injury induced by mechanical ventilation, PEEP has been used to prevent such injury.[31] Reducing this cyclic stress on the pulmonary structure seems to be essential to resolving cases of acute lung injury. Therefore, it is likely that the prone position could also make a contribution. Bearing this in mind, Broccard et al. carried out a comparative study of the extent of mechanical ventilation-induced injury in the prone position and that seen in the supine position.[32] The study, involving dogs, used tidal volumes that were high enough to reach transpulmonary pressures of 35 cmH_2O at a PEEP of zero. Such tidal volumes are capable of reproducing lung injury, as has been demonstrated in a previous study. Histological scores were calculated in order to quantify the extent of the injuries in the different pulmonary regions. The mean histological score was significantly higher in the supine position group. However, in the supine position, the scores were similar in the nondependent regions of the lungs of both groups, whereas, in the dependent regions, they were much higher. Wet weight/body weight and wet weight/dry weight ratios were determined in order to analyze the severity of the injury. Both regions - dependent and nondependent - presented higher wet weight/body weight ratios and higher wet lung weight/dry lung weight ratios in the supine position. However, comparing values for the same animal, the authors found that the wet weight/dry weight ratio was higher in the dependent regions. In the prone position, despite the same profile, the disparity between dependent and nondependent regions was smaller (supine: 9.4 ± 1.9 vs. 6.7 ± 0.9, $p = 0.01$; prone: 6.7 ± 1.1 vs. 5.8 ± 0.5, $p = 0.054$).

THE PRONE POSITION IN COMBINATION WITH RECRUITING MANEUVERS

The alveolar recruiting maneuver, which involves using low tidal volumes and the maintaining the alveoli aerated, is another technique that has been used to achieve the conflicting goals of the strategy of lung protection.

There are several means of applying the alveolar recruiting maneuver. In general, high levels of inspiratory pressure are applied with the objective of expanding the collapsed alveoli, thereby increasing PaO_2. In addition, high PEEP levels, which are necessary for maintaining the gains achieved, are used.

Although the maneuver reduces the cyclic stress created by alveolar opening and closing, high pressure levels applied continuously may also be accompanied by side effects. In experimental studies using canine models, Lim et al. (in 1999) and Cakar et al. (in 2000) showed that low PEEP levels are necessary to preserve the effects of the recruiting maneuvers performed when the subject is the prone position.[33-34] In 2003, Pelosi et al. confirmed these results and, delving further, showed that the mechanisms by which PaO_2 increases in the prone position differ from the mechanism involved in the alveolar recruiting maneuvers.[35] The authors attempted to correlate end-expiratory pulmonary volume and pulmonary static compliance with the increase in PaO_2, and found a positive correlation between these data and the recruiting maneuver, whereas they found no correlation between the modest increase in end-expiratory pulmonary volume and the significant increase in PaO_2 seen in the prone position. This shows, as previously mentioned, that other mechanisms are involved.

RESPONSE FACTORS

So far, we have treated the prone position as a strategy in which positive results would be obtained in 100% of cases. In fact, as illustrated in Chart 1, we can encounter responsive patients (70% to 80% of all patients), defined as those in whom PaO2 increases by at least 20% in the prone position, and nonresponsive patients (~25% of all patients).[13] The responsive patients can be subdivided into persistent responders (those who maintain the achieved gain in PaO_2 after returning to the supine position) and nonpersistent responders (those who do not maintain the gain after being repositioned). Persistent responders typically outnumber nonpersistent responders by a ratio of 2:1.

However, can we predict which patients will respond? A small number of studies have concentrated on identifying predictors of response. In 1997, Chatte et al. found that PEEP level, time on mechanical ventilation prior to the maneuver and FiO_2 were predictive of response, and that higher PEEP levels (13.1 ± 5 vs. 7.9 ± 4.3), longer time on mechanical ventilation (5 ± 8 vs. 8 ± 10) and higher FiO_2 (0.93 ± 0.1 vs. 0.71 ± 0.16) are found in responsive patients, that is, patients who presented an increase in PaO_2 greater than 20 mmHg. Other factors such as age, simplified acute physiology score, lung injury score and tidal volume had no significance.[13]

Similar to what happens in recruiting maneuvers, the response to the prone position is expected to be greater in early ARDS since, in this phase, there is an increase in the occurrence of pulmonary edema and atelectasis, both of which can be reversed more easily than in the late phase, when there is fibroproliferation.[36] Despite this fact, the results in the literature are controversial, suggesting that, even in the late phase, the prone position can be an option.

The etiology of ARDS may also play an important role in the response to the prone position. Although ARDS becomes a uniform pathology in the advanced stages, it may vary in the early stages depending on the etiology. Based on previous data obtained in studies of alveolar recruitment maneuvers, we know that the PaO_2 response may differ depending on whether the primary insult was pulmonary or extrapulmonary. Although both types of ARDS respond positively to the prone position, 63% of the patients with extrapulmonary ARDS, in contrast to only 29% of patients with pulmonary ARDS, present a significant response after one hour in the position. Longer periods spent in the prone position, two hours or more, are required to obtain a response in cases of pulmonary ARDS. However, in cases of extrapulmonary ARDS, PaO_2 may not change between that seen in the first thirty minutes and that seen over the next two hours. This can be explained by the fact that alveolar interstitial edema and compression atelectasis, which are more pronounced in extrapulmonary ARDS, yield more easily to the changes in transpulmonary pressure than does the consolidation caused by epithelial damage and exudative inflammation, found in pulmonary ARDS. Although extrapulmonary ARDS seems to present a better response to the prone position, mortality rates among such patients remains higher, regardless of whether the prone position was used or not.[38]

LENGTH OF APPLICATION

There is no consensus regarding the ideal length of time patients should be maintained in the prone position. What most researchers agree on is that there is a more significant response in oxygenation in the first two hours, with some small increases in the next four hours. Some facilities apply it for four, six and ten hours, and, recently, it has been used continuously.[11,17,39] We often need to maintain patients in the prone position continuously because when they are repositioned in the supine position, there is renewed worsening in their blood gas analysis results. The response seen in the early phase of ARDS is given the greatest importance. Therefore, we recommend that patients be kept in the prone position for as long as possible, until their condition has stabilized, and then returned to the supine position in order to evaluate whether it is necessary to place them in the prone position once again.

TECHNIQUE

Indications

Although it has been demonstrated that the prone position has beneficial effects in various pulmonary pathologies, ARDS is the main indication for its use and is the condition in which it has been most widely studied. The use of the prone position may have different objectives. When the desired effect is improved arterial oxygenation, it should be used only if high FiO_2 values are needed in order to achieve adequate oxygenation. However, when the main objective is to minimize lung injury induced by mechanical ventilation, the prone position should be used as early as possible (immediately after the diagnosis of ARDS/acute lung injury is made) and for as long as possible. Since ventilator-induced lung injury may begin to occur after a few minutes on nonprotective mechanical ventilation, there are doubts as to whether it is really necessary to return patients to the supine position.

Contraindications

The prone position is contraindicated in cases of burn or injury on the face or on the ventral area of the body, instability of the spinal column, intracranial hypertension, severe arrhythmias or acute hypotension. In addition, although it does not constitute a contraindication, the presence of dialysis catheters and thoracic drains should be taken into consideration.[40]

Procedure

Four persons are needed in order to position the patient. One should remain at the head of the bed and be responsible for the endotracheal tube. It is advisable that this person be prepared to aspirate the tube since there is abundant secretion drainage after prone positioning. A second person should be in charge of making sure that the catheters, drains and connections are not disconnected. The third and fourth persons, one on each side of the bed, should be responsible for turning the patient, first to lateral decubitus, and then to the prone position.

The arms should be positioned alongside the body, with the head turned to one side, and the electrodes for cardiac monitoring fixed on the back. It is not necessary to employ abdominal suspension since this procedure does not add to the positive response of the position.

Failure criteria

Oxygenation may drop during the procedure of turning from the prone to the supine position. This datum should not be seen as failure since oxygenation should quickly improve. Only after 30 minutes without improvement in oxygenation should we consider a potential failure of the process and maintain a vigil, waiting for a possible response, for up to two hours. It is important to emphasize that patients in whom the technique has previously failed may respond to a second attempt.[13]

Precautions

In order to minimize some complications, it is important, prior to the procedure, to verify that the endotracheal tube is securely fixed in a position 2 cm above the carina and to interrupt enteral feeding (checking for the presence of food residues), as well as to make sure that all accesses and catheters are disconnected. While the patient is in the prone position, the head should be repositioned every two to four hours.

COMPLICATIONS

As Gattinoni et al. reported, the incidence of severe complications, such as accidental extubation, severe hypotension and arrhythmias, is low in the prone position.[41] The authors speculated that this is due to the diligence of nurses and physiotherapists in the management of patients in this position. However, they also found that other, less severe complications are more common.

Facial edema is the most common complication, occurring in practically 100% of the patients who remain few hours in the prone position. However, studies that reported this complication observed there was total regression of the edema a few hours after the patient had been returned to the supine position. There are groups that managed to reduce facial edema by placing the patient in reverse Trendelenburg position (10°), without it resulting in severe hypotension.

Skin ulcerations also occur, frequently involving the chin, ears, anterior region of the chest, iliac crests and knees. Their severity is directly correlated with length of time and age of patients. However, such ulcerations typically do not require specific topical treatment.[38,42]

In some cases, difficult enteral feeding, due to vomiting or an increase in gastric residue, is observed. This problem can be circumvented by reducing the volume of food administered as well as by using the reverse Trendelenburg position, which may again prove beneficial, this time reducing the esophageal reflux.

Airway obstruction may occur due to accumulation of secretions. However, it can be avoided by aspirating the endotracheal tube more frequently.

Other complications, such as dislocation of the central venous catheter and barotrauma due to selective tracheal intubation, are rare. Only one case of infectious corneal ulceration has been reported.[43]

Another disadvantage is that, in the prone position, the need for sedation is greater. This is alarming since it can increase the occurrence of neuromuscular paresis, which frequently appears in critically ill patients in intensive care units (Chart 2).

Chart 2 - Main side effects related to the prone position

Facial edema
Airway obstruction
Skin lesions
Difficulties with enteral feeding
Transitory decrease in oxygen saturation
Hypotension
Arrhythmias
Loss of venous accesses and probes
Loss of dialysis drains and catheters
Accidental extubation
Apical atelectasis due to incorrect positioning of the tracheal tube
Increased need for sedation

MORTALITY

The importance of the role played by the prone position in improving arterial oxygenation in ARDS patients is indisputable. However, its efficacy in reducing mortality has yet to be demonstrated. The first randomized prospective study on the effect of the prone position on survival rates among such patients was carried out by Gattinoni et al.(44) The authors studied 304 patients. For six or more hours a day for ten days, 152 patients were placed in conventional decubitus, and 152 were placed in prone decubitus. Although oxygenation improved in more than 70% of the patients placed in the prone position, mortality rates were similar over the ten-day period (21.1% for the conventional position vs. 25.0% for the prone position), after discharge from the intensive care unit (50.7% vs. 48.0%) and after 60 days (62.5% vs. 58.6%). However, when the authors carried out the post-hoc analysis, mortality rates in the groups whose PaO2/FiO2 ratio was below 88 were significantly lower than in the group in which patients were placed in the prone position (23.1% vs. 47.2%). More recently, At the latest American Thoracic Society Conference (2003 - Seattle), Mancebo et al. presented the results of a multicenter study in which the prone position was used for 20 hours a day.(45) The study was discontinued after only 133 patients had been evaluated because the authors failed to demonstrate a statistically significant decrease in mortality in the intensive care unit (supine: 58.6%; prone: 44.4%).

CONCLUSION

If we consider the use of the prone position in terms of decreased mortality, the results of the studies published do not justify its use in all ARDS patients. However, its use may be beneficial in patients with more severe hypoxemia. Despite this uncertainty, since the occurrence of side effects is minimal, we recommend that it be used, especially when high FiO_2 values are needed.

REFERÊNCIAS

1. Drakulovic MB, Torres A, Bauer TT, Nicolas JM, Nogue S, Ferrer M. Supine body position as a risk fator for nosocomial pneumonia in mechanically ventilated patients: a randomized trial. Lancet. 1999;354(9193):1851-8.
2. Fink MP, Helsmoortel CM, Stein KL, Lee PC, Cohn SM. The efficacy of an oscillating bed in the prevention of lower respiratory tract infection in critically ill victims of blunt trauma. A prospective study. Chest. 1990;97(1):132-7.
3. Gentilello L, Thompson DA, Tonnesen AS, Hernandez D, Kapadia AS, Allen SJ, et al. Effects of a rotating bed on the incidence of pulmonary complications in critically ill patients. Crit Care Med. 1988;16(3):783-6.
4. Bryan AC. Conference on the scientific basis of respiratory therapy. Pulmonary physiotherapy in the pediatric age group. Comments of a devil's advocate. Am Rev Respir Dis. 1974;110(6 Pt 2):143-4.
5. Piehl MA, Brown RS. Use of extreme position changes in acute respiratory failure. Crit Care Med. 1976;4(1):13-4.
6. Douglas WW, Rehder K, Beynen FM, Sessler AD, Marsh HM. Improved oxygenation in patients with acute respiratory failure: the prone position. Am Rev Respir Dis. 1977;115(4):559-66.
7. Albert RK, Leasa D, Sanderson M, Robertson HT, Hlastala MP. The prone position improves arterial oxygenation and reduces shunt in oleic-acid-induced acute lung injury. Am Rev Respir Dis. 1987;135(3):628-33.
8. Langer M, Mascheroni D, Marcolin R, Gattinoni L. The prone position in ARDS patients. A clinical study. Chest. 1988;94(1):103-7.
9. Beppu OS. The prone position improves arterial oxygenation in patients with pulmonary insufficiency submitted to mechanical ventilation. In: 5° Congress on Intensive & Critical Care Medicine, 1989, Sept 3-8. Kyoto, Japan, 1989.
10. Pappert D, Rossaint R, Slama K, Gruning T, Falke KJ. Influence of positioning on ventilation-perfusion relationships in severe adult respiratory distress syndrome. Chest. 1994;106(5):1511-6.
11. Blanch L, Mancebo J, Perez M, Martinez M, Mas A, Betbese AJ, et al. Short-term effects of prone position in critically ill patients with acute respiratory distress syndrome. Intensive Care Med. 1997;23(10):1033-9.
12. Servillo G, Roupie E, De Robertis E, Rossano F, Brochard L, Lemaire F, et al. Effects of ventilation in ventral decubitus position on respiratory mechanics in adult respiratory distress syndrome. Intensive Care Med. 1997;23(12):1219-24.
13. Chatte G, Sab JM, Dubois JM, Sirodot M, Gaussorgues P, Robert D. Prone position in mechanically ventilated patients with sever acute respiratory failure. Am J Respir Crit Care Med. 1997;155(2):473-8.
14. Pelosi P, Tubiolo D, Mascheroni D, Vicardi P, Crotti S, Valenza F, et al. Effects of prone position on respiratory mechanics and gas exchange during acute lung injury. Am J Respir Crit Care Med. 1998;157(2):387-93.
15. Rosseti HB. Efeito da ventilação em posição prona na oxigenação arterial de pacientes com síndrome da angústia respiratória aguda [tese]. São Paulo: Universidade Federal de São Paulo; 1998.
16. Flaatten H, Aardal S, Hevroy O. Improved oxygenation using the prone position in patients with ARDS. Acta Anaesthesiol Scand. 1998;42(3):329-34.
17. Mc Auley DF, Giles S, Fichter H, Perkins GD, Gao F. What is the optimal duration of ventilation in the prone position in acute lung injury and acute respiratory distress syndrome? Intensive Care Med. 2002;28(4):414- 8.
18. Gattinoni L, Pelosi P, Valenza F, Mascheroni D. Patient positioning in acute respiratory failure. In: Tobin M, editor. Principles and practice of mechanical ventilation. New York: McGraw-Hill; 1994. p.1067-76.
19. Pelosi P, Brazzi L, Gattinoni L. Prone position in acute respiratory distress syndrome. Eur Respir J. 2002; 20(4):1017-28.
20. Pelosi P, D'Andrea L, Vitale G, Pesenti A, Gattinoni L. Vertical gradient of regional lung inflation in adult respiratory distress syndrome. Am J Respir Crit Care Med. 1994;149(1):8-13.
21. Albert RK, Hubmavr RD. The prone position eliminates the compression of the lungs by the heart. Am J Respir Crit Care Med. 2000;161(5):1660-5.
22. Malbouisson LM, Busch CJ, Puybasset L, Lu Q, Cluzel P, Rouby JJ. Role of the heart in the loss of aeration characterizing lower lobes in acute respiratory distress syndrome. Am J Respir Crit Care Med. 2000; 161(6): 2005-12.
23. Krayer S, Rehder K, Vettermann J, Didier P, Ritman EL. Position and motion of the human diaphragm during anesthesia-paralysis. Anesthesiology. 1989;70(6):891-8.
24. Froese AB, Bryan AC. Effects of anesthesia and paralysis on diafragmatic mechanics in man. Anesthesiology. 1974;41(3):242-55.
25. Gattinoni L, Pelosi P, Vitale G, Pesenti A, D'Andrea L, Mascheroni D. Body position changes redistribute lung computed-tomographic density in patients with acute respiratory failure. Anesthesiology. 1991;74(1):15-23.
26. West JB, Dollery CT, Naimark A. Distribution of blood flow in isolated lungs: relation to vascular and alveolar pressures. J Appl Physiol. 1964;19:713-24.
27. Glenny RW, Lamm WJ, Albert RK, Robertson HT. Gravity is a minor determinant of pulmonary blood flow distribution. J Appl Physiol. 1991;71(2): 620-9.
28. Wiener CM, Kirk W, Albert RK. Prone position reverses the gravitational distribution of perfusion in dog lungs with oleic acid-induced injury. J Appl Physiol. 1990; 68(4):386-92.
29. Mure M, Domino KB, Lindahl SG, Hlastla MP, Altemeier WA, Glenny RW. Regional ventilation-perfusion distribution is more uniform in the prone position. J Appl Physiol. 2000;88(3):1076-83.
30. Mure M, Glenny RW, Domino KB, Hlastala MP. Pulmonary gas exchange improves in the prone position with abdominal distension. Am J Respir Crit Care Med. 1998;157(6 Pt 1):1785-90.
31. Corbridge TC, Wood LD, Crawford GP, Chudoba MJ, Yanos J, Sznajder JI. Adverse effects of large tidal volume and low PEEP in canine acid aspiration. Am Rev Respir Dis. 1990;142(2):311-5.
32. Broccard A, Shapiro RS, Schmitz LL, Adams AB, Nahum A, Marini JJ. Prone position attenuates and redistributes ventilator-induced injury in dogs. Crit Care Med. 2000;28(2):295-303.

33. Lim CM, Koh Y, Chin JY, Lee JS, Lee SD, Kim WS, et al. Respiratory and haemodynamic effects of the prone position at two different levels of PEEP in a canine acute lung injury model. Eur Respir J. 1999;13(1):163-8.
34. Cakar N, Der Kloot TV, Youngblood M, Adams A, Nahum A. Oxygenation response to a recruitment maneuver during supine and prone positions in an oleic acidinduced lung injury model. Am J Respir Crit Care Med. 2000;161(6): 1949-56.
35. Pelosi P, Bottino N, Chiumello D, Caironi P, Panigada M, Gamberoni C, et al. Sigh in supine and prone position during acute respiratory distress syndrome. Am J Respir Crit Care Med. 2003;167(4):521-7.
36. Gattinoni L, Bombino M, Pelosi P, Lissoni A, Pesenti A, Fumagalli R, et al. Lung structure and function in different stages of severe adult respiratory distress syndrome. JAMA. 1994;271(22):1772-9.
37. Gattinoni LP, Pelosi P, Suter PM, Pedoto A, Vercesi P, Lissoni A. Acute respiratory distress syndrome caused by pulmonary and extrapulmonary disease. Different syndromes? Am J Respir Crit Care Med. 1998;158(1):3-11.
38. Lim CM, Kim EK, Lee JS, Shim TS, Lee SD, Koh Y, et al. Comparison of the response to the prone position between pulmonary and extra pulmonary acute respiratory distress syndrome. Intensive Care Med. 2001;27(3):477-85.
39. Fridrich P, Krafft P, Hochleuthener H, Mauritz W. The effects of long-term prone positioning in patients with trauma-induced acute respiratory distress syndrome. Anesth Analg. 1996;83(6):1206-11.
40. Messerole E, Peine P, Wittkopp S, Marini JJ, Albert RK. The pragmatics of prone position. Am J Respir Crit Care Med. 2002;165(10):1359-63.
41. Gattinoni L, Pelosi P, Crotti S, Valenza F. Effects of positive end-expiratory pressure on regional distribution of tidal volume and recruitment in adult respiratory distress syndrome. Am J Respir Crit Care Med. 1995;151(6):1807- 14.
42. L'Her E, Renault A, Oger E, Robaux MA, Boles JM. A prospective survey of early 12-h prone positioning effects in patients with the acute respiratory distress syndrome. Intensive Care Med. 2002;28(5):570-5.
43. Stocker R, Neff T, Stein S, Ecknauer E, Trentz O, Russi E. Prone positioning and low-volume pressure-limited ventilation improve survival in patients with severe ARDS. Chest. 1997;111(4):1008-17.
44. Gattinoni L, Tognoni G, Pesenti A, Taccone P, Mascheroni D, Labarta V, et al. Effect of prone position on the survival of patients with acute respiratory distress syndrome. N Engl J Med. 2001;345(8):568-73.
45. Mancebo J, Rialp G, Fernández R, Gordo F, Albert RK. Prone vs supine position in ARDS patients. Results of a randomized multicenter trial [abstract]. ATS 99th International Conference. 2003, May 16-21, Seattle WA.