Effect of Prone Positioning Systems on Hemodynamic and Cardiac Function During Lumbar Spine Surgery: An Echocardiographic Study

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Abstract

Study Design. Prospective randomized study of patients undergoing spine surgery.

Objective. To compare changes in hemodynamic and cardiac function after prone positioning using different prone positioners.

Summary of Background Data. Prone positioning decreases blood pressure and cardiac function. Several studies have evaluated changes in cardiac function after prone positioning, and linked them to reduced venous return and ventricular compliance. This study compares different prone positioners using transesophageal echocardiography, and determines their effect on cardiac function and hemodynamics.

Methods. After correction of fluid deficits with the patient under stable anesthesia, hemodynamic and cardiac performance was measured using transesophageal echocardiography. After prone positioning, repeat measurements were performed, and comparisons were made between prone and supine positions.

Results. No intergroup differences in demographics, fluid deficit, baseline hemodynamics, or differences from supine to prone position were noted. Cardiac output decreased with the Wilson (Union City, CA) and Siemens AG (Munich, Germany) frames, while cardiac index and stroke volume decreased with the Andrews (Hollywood, CA), Wilson, and Siemens systems. Cardiac preload decreased using the Andrews frame. The Jackson spine table (Hollywood, CA) and bolsters had the least effect on cardiac performance.

Conclusion. Adequate fluid replacement reduced hypotension and hemodynamic instability after prone positioning. The Jackson spine table and longitudinal bolsters had minimal effects on cardiac function, and should be considered in patients with limited cardiac reserve.

Anesthesia for posterior lumbar spine surgery usually requires that the patients be turned prone from the supine position. Prone positioning with the patient under general anesthesia elicits hemodynamic changes, which produce decreases in both arterial pressure and tissue perfusion.1-3 There have been a limited number of studies investigating the hemodynamic effects of the prone position during general anesthesia.4,5 A few reports focused on describing changes in central venous pressure and cardiac index, and related most of the hemodynamic changes to alterations in intra-abdominal pressure, resulting in decreases in preload to the heart.6-8

Other studies compared different prone positioning systems and attempted to correlate increases in central venous pressure with blood loss.9 Still another study evaluated the hemodynamic effects of prone positioning by transesophageal echocardiography (TEE) using a longitudinal bolster prone positioning system.10 They found a decrease in left ventricular volume and reduced systolic pulmonary venous flow velocity with enhanced diastolic pulmonary flow velocity. They concluded
that these changes were caused by a decrease in venous return from inferior vena cava compression and decreased left ventricular compliance secondary to increased intrathoracic pressure.

There is a large number of prone positioning systems that are presently used to satisfactorily position patients for posterior lumbar spine surgery. To our knowledge, no studies have compared the hemodynamic or cardiac effects of these different prone positioning systems to determine which provides the least amount of hemodynamic alterations and changes in cardiac function. This study compares the hemodynamic and cardiac effects of different prone positioning systems using TEE to determine the effect of each system on hemodynamic and cardiac function. We will attempt to determine the best positioning method for reducing hemodynamic variability with prone positioning in patients undergoing posterior spine surgery.

Materials and Methods

The institutional review board for the Protection of Human Subjects approved the protocol. Informed consent was obtained from all patients participating in the study. A total of 51 adult patients (American Society of Anesthesiologists physical status 1-3), scheduled for elective lumbar spine surgery, were admitted into the study. Patients were excluded from the study if they were obese (>130% of ideal body weight), had significant cardiac disease, were on medications that could significantly alter cardiac function, or were pregnant. Patients were randomly assigned to 1 of 5 groups. The prone positioning system used designated each group.

Management of Anesthesia

After patient arrival to the preoperative holding area, an intravenous (IV) infusion was started. The patient’s fluid deficit was calculated (body weight × 1.5 mL × hours fasted), and three fourths of this fluid deficit was administered before induction of general anesthesia. This procedure was performed to ensure normovolemia before induction of general anesthesia.

Aside from the usual American Society of Anesthesiologists standard monitors, an invasive arterial pressure catheter (20 G, 1.88 in cannula [BD Angiocath; Becton Dickinson, Sandy, UT]) was attached to 72-96 inches of high-pressure tubing (Walrus; Medical Parameters, Woburn, MA) and connected to a disposable transducer (Abbott Critical Care Systems; Abbott Laboratories, North Chicago, IL). All patients were fitted with TED hose (Kendall; Tyco Healthcare, Mansfield, MA) and sequential compression sleeves (Tyco Healthcare) to the lower extremities before surgery to prevent venous stasis and blood clot formation.

After preoxygenation in supine position and just before anesthetic induction, all patients were given midazolam 2 mg IV, and then had their heart rate and mean arterial pressure recorded (baseline). They were then anesthetized using thiopental 3-5 mg/kg IV, fentanyl 2 µg/kg IV, and vecuronium 0.1 mg/kg IV. Maintenance of anesthesia consisted of oxygen and nitrous oxide in 40/60 mixture and isoflurane of 0.8% to 1.3% end tidal concentration. During this period, mean arterial pressure was kept within 10% of the baseline values. Ephedrine in 5-mg increments IV was used if mean arterial pressure decreased by more than 15% of baseline values. Depth of anesthesia was increased if mean arterial pressure was increased by 15% of baseline value. Normothermia was maintained throughout the study. Ventilation was controlled to maintain end tidal pCO₂ between 35 and 40-mm Hg.

Hemodynamic and Cardiac Function

Heart rate and mean arterial pressure were measured either invasively or noninvasively using a Datex Monitoring System (Type F-CU-8-28-05; Datex-Engstrom Instrument Corp., Helsinki, Finland). These variables were recorded 5 minutes after induction of anesthesia and intubation, with the patient supine, under stable maintenance anesthesia. These hemodynamic variables were again measured 5 minutes after the patient was turned prone. A 5-MHz multiplane TEE probe (Accuson, 128/XP, Mountain View, CA) was inserted after induction of the general anesthesia. The left ventricular area at the end of systole (LVESA) and diastole (LVEDA) was determined at the transgastric level. From these images, the contractility index was calculated as well as the fractional area of change. The fractional area of change is calculated and is an approximation of left ventricular ejection fraction. Mitral flow velocities at the level of the anulus were measured using pulse wave Doppler recordings. From the pulse wave recordings, the time velocity integral was measured. Time velocity integral determines velocity of blood flow over time through the mitral valve and is used to assess...
cardiac output.

Mitral valve anular diameter was measured and mitral anular area calculated using $[\pi D^2/4]$. The time velocity integral multiplied by the mitral anular area yielded the stroke volume measured in milliliters/contraction. This result permitted the calculation of cardiac output (liters of blood per minute) as well as cardiac index (liters of blood per $M^2$ per minute). Multiple recordings of each variable were performed, and an average value was obtained. Echocardiographic measurement along with mean arterial pressure and heart rate were obtained after 5 minutes of stable anesthesia, during supine positioning and then 5 minutes after prone positioning. The TEE probe was then removed, and the subsequent anesthetic management was left to the discretion of the anesthesiologist. TEE images were recorded on a videocassette, and a cardiologist who was blinded to which prone positioning system was used evaluated them.

Prone Positioning Systems Under Study.  

We evaluated 5 different positioning systems, including Siemens, which is no longer manufactured by the company. These positioning systems included: the Siemens frame, which, using a previous Siemens frame as a model, George and Tom Upholstery (Villa Park, IL) custom made; Andrews frame (model No. 914; Hollywood, CA); Wilson frame (OSI model No. 5319[G] 5321[G], Union City, CA); Jackson frame (OSI model No. 5840-831; Hollywood, CA); and the bolster system, which consisted of rolled-up blankets. The size of the patient determined the diameter of the bolster system (i.e., to ensure a “free hanging” abdominal wall). These systems and their important characteristics are described in Figure 1.

Demographic variables were recorded along with the calculated fluid deficit and total fluids received before induction of anesthesia. These values were compared among the 5 groups of patients. Hemodynamic variables were recorded before anesthesia (baseline), then after supine and prone positioning after stabilization of hemodynamics. TEE variables recorded after supine and prone positioning were cardiac output, cardiac index, stroke volume, time velocity integral, fractional area of change, LVEDA, LVESA, and contractility score. Intra-group comparisons of these variables between supine and prone positions using the different prone positioning systems were performed using paired $t$ analysis, while intergroup comparisons were performed using analysis of variance. Significance was set at $P < 0.05$.

Results  

Demographic variables were similar in all 5 groups of patients (Table 1). Fasting times before surgery were also similar in all groups of patients as were mean calculated fluid deficits and the total amount of fluid received before induction of anesthesia (Table 2). No significant intergroup differences were noted in baseline hemodynamic variables (Table 3). Heart rates were decreased from baseline values after both supine and prone positioning in the Andrews frame group. Heart rates were also lower in the prone position compared to baseline in the Siemens group, while supine position heart rates were lower than baseline in the Jackson group (Table 3). Mean arterial pressures were lower in all groups compared to baseline values. No appreciable hemodynamic changes were noted with any of the positioning systems when moving from supine to prone position (Table 3).
Cardiac output was reduced with all positioning systems when patients were placed prone but was significantly reduced in both the Wilson and Siemens positioning systems. Cardiac index showed substantial decreases after prone positioning with the Andrews, Wilson, and Siemens systems (Table 4). Stroke volume was also reduced with the prone position in these same 3 systems. Fractional area of change was significantly increased only with the Siemens positioner. LVESA was reduced with prone positioning in all 5 positioning systems. However, clinically significant changes were not observed (Table 4). LVEDA was significantly reduced with the Andrews positioning system when patients were placed prone, which was not observed in patients using the 4 other positioning systems. Contractility scores were unchanged in all groups when patients were turned from the supine to prone position (Table 4).
Table 4. TEE Measurements of Cardiac Performance in Supine and Prone Positions

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Discussion

To our knowledge, this article is the first to evaluate the hemodynamic and cardiac effects of prone positioning in 5 commonly used systems. Each of these positions was designed to allow unrestricted thoracic ventilatory excursion with minimal risk to peripheral nerves. Other studies have examined the hemodynamic effects of prone positioning using either the convex saddle frame, similar to the Wilson frame, or the longitudinal bolster. In both studies, minimal changes in hemodynamic variables were noted with prone positioning, as was the observation with the present study. Cardiac index was diminished with the Wilson frame, an observation similar to our own.

However, the findings of Toyota and Amaki of diminished left ventricular volume and pulmonary venous flow velocity, suggestive of diminished venous return and left ventricular compliance, was not observed in our study. This difference may be caused by the type and size of the longitudinal bolster used, and how these bolsters were positioned under the chest and pelvis. In addition, the use of compression stockings or TED hose may also affect venous return, along with a change in position of the lower extremities in relation to the heart. They did not describe their positioning, but we were meticulous with our positioning, ensuring that the bolster had adequate length and height to allow for excursion of the abdomen. In addition, the pads were placed as far lateral as possible to avoid reduction in chest wall compliance, and all patients had sequential compression sleeves placed on the lower extremities to improve venous return.

Other reports have documented blood pressure decreases and/or tachycardia with prone positioning. One study examined obese patients placed on a Hall frame and noted decreased circulation. Another study noted that transverse bolster positioning across the chest resulted in compression of the right ventricle by the sternum, which was a pediatric patient with pectus excavatum. The third study evaluated healthy patients under spinal or general anesthesia and noted a significant increase in heart rate, with a decrement in blood pressure after prone positioning. We noted no such changes in the present study. Our patients were healthy, nonobese, and adult. We also administered fluids to replace the deficits calculated after an overnight fast. Fluid replacement before induction of anesthesia and prone positioning reduced the hemodynamic responses to prone position noted by Tetzlaff et al. This effect may be the reason that minimal hemodynamic changes were noted, despite the alterations in cardiac function observed with the different prone positioning systems evaluated.

A decrease in cardiac index in our study was most likely caused by a decrease in stroke volume observed with the Andrews, Wilson, and Siemens frames. Our observation that the indexes of contractility were unchanged after prone positioning with these 3 positioners suggests that changes in stroke volume had to be secondary to a decreased preload, an increased afterload, or some combination of both. The decrease in stroke volume with the Andrews frame is probably caused by a decrease in preload, as shown by the large decrease in LVEDA, despite adequate rehydration before induction of anesthesia. The positioning of the legs below the heart produced pooling of blood in the extremities with the patient under general anesthesia. Although the hips are slightly elevated above the level of the heart and compression sleeves are placed on all patients, there still was reduced preload in these patients, as represented by a diminished LVEDA. These results are similar to those of Wadsworth et al. when patients were placed in the knee-chest position, one similar to that produced by the Andrews frame.

The decrease in cardiac output and stroke volume with the Wilson frame does not seem to be caused by diminished
preload because LVEDA was unchanged. However, flow through the mitral valve was reduced, suggesting a change in diastolic function, possibly caused by an increase in myocardial wall tension associated with increased afterload from diminished chest wall compliance. The Wilson frame has 2 full pad lengths that support the chest and pelvis, allowing the abdomen to hang between the pads. Afterload with this positioner might also increase secondary to increased intra-abdominal pressure, which is transmitted to the thorax, increasing intrathoracic pressure during ventilation.10

The Siemens positioning frame also produced changes in cardiac output, cardiac index, and stroke volume similar to both the Andrews and Wilson frames. However, LVEDA was minimally reduced after positioning, and time velocity integral was unchanged, suggesting no difference in preload. Fractional area of change also increased, suggesting an increase in cardiac ejection fraction after prone positioning. However, none of the components of fractional area of change differed significantly, and the contractility score was unchanged, suggesting this to be a statistical artifact. In fact, a recent article using 99mTc-Sestabibi SPECT perfusion scanning showed no change in ejection fraction with prone positioning,17 a finding similar to our data.

The Jackson spine table and use of longitudinal bolsters produced the least perturbation in cardiac performance after prone positioning. With both systems, the abdomen is totally unobstructed, and the legs were at heart level, allowing adequate venous return. The transverse bolster produces minimal changes in chest wall compliance, and because patients were adults without chest wall anomalies (pectus excavatum), no compression of the heart was noted.

Conclusions

This study shows that adequate volume resuscitation after a presurgical fast reduces the changes in blood pressure and heart rate normally seen with prone positioning for spine surgery. TEE evaluation of the 5 different prone positioning systems showed that the Jackson spine table produced the least effect on cardiac function. The Andrews, Wilson, and Siemens systems caused major reductions in cardiac index and stroke volume secondary to diminished preload, increased afterload, or some combination of the two. Although the changes in cardiac function produced by the different prone positioning systems may not be clinically significant in healthy individuals, these alterations may produce a significant hemodynamic effect in individuals with diminished cardiac reserve. This study suggests that the Jackson spine table or use of properly positioned longitudinal bolsters produced the least effect on cardiac function, and may be superior to Siemens, Wilson, and Andrews frames for patients with reduced cardiac function undergoing spinal surgery.

Key Points

* Hemodynamic changes occur from supine to prone position.
* Cardiac function was assessed with TEE.
* There were 5 different prone positioning systems evaluated.
* Cardiac variables compared from supine to prone position.

References


Key words: prone position; transesophageal echocardiography; cardiac output; hemodynamics; Wilson frame; Andrews frame