The Effect of the Prone Position on Pulmonary Mechanics Is Frame-Dependent

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By compressing the abdomen and restricting chest wall movement, the prone position compromises pulmonary compliance. For spine surgery, placing the anesthetized patient into the prone position increases the risk of improper ventilation. In this study, we tested the hypothesis that the compromise in pulmonary compliance is related to the patient's body habitus and the surgical frame used to support the patient while in the prone position. Seventy-seven adult patients were divided into three groups according to body mass index: normal (n = 36) ≤27 kg/m^2, heavy (n = 21) 28–31 kg/m^2, and obese (n = 20) ≥32 kg/m^2. Patients were placed in the prone position supported by chest rolls, a Wilson frame, or the Jackson spinal surgery table (Jackson table) according to the surgeon's preferences. Peak airway pressure (at the proximal endotracheal tube), pleural pressure (esophageal balloon), and mean arterial pressure were recorded in the supine position and prone position within 15 min of the turn. Dynamic mean (± SD) pulmonary compliance (mL/cm H_2O) decreased when turning from the supine to the prone position in all three body mass groups when using chest rolls (normal 37 ± 5 to 29 ± 6; heavy 43 ± 2 to 34 ± 4; obese 42 ± 8 to 32 ± 6) or the Wilson frame (normal 39 ± 6 to 32 ± 7; heavy 43 ± 16 to 34 ± 10; obese 36 ± 11 to 28 ± 9). The dynamic pulmonary compliance was not altered in patients positioned on the Jackson table. Regardless of body habitus, using the Jackson table for prone positioning was not associated with a significant alteration in pulmonary or hemodynamic variables. We conclude that moving patients from the supine to the prone position during anesthesia results in a decrease in pulmonary compliance that is frame-dependent but that is not affected by body habitus. **Implications:** We hypothesized that compromise in pulmonary compliance in the prone position is related to the patient's body mass index and the surgical frame used. In this study, we demonstrated that prone positioning during anesthesia results in a decrease in pulmonary compliance that is frame-dependent but that is not affected by body mass index.

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The prone position is required for surgical exposure during posterior spine surgery. During general anesthesia, changing from the supine to prone position may have adverse effects on epidural venous pressure and airway pressure (1,2). These effects may be more pronounced in obese patients because pressure on the abdominal wall may further accentuate the restrictive nature of the pulmonary disease common in this patient population. Several surgical frames have been designed to minimize the adverse cardiopulmonary response to the prone position. To surgeons, the major problems encountered performing spine surgery are those of exposure and bleeding. To anesthesiologists, the major problems noted in those patients are difficulties with ventilation and with cardiac dysfunction if the abdomen and chest are restricted. Even in nonobese patients, the prone position alters respiratory dynamics by decreasing respiratory compliance (3,4). Although it would be anticipated that obese patients would demonstrate accentuated deterioration of respiratory compliance in the prone position, little is known about how body mass index (BMI) affects pulmonary mechanics with different supporting frames.

In the setting of reduced compliance, very high airway pressures may be required to attain adequate ventilation for the patient. High airway pressures may, in turn, impair venous return to the heart, decrease cardiac output and increase systemic venous pressure. High pressure in epidural veins is a common cause of excessive surgical bleeding. In addition, high venous pressure may result in decreased spinal cord perfusion pressure (mean arterial pressure − spinal

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venous pressure), putting the patient at increased risk of neurologic complications.

In this study, we tested the hypothesis that the degree of compromise in ventilatory function is dependent on the patient's body habitus and the surgical frame used to support the patient while in the prone position.

Methods

We received approval for this study from our Joint Committee on Clinical Investigation. Because the study was purely observational, the committee judged that no consent was required. Seventy-seven adult patients, female and male, ASA physical status I–III, undergoing posterior spinal surgery under general anesthesia were studied prospectively. They were divided into three groups according to BMI: normal (n = 31) ≤27 kg/m^2, heavy (n = 16) 28–31 kg/m^2, and obese (n = 20) ≥32 kg/m^2. Those patients with severely debilitating pulmonary disease were excluded from the study because it would have been difficult to distinguish whether the change in compliance was the result of the patients' increased BMI or pulmonary disease. The patient's baseline weight and height were recorded. Any existing pulmonary disease, such as smoking, the patient's ASA physical status, age, and gender were also recorded. The anesthetic protocol was not standardized. The anesthetics administered consisted of a narcotic such as fentanyl, morphine, or dilaudid, an inhaled anesthetic such as isoflurane or desflurane with or without nitrous oxide, and paralysis with a nondepolarizing muscle relaxant, usually pancuronium bromide or vecuronium bromide. Before the study, each patient was noted to have no more than two twitches on train-of-four stimulation. After induction, the esophageal stethoscope was placed and was used as an esophageal balloon to measure pleural pressure. Auscultation with an earpiece was used to determine initial placement. The proximal end of the esophageal balloon was then attached to a pressure transducer, and the position of the balloon was gradually moved to obtain maximal respiratory variation with each mechanical ventilation. The trachea of each female patient was intubated with a 7.5-mm inner diameter (ID) endotracheal tube (ETT), and the trachea of each male was intubated with an 8.0-mm ID ETT (both approximately 30 cm long) regardless of body habitus. A baseline mean arterial pressure (MAP) (cuff or indwelling arterial catheter), pleural pressure (PP), and peak airway pressure (PAP) measured at the proximal ETT with zero position end-expiratory pressure and a tidal volume of 10 mL/kg were recorded. The patients were then placed in the prone position supported by either chest rolls, a Wilson frame, or a Jackson table (Figure 1), according to the surgeon's preferences. Airway pressure, PP, MAP, and tidal volume were then recorded in the prone position within 15 min after the turn. The change in PAP, MAP, and PP from supine to prone were compared and analyzed according to the BMI and the frame used. Lung compliance was calculated from airway pressure and tidal volume. Although mechanical ventilation was adjusted in some patients to maintain the same exhaled tidal volume, no adjustments were made to total fresh gas flow. The inspiratory to expiratory ratio, inspiratory flow, and rate of ventilation also remained unchanged. Two-way analysis of variance (ANOVA) was used to determine the effect of body size on position-induced changes in each variable for each frame. One-way ANOVA was used to determine the effect of body habitus with a single

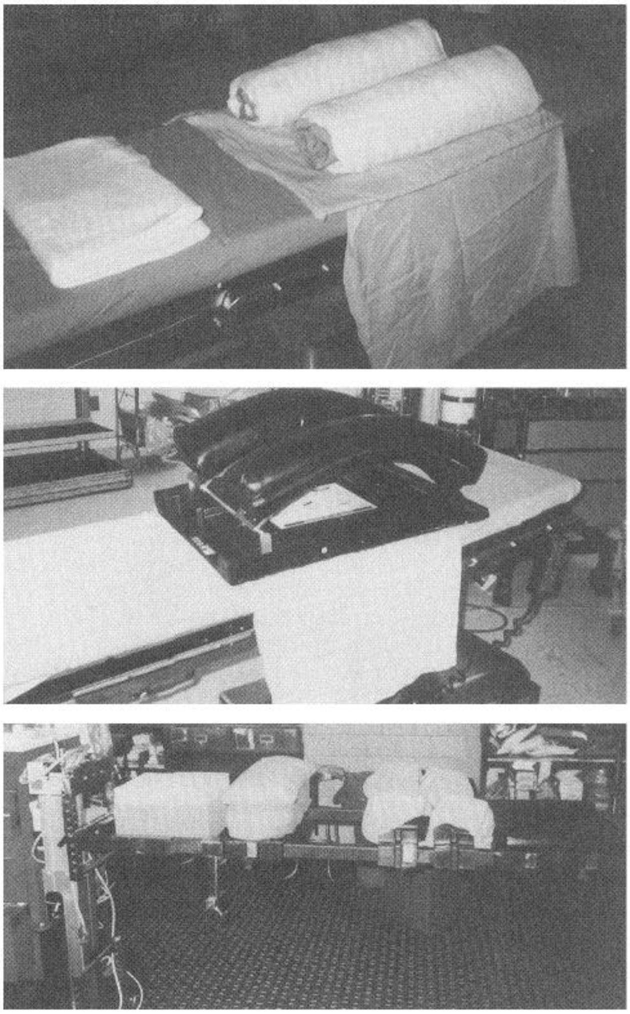

Figure 1. The three devices used for prone positioning in this study. Size of chest rolls (a) was adjusted to patient size. Likewise, exact position of lateral support structures on the Wilson frame (b) and the Jackson surgical table (c) were adjusted to minimize pressure on the abdomen and chest.

Table 1. Patient Demographics

	Normal	Heavy	Obese
Age (yr)	53 ± 18	53 ± 14	49 ± 16
BMI (kg/m^2)	24 ± 3	31 ± 3	42 ± 24
Smoking history	5	3	2
Coexisting pulmonary disease	5	0	2
ASA physical status			
I	2	2	0
II	27	15	11
III	7	4	9

Values are mean ± SD or *n*.
BMI = body mass index.

frame and the effect of frame for a particular body habitus.

Results

The groups were similar for age, smoking history, co-existing pulmonary disease, and ASA physical status (most were ASA physical status II). The average BMI for the normal, heavy, and obese groups were within the limits set for the study (Table 1). When considering all patients in the supine position, PAP was higher in the heavy (23 ± 5 cm H_2O), and obese (26 ± 5 cm H_2O) groups than in the normal group (20 ± 3 cm H_2O). However, there was no difference in compliance among the groups in this position.

When patients were turned to the prone position on the Wilson frame, there was an increase in PAP and a decrease in pulmonary compliance in each group (Table 2). Patients positioned prone on the Wilson frame had an increase in MAP in the obese group but not in the heavy or normal groups (Table 2). Patients turned to the prone position on chest rolls had an increase in PAP and a decrease in pulmonary compliance in all groups (Table 3). Moving to the prone position onto chest rolls had no effect on MAP in any group (Table 3). To the contrary, when using the Jackson table, there was no change in PAP or compliance when moving from the supine to the prone position in the normal or obese group (Table 4). The heavy group demonstrated a small increase in PAP and a small decrease in compliance on the Jackson table (Table 4). When moving from the supine to the prone position, the increase in PAP and decrease in lung compliance observed in heavy and obese patients were greater when using the Wilson frame or chest rolls compared with the Jackson table (Figures 2 and 3).

Within the cohort of 77 patients for whom we used PAP and tidal volume to calculate dynamic compliance were 10 patients for whom plateau pressures and static compliance were also measured. This cohort of five normal and five heavy patients revealed that the percent change in dynamic compliance was similar to the percent change in static compliance.

Table 2. PAP, PP, TV, Compliance, and MAP for the Wilson Frame

	Normal (*n* = 18)	Heavy (*n* = 9)	Obese (*n* = 7)
PAP (cm H_2O)			
Supine	19 ± 3	24 ± 6*	27 ± 4*
Prone	24 ± 5†	29 ± 7†	34 ± 7*†
PP (mm Hg)			
Supine	1 ± 1	1 ± 1	1 ± 1
Prone	1 ± 1	2 ± 1	3 ± 5
TV (mL)			
Supine	750 ± 131	933 ± 111*	907 ± 150*
Prone	756 ± 128	934 ± 112*	913 ± 149*
Compliance (mL/cm H_2O)			
Supine	39 ± 6‡	43 ± 16‡	36 ± 11‡
Prone	32 ± 7	34 ± 10	28 ± 9
MAP (mm Hg)			
Supine	91 ± 14	103 ± 7	82 ± 12
Prone	89 ± 12	93 ± 7	97 ± 17†

PAP = peak airway pressure, PP = pleural pressure, TV = tidal volume, MAP = mean arterial pressure.
* $P \leq 0.05$ versus normal.
† $P \leq 0.05$ for prone versus supine.
‡ $P \leq 0.05$ for supine versus prone.

Table 3. PAP, PP, TV, Compliance, and MAP for the Chest Rolls

	Normal (*n* = 8)	Heavy (*n* = 5)	Obese (*n* = 7)
PAP (cm H_2O)			
Supine	20 ± 3	21 ± 3	24 ± 4
Prone	26 ± 5†	27 ± 5†	32 ± 6†
PP (mm Hg)			
Supine	1 ± 1	1 ± 1	1 ± 1
Prone	1 ± 1	3 ± 2	1 ± 2
TV (mL)			
Supine	748 ± 113	908 ± 120*	975 ± 86*
Prone	746 ± 114	916 ± 103*	1000 ± 113*
Compliance (mL/cm H_2O)			
Supine	37 ± 5‡	43 ± 2‡	42 ± 8‡
Prone	29 ± 6	34 ± 4	32 ± 6
MAP (mm Hg)			
Supine	94 ± 13	77 ± 13	86 ± 6
Prone	96 ± 19	76 ± 9	98 ± 12

PAP = peak airway pressure, PP = pleural pressure, TV = tidal volume, MAP = mean arterial pressure.
* $P \leq 0.05$ versus normal.
† $P \leq 0.05$ for prone versus supine.
‡ $P \leq 0.05$ for supine versus prone.

Discussion

In this study, we hypothesized that compromise in ventilatory function in the prone position is related to the patient's body habitus and the surgical frame used to support the patient while in the prone position.

Table 4. PAP, PP, TV, Compliance, and MAP for the Jackson Table

	Normal (n = 10)	Heavy (n = 7)	Obese (n = 6)
PAP (cm H_2O)			
Supine	20 ± 4	24 ± 3*	28 ± 5*
Prone	22 ± 6	26 ± 4†	29 ± 6*
PP (mm Hg)			
Supine	0 ± 2	0 ± 0	1 ± 1
Prone	0 ± 3	1 ± 1	0 ± 1
TV (mL)			
Supine	650 ± 113	893 ± 176*	906 ± 149*
Prone	644 ± 109	893 ± 179*	908 ± 153*
Compliance (mL/cm H_2O)			
Supine	33 ± 4	37 ± 8‡	34 ± 10
Prone	31 ± 9	35 ± 8	33 ± 10
MAP (mm Hg)			
Supine	84 ± 19	88 ± 21	78 ± 14
Prone	84 ± 17	83 ± 15	76 ± 16

PAP = peak airway pressure, PP = pleural pressure, TV = tidal volume, MAP = mean arterial pressure.
* $P \leq 0.05$ versus normal.
† $P \leq 0.05$ for prone versus supine.
‡ $P \leq 0.05$ for supine versus prone.

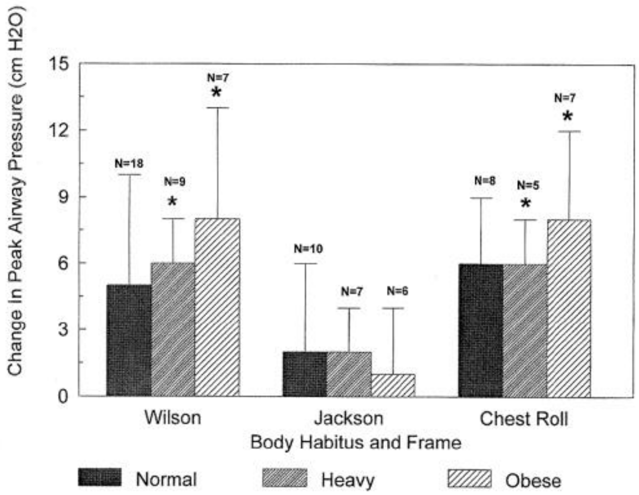

Figure 2. Change in peak airway pressure (prone − supine) when moving from the supine to prone position in relation to the body habitus and surgical frame. *$P \leq 0.05$ versus the Jackson table.

Although most surgical frames for prone procedures are configured to allow the abdomen to hang completely free, this is difficult to accomplish in overweight patients. Our results demonstrate that all patients had greater compromise in ventilatory function (decreased compliance, higher PAP) when they were placed on the Wilson frame or on chest rolls than when they were positioned on the Jackson table. When the change in lung compliance from supine to prone position on each individual frame was compared, we found that the compliance change was not affected by body habitus but that it was affected by the positioning frame (Figure 3).

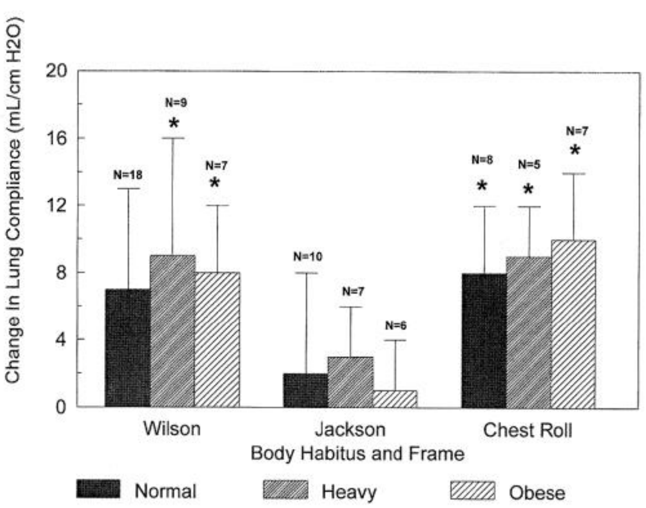

Figure 3. Change (supine − prone) in lung compliance (volume/peak airway pressure) when moving from the supine to prone position in relation to the body habitus and surgical frame. *$P \leq 0.05$ versus the Jackson table.

This study brings to light important patient safety issues when dealing with patients for spine surgery. Any increased pressure in the thoracic or abdominal cavity allows for shunting of blood and an increase in pressure in the vertebral venous system. The increased PAP and decrease in compliance seen in this study when using the Wilson frame or chest rolls can cause increased surgical bleeding, as well as ventilatory compromise.

Several positioning devices are currently in common usage. In this study, we evaluated the three most popular positioning devices at our hospital. The chest rolls are placed longitudinally along the lateral torso from just below the clavicle to the pelvis (Figure 1a). The Wilson frame is a curved frame that supports the torso and pelvis along the lateral edges (Figure 1b). The Jackson table has padded supports under the chest and pelvis (Figure 1c). These devices are intended to elevate the anterior surface of the body so that the abdomen can hang freely and prevent the abdominal viscera from impeding the inspiratory movement of the diaphragm. Unlike the Jackson table, the Wilson frame and chest rolls are surgical frames that do not allow the abdomen to hang completely free, especially in the heavy and obese population; therefore, these devices can cause increased PAP and decreased compliance. By reducing abdominal and thoracic pressures, we found that the Jackson table is the best table to use for surgery of the spine in cervical, thoracic, and lumbar regions to optimize respiratory mechanics.

There are several studies of respiratory dynamics in nonobese surgical patients in the prone position (3–9). Kaneko and colleagues (4) placed patients in the prone position and discovered that pulmonary blood flow in the prone and supine positions was similarly homogenous. Stone and Khambatta (3) showed that no changes in the magnitude of pulmonary shunting occurred from the supine to prone position in patients positioned prone on parallel rubber bolsters with the abdomen allowed to hang free. Douglas et al. (5) studied patients in the intensive care unit with respiratory failure and discovered that pronating these patients with the abdomen hanging freely improved arterial oxygen values. Pelosi et al. (10) showed that, in anesthetized, paralyzed, obese patients positioned prone with their abdomens hanging freely, lung volume, lung compliance, and oxygenation increased. All of these studies support the use of the Jackson table, which allows the abdomen to hang freely. Patients who are obese or who have coexisting respiratory disease may have improved ventilation when positioned prone on this particular frame. If tidal volume is sacrificed for the sake of increased PAP, then atelectasis may become a problem in the underventilated patient.

We calculated static and dynamic compliance in a cohort of five normal and five heavy patients. Static compliance is calculated using tidal volume and plateau airway pressures and is a reflection of actual lung compliance. Dynamic compliance is calculated using tidal volume and PAP and reflects compliance of the thoracic cage. Both static and dynamic compliance were altered in this study. The group of 10 patients for whom both were measured revealed that the percent change in static compliance was similar to the percent change in dynamic compliance. Many variables can alter compliance. The factors most likely involved in this study were restriction of chest expansion and decreased chest wall elasticity, obesity, muscle relaxation, and abdominal wall compression when moving to the prone position. A relaxed diaphragm transmits pressure from the abdomen. Abdominal pressure is increased by obesity, abdominal distension, and venous congestion. In this study, we had the added problem of partial compression of the anterior abdominal wall by the chest rolls and Wilson frame. This compression was probably responsible for the decrease in compliance in the prone position observed with these frames. However, compliance was not decreased in these patients in the supine position by increasing body mass. We believe that this most likely reflects the effects of anesthesia and muscle relaxation. Reference information concerning the effect of obesity on pulmonary compliance is typically obtained in awake patients and cannot be extrapolated to the anesthetized and relaxed patient.

Some studies support the use of the knee-chest frame for prone surgery. In a study involving healthy volunteers, the knee-chest frame was the best in terms of functional residual capacity, expiratory reserve volume, residual volume, and total lung capacity (8). Another study that evaluated dynamic pulmonary compliance with various surgical positions in nonobese patients concluded that compliance decreased in the lateral and prone positions and that the kneeling position was preferable for prone cases (11). However, caution must be used to avoid the complications of nerve palsies secondary to positioning and hypotension due to venous pooling in the dependent lower extremities.

When the nonobese patient is positioned prone, cardiovascular problems are unusual. The patient is usually positioned so that the inferior vena cava and femoral veins are not compressed; otherwise, venous return for cardiac filling may be compromised. In our study, there were no significant decreases in MAP. In fact, there was an increase in MAP in the obese group when they were moved from the supine to the prone position, which was greater on the Wilson frame. Only a few studies have analyzed the cardiovascular effects of prone positioning. Backofen and Schauble[1] concluded that, in nonobese patients in the prone position, heart rate, mean arterial, venous, and pulmonary artery occlusion pressures were not altered. However, there were significant increases in systemic and pulmonary vascular resistances that could not prevent significant decreases in stroke volume and cardiac index. Wadsworth et al. (12) studied cardiovascular variables in nonobese healthy volunteers in four different prone positions. They discovered that the MAP and heart rate did not change, but that cardiac index decreased significantly when moving from the supine to the knee-chest position and onto pelvic props (12). Because there were no significant changes in MAP, except in the obese group on the Wilson frame, it is difficult to conclude anything from our study in terms of cardiovascular risk. A separate study is needed to more accurately analyze the cardiovascular effects (cardiac index) in the obese population using these frames.

One study has analyzed the effects of body habitus in relation to using various frames to support patients in the prone position. Distefano et al. (13) discovered that when thin to medium size patients were placed in the prone position with their abdomens restricted, they had higher inferior venal caval pressures than when their abdomens were without restriction. They suggested the routine use of the Canadian frame, which allows the abdomen to hang free for back surgery (13).

In conclusion, patients undergoing spinal surgery in the prone position have an increase in PAP and decrease in lung compliance when moved from the supine to the prone position when using either chest rolls or the Wilson frame, but not when using the Jackson table. We believe that these changes are due to

[1] Backofen JE, Schauble JF. Hemodynamic changes with prone position during general anesthesia [abstract]. Anesth Analg 1985;64:194.

differences in the degree in which these frames prevent abdominal compression.

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