

PEEP Does Not Affect Left Atrial-Right Atrial Pressure Difference in Neurosurgical Patients

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Positive end-expiratory pressure (PEEP) has been used to prevent and treat venous air embolism in patients in the seated position undergoing neurosurgical operations. However, the safety of PEEP has recently been questioned, because of concern that PEEP might increase right atrial pressure (RAP) more than left atrial pressure, thereby predisposing patients with a probe-patent foramen ovale to paradoxical air embolism. In a prior study in dogs, the authors found that to up 10 cm H₂O PEEP did not affect the interatrial pressure difference. In the present study, the authors examined the effects of 0, 5, and 10 cm H₂O PEEP in 12 anesthetized neurosurgical patients positioned both supine and seated prior to operation. Measurements were made of systemic arterial pressure, RAP, mean pulmonary artery pressure (PAP), pulmonary artery wedge pressure (PAWP), and cardiac output. PAWP was higher (average 2 mmHg) than RAP in all patients. PEEP increased RAP and PAWP in patients, both seated and supine (mean 3 mmHg at 10 cm H₂O), but did not affect the PAWP-RAP difference. In an additional eight patients in the seated position, the authors examined the effects of 0, 10, and 20 cm H₂O PEEP during operation. PEEP again increased PAWP and RAP, but did not significantly affect the PAWP-RAP difference. The PAWP-RAP difference became negative (-1 mmHg) in one patient with 20 cm H₂O PEEP. The authors conclude that levels of PEEP up to 10 cm H₂O do not alter the interatrial pressure difference in seated neurosurgical patients, and, therefore, would not predispose these patients to paradoxical air embolism. (Key words: Anesthesia; neurosurgical. Embolism; air; paradoxical. Position: seated. Ventilation: PEEP.)

VENOUS AIR EMBOLISM represents a serious problem for patients in the seated position undergoing neurosurgical procedures. The incidence of venous air embolism varies widely, depending in part on methods used for its detection. When precordial ultrasonic (Doppler) and end-tidal carbon dioxide monitoring and aspiration of air from a right atrial catheter are used, studies report the occurrence of venous air embolism in 31%¹ and 36%² of patients in the seated position undergoing neurosurgery. Positive end-expiratory pressure (PEEP) has been used for many years as a means of preventing and treating venous air embolism.³⁻⁶ PEEP is believed to be beneficial by increasing right atrial and peripheral

venous pressures, thereby impeding entry of air into the central circulation.⁷⁻⁸ Recently, based on questions of the efficacy⁹ and safety¹⁰ of PEEP, some have urged that PEEP not be used in seated neurosurgical patients.** The study upon which the question of safety is primarily based is one which reported that PEEP caused right atrial pressure (RAP) to increase above left atrial pressure (LAP), thereby predisposing patients with a probe-patent foramen ovale to paradoxical air embolism.¹¹ In a prior study in dogs, we found that PEEP did increase RAP, but did not affect the interatrial pressure difference (LAP minus RAP), either before or during the course of venous air embolism.¹² As a follow-up to the animal study, we undertook the present study to examine the hemodynamic effects of PEEP in anesthetized, neurosurgical patients who were in the supine and seated positions.

Materials and Methods

EFFECTS OF PEEP (0, 5, AND 10 CM H₂O) AND POSITION PRIOR TO SURGERY

Twelve healthy (ASA Physical Status I or II) adult patients scheduled for cervical laminectomy (N = 11) or posterior fossa craniotomy (N = 1) in the seated position were studied following written informed consent. The protocol was approved by the Stanford University Medical Committee for the Protection of Human Subjects in Research. Patients were premedicated with meperidine 2 mg/kg and promethazine 0.2 mg/kg intramuscularly, and diazepam 0.1 mg/kg orally. Radial and pulmonary artery catheters were inserted prior to induction of anesthesia. Anesthesia was induced with meperidine 2 mg/kg and thiopental 2 mg/kg iv, and maintained with nitrous oxide 67% in oxygen. Vecuronium 0.1 mg/kg iv was given to facilitate endotracheal intubation, followed by mechanical ventilation at a tidal volume of 12 ml/kg and a rate of 10/minute. All patients received normal saline 500 ml iv during induction.

Following induction of anesthesia, hemodynamic measurements (see below) were made during application of 0, 5, and 10 cm H₂O PEEP while the subjects

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** Hanowell LH, Gronert GA: Air embolism and the sitting position. *Curr Rev Clin Anesth* 7:203-207, 1987.

TABLE 1. Hemodynamic Effects of PEEP and Position

	PEEP (cm H ₂ O)					
	Supine			Seated		
	0	5	10	0	5	10
PAWP (mmHg)	9.1 ± 0.7	10.8 ± 0.5*	12.3 ± 0.5*	5.1 ± 0.8†	6.0 ± 0.7†‡	7.8 ± 0.8*†
RAP (mmHg)	6.7 ± 0.8	8.3 ± 0.7*	10.1 ± 0.6*	3.2 ± 0.7†	4.2 ± 0.8†§	5.6 ± 0.6*§
CO (l/min)	4.4 ± 0.4	4.0 ± 0.4	3.7 ± 0.30‡	3.7 ± 0.3	3.8 ± 0.5	3.5 ± 0.4
PVR (dynes · sec · cm ⁻⁵)	103 ± 12	108 ± 14	137 ± 21*	118 ± 15	146 ± 19†‡	176 ± 20*§
PAP (mmHg)	14.5 ± 0.8	15.9 ± 0.8*	18.1 ± 1.0*	10.1 ± 0.7†	12.1 ± 0.6*†	14.6 ± 0.6*†
SAP (mmHg)	76 ± 3	74 ± 3	68 ± 3*	83 ± 3	79 ± 3	80 ± 3†

Values are means ± SEM of 12 patients. PAWP = pulmonary artery wedge pressure; RAP = right atrial pressure; CO = cardiac output; PVR = pulmonary vascular resistance; PAP = mean pulmonary arterial pressure; SAP = mean systemic arterial pressure.

* *P* < 0.01 versus PEEP = 0 cm H₂O.
 † *P* < 0.05 versus corresponding supine position value.
 ‡ *P* < 0.05 versus PEEP = 0 cm H₂O.
 § *P* < 0.01 versus corresponding supine position value.

were in the supine position. A skull clamp was then applied and the patient placed in the seated position with the spine oriented 80–90° from the horizontal plane. Hemodynamic measurements were repeated during 0, 5, and 10 cm H₂O PEEP. The three levels of PEEP were applied in random order in each body position and maintained for 5 min before measurements were made. The operation did not commence until all study measurements had been completed. At the conclusion of surgery, the location of the tip of the pulmonary artery catheter when in the wedge position was determined by a lateral chest radiograph with the patient in the supine position and an anteroposterior chest radiograph with the patient in the seated position.

Hemodynamic measurements included heart rate (HR), mean systemic arterial pressure (SAP), right atrial pressure (RAP), mean pulmonary artery pressure (PAP), pulmonary artery wedge pressure (PAWP), and cardiac output (CO), in triplicate by thermodilution technique. SAP, RAP, and PAWP were measured at end-expiration using three separate transducers and a continuous strip chart recorder. Each measurement was referenced to zero at the time that the measurement was made. All pressures were referenced to the mid-axillary line in the supine position and to the anterior 5th intercostal space when the patients were in the seated position.

EFFECTS OF PEEP (0, 10, AND 20 CM H₂O) DURING SURGERY

Eight healthy adult patients scheduled for cervical laminectomy were studied following written informed consent. Prior to skin incision, anesthetic management was identical to the above protocol. Anesthetic management for the remainder of the operation consisted of isoflurane (0.5–1%) in oxygen with controlled ventilation to maintain PaCO₂ at values of 35–40 mmHg. One hour after skin incision, hemodynamic measurements

were made as described above at 0, 10, and 20 cm H₂O PEEP in patients in the seated position. At the conclusion of surgery, the position of the tip of the pulmonary artery catheter was confirmed as described above in the wedge position.

STATISTICS

For the first protocol, effects of PEEP and position were compared using two-way repeated measures analysis of variance (PEEP × position), followed by the Newman-Keuls' multiple range test when appropriate.

In the second protocol, values during the different levels of PEEP were compared using repeated measures analysis of variance followed by Newman-Keuls' test when appropriate. A probability value less than 0.05 was considered significant.

Results

EFFECTS OF PEEP (0, 5, 10 CM H₂O) AND POSITION PRIOR TO SURGERY

In all 12 patients, the tip of the pulmonary artery catheter was in the right lower lobe below the level of the left atrium, both in the supine and seated positions. In all patients, PAWP was higher than RAP at all levels of PEEP. Both 5 and 10 cm H₂O PEEP increased both RAP and PAWP in the subjects in both the seated and supine positions (table 1). At each level of PEEP (0, 5, 10) both RAP and PAWP were higher in subjects in the supine than in the seated position. The changes in RAP and PAWP were always in the same direction and of the same magnitude, so that the pressure difference between PAWP and RAP did not change with PEEP or body position (fig. 1). In each patient, this difference at the three different levels of PEEP never differed by more than 2 mmHg.

Both 5 and 10 cm H₂O PEEP increased PAP in both the seated and supine subjects. PAP at each level of

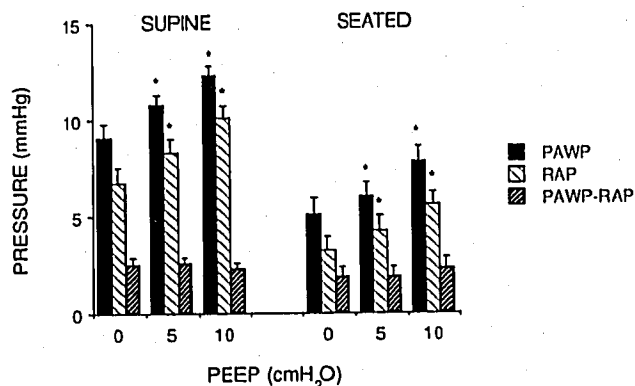


FIG. 1. Pulmonary artery wedge pressure (PAWP), right atrial pressure (RAP), and the difference between pulmonary artery wedge pressure and right atrial pressure (PAWP-RAP) at 0, 5, and 10 cm H₂O PEEP in the supine and seated position. Values are mean \pm SEM from 12 patients obtained prior to surgery. * $P < 0.01$ compared to 0 PEEP.

PEEP (0, 5, 10) was higher in the subjects in the supine than in the seated position. Cardiac output did not change significantly with body position, but did decrease with 10 cm H₂O PEEP.

PVR at 5 and 10 cm H₂O PEEP was higher in subjects in the seated than in the supine position. PEEP 10 cm H₂O in subjects in the supine position and both 5 and 10 cm H₂O in subjects in the seated position caused modest but statistically significant increases in PVR.

SAP was higher in subjects in the seated than in the supine position, probably a result of the stimulation from skull clamp application. PEEP 10 cm H₂O in subjects in the supine position caused a small but statistically significant decrease in SAP. PEEP had no effect on SVR. SVR at each level of PEEP was higher in subjects in the seated than supine position.

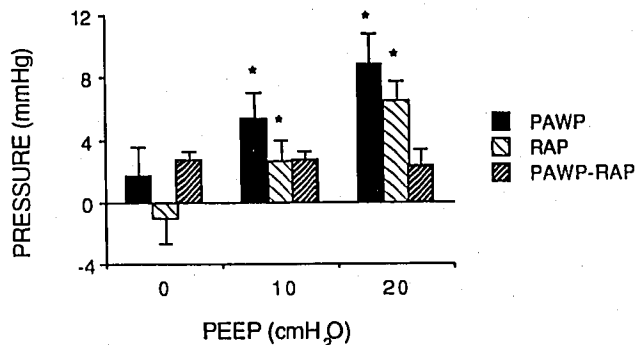


FIG. 2. Pulmonary artery wedge pressure (PAWP), right atrial pressure (RAP), and the difference between pulmonary artery wedge pressure and right atrial pressure (PAWP-RAP) at 0, 10, and 20 cm H₂O PEEP. Values are mean \pm SEM from eight patients obtained during surgery in the seated position. * $P < 0.01$ compared to 0 PEEP.

EFFECTS OF PEEP (0, 10, AND 20 CM H₂O) DURING SURGERY

One hour after skin incision, both 10 cm H₂O and 20 cm H₂O PEEP increased both pulmonary artery wedge pressure and right atrial pressure (fig. 2). The increases were of a similar magnitude, so that there was no effect of PEEP on the pulmonary artery wedge pressure-right atrial pressure difference. In six of the eight patients, the effect on this difference at either 10 or 20 cm H₂O PEEP was less than 1 mmHg. In one patient, 20 cm H₂O PEEP increased the difference by 4 mmHg and, in one patient, 20 cm H₂O PEEP decreased the difference by 5 mmHg; the effect of 20 cm H₂O PEEP in both of these patients could be reproduced. Air embolism was not detected in any of the eight patients during surgery using Doppler ultrasound, end-tidal carbon dioxide, RAP, and PAWP monitoring.

Discussion

In this study, PEEP increased both PAWP and RAP equally so that it did not affect the pressure difference between the two. Since PAWP accurately reflects LAP when the tip of the wedged pulmonary artery catheter is in a perfused, dependent lung segment,^{13,14} we conclude that up to 10 cm H₂O PEEP does not affect the interatrial pressure difference (LAP minus RAP) either before or during surgery in seated neurosurgical patients.

The effect of PEEP on atrial pressures in seated neurosurgical patients is of critical importance in determining the safety of PEEP in the estimated 20–30% of adults who have a probe-patent foramen ovale. If air bubbles are present in the right atrium of such patients, reversal of the normal interatrial pressure difference may cause right-to-left movement of air into the systemic circulation, a potentially catastrophic event.^{10,15} In their study of seated neurosurgical patients, Perkins and Bedford reported that 10 cm H₂O PEEP did cause such a reversal of the interatrial pressure difference.¹¹

There are several possible explanations for the discrepancy between that study and ours. There were minor differences in anesthetic technique, but these seem unlikely to account for the differences in results. In the Perkins and Bedford study, control measurements were always made before the PEEP measurement, whereas in our study, the different levels of PEEP were applied in random order. Randomization may be important because of a possible reversal of the interatrial pressure difference with time.² There likely were other important differences in methodology between the two studies. In our study, SAP, RAP, and PAWP were measured at end-expiration and recorded on a continuous strip-chart recording with each measure-

ment referenced to zero at the time the measurement was made. The study by Perkins and Bedford does not indicate the timing of measurements during the respiratory cycle or whether each measurement was referenced to zero at the time of measurement. These details of measurement procedure are important because the interatrial pressure difference is small; therefore, minor differences in measurement procedure could dramatically alter the results obtained.

Although PEEP increases both LAP and RAP, it is not surprising that it has no effect upon the interatrial pressure difference (LAP minus RAP). As we concluded from our study in dogs,¹² the major hemodynamic effects of low to moderate levels of PEEP are mediated by the increase in intrathoracic pressure. This increase in intrathoracic pressure should affect all cardiac chambers equally. Any selective right-sided hemodynamic effect of PEEP (increase in PVR) at levels up to 10 cm H₂O is sufficiently small that it should not adversely affect right ventricular function and selectively increase RAP.

This study provides evidence to support the conclusion that the use of low levels of PEEP in seated neurosurgical patients does not affect interatrial pressure differences, and, therefore, should not predispose patients with a probe-patent foramen ovale to paradoxical air embolism. Whether these low levels of PEEP are efficacious remains a controversial issue. There is clinical evidence which suggests that these and higher levels of PEEP may prevent air embolism⁶ or aid in detecting its source.⁵ Our finding that 20 cm H₂O PEEP did reverse the interatrial pressure difference in one of eight patients is consistent with other data,¹⁵ and suggests caution with the use of this high level of PEEP in seated neurosurgical patients.

References

1. Cucchiara RF, Bowers B: Air embolism in children undergoing suboccipital craniotomy. *ANESTHESIOLOGY* 57:338-339, 1982
2. Perkins-Pearson NAK, Marshall WK, Bedford RF: Atrial pressures in the seated position: Implication for paradoxical air embolism. *ANESTHESIOLOGY* 57:493-497, 1982
3. Hewer AJH, Logue V: Methods of increasing the safety of neuroanaesthesia in the sitting position. *Anaesthesia* 17:476-481, 1962
4. Albin MS, Carroll RG, Maroon JC: Clinical considerations concerning detection of venous air embolism. *Neurosurgery* 3:380-384, 1978
5. Muravchick S, DeLisser E, Welch F: The use of PEEP to identify the source of cardiopulmonary air embolism. *ANESTHESIOLOGY* 49:294-295, 1978
6. Voorhies RM, Fraser RAR, Van Poznak A: Prevention of air embolism with positive end expiratory pressure. *Neurosurgery* 12:503-506, 1983
7. Pick RA, Handler JB, Murata GH, Friedman AS: The cardiovascular effects of positive end-expiratory pressure. *Chest* 82:345-350, 1982
8. Luce JM: The cardiovascular effects of mechanical ventilation and positive end-expiratory pressure. *JAMA* 252:807-811, 1984
9. Toung T, Ngeow YK, Long DL, Rogers MC, Traystman RJ: Comparison of the effects of positive end-expiratory pressure and jugular venous compression on canine cerebral venous pressure. *ANESTHESIOLOGY* 61:169-172, 1984
10. Gronert GA, Messick JM Jr, Cucchiara RF, Michenfelder JD: Paradoxical air embolism from a patent foramen ovale. *ANESTHESIOLOGY* 50:548-549, 1979
11. Perkins NAK, Bedford RF: Hemodynamic consequences of PEEP in seated neurological patients—Implications for paradoxical air embolism. *Anesth Analg* 63:429-432, 1984
12. Pearl RG, Larson CP Jr: Hemodynamic effects of positive end-expiratory pressure during continuous venous air embolism in the dog. *ANESTHESIOLOGY* 64:724-729, 1986
13. Roy R, Powers SR Jr, Fenstel PJ, Dutton RE: Pulmonary wedge catheterization during positive end-expiratory pressure ventilation in the dog. *ANESTHESIOLOGY* 46:385-390, 1977
14. Berryhill RE, Benumof JL: PEEP-induced discrepancy between pulmonary artery wedge pressure and left atrial pressure: The effects of controlled vs. spontaneous ventilation and compliant vs. noncompliant lungs in the dog. *ANESTHESIOLOGY* 51:303-308, 1979
15. Cucchiara RF, Seward JB, Nishimura RA, Nugent M, Faust RJ: Identification of patent foramen ovale during sitting position craniotomy by transesophageal echocardiography with positive airway pressure. *ANESTHESIOLOGY* 63:107-109, 1985