Does peep reduce the incidence of aspiration around endotracheal tubes?

Brad A. Janson BS, Thomas J. Poulton MD

Despite improved endotracheal tube designs, aspiration remains a cause of pulmonary complications. This in vitro *study evaluates the efficacy of positive end-expiratory pressure (PEEP) in reducing the incidence of seepage around endotracheal tubes during mechanical (MV) and spontaneous ventilation (SV). Two transparent plastic "tracheas" with cuffed and uncuffed endotracheal tubes simulated adult and paediatric airways respectively. Ten trials without PEEP and ten with PEEP at each of two different levels were completed for each model using both SV and MV. Simulated SV in both models was associated with seepage nearly 100 per cent of the time, regardless of PEEP level. During MV without PEEP, seepage occurred in 55 per cent of the adult trials and 100 per cent of the paediatric trials. In contrast, MV with 5 cm H_2O PEEP produced seepage rates of 15 per cent in the adult model and 0 per cent in the paediatric model. Compared to trials without PEEP, seepage occurred less frequently, was reduced in amount and delayed in onset. MV with PEEP significantly ($p < 0.05$) decreased the incidence of seepage around endotracheal tubes.*

Key words

EQUIPMENT, TUBES: endotracheal; COMPLICATIONS: aspiration; VENTILATION: PEEP, mechanical, spontaneous.

From the Departments of Anesthesiology, Pediatrics, and Internal Medicine, Creighton University School of Medicine, Omaha, Nebraska.

Address correspondence to: Dr. Thomas J. Poulton, Department of Anesthesiology, Creighton University School of Medicine, 601 North 30th Street, Omaha, Nebraska 68131.

Supported in part by a Creighton University School of Medicine Dean's Research Grant.

Atelectasis, hypoxemia and pneumonia are complications of pulmonary aspiration of oropharyngeal secretions or gastric contents. Consequently, numerous techniques have been designed to minimize aspiration around endotracheal tubes (ETTs). The modern high-volume, low-pressure ETT cuff has significantly decreased the incidence of aspiration.[1-3] Similar benefits have accrued by using large diameter, thin-walled cuffs and carefully adjusting intracuff pressures.[2,4,5] Despite improved endotracheal tube design, aspiration remains an important cause of perioperative pulmonary complications.[6,7] Intubated or not, up to 26 per cent of anaesthetized patients have clinically unrecognized regurgitation[6,8,9] and the incidence of at least minor aspiration around cuffed endotracheal tubes may be as high as 56 per cent.[1,4,9-13]

Two recent studies evaluated modified ventilation techniques to prevent aspiration. In a study of 22 children and infants, 2.5 cm H_2O continuous positive airway pressure (CPAP) did not decrease the incidence of aspiration during mechanical ventilation.[12] However, a study on dogs revealed that the positive pressure effects of high frequency jet ventilation did in fact prevent aspiration by causing a nearly continuous flow of gas out through the larynx.[14]

We designed a laboratory study to evaluate the efficacy of positive end-expiratory pressure (PEEP) in reducing the incidence of "aspiration" (seepage around ETTS) during mechanical (MV) and spontaneous ventilation (SV).

Methods

We studied two models, simulating adult and paediatric tracheas, using cuffed and uncuffed endotracheal tubes respectively. The models used transparent plastic trachea and a Bear "Cub" ventilator (Bourns, Riverside, CA).

The adult model used a 7.5 mm ID endotracheal tube with a high-volume, low-pressure cuff (Mallinckrodt, McGaw Park, IL) placed in the adult model trachea (Imatrach®, Mallinckrodt; internal dimensions 1.7 × 2.0 cm). Normal tracheal secretions were simulated by coating the cuff with 0.3 cc water soluble surgical lubricating jelly (Surgilube®, E. Fougera & Co., New York City). Following placement in the "trachea," intracuff pressure was increased to support a 2 cm column of water above the cuff without leaks (Figure 1). Methylene blue coloured the water column to facilitate observation. Distal to the "trachea," two one-liter inflatable anaesthesia breathing bags simulated lungs.

Using an aneroid manometer and the method of Cox,[15] the cuff was slowly deflated to a previously determined minimal occlusion pressure of 8 cm H_2O. In pilot studies using mechanical ventilation without PEEP (peak inspiratory pressure = 20 cm H_2O), an occlusion pressure of 8 cm H_2O was associated with a 50 to 80 per cent "aspiration" (seepage) rate during a 30-minute observation period. That pressure was chosen since the associated aspiration rate was high enough to allow assessment of treatment effects. The same intracuff pressure was monitored continuously and maintained during each trial in the adult study.

In the adult model, trials with and without PEEP were conducted in random order during both MV and simulated SV, each with a respiratory rate of 12 cycles/min (Table I). Spontaneous breathing was simulated by withdrawing the plunger of a "super syringe" (RNA Medical Corp. PUL-MARK-1, Woburn, MA) connected distally to the "trachea." Tidal volume was 500 cc and the peak inspiratory flow rate was 45 ± 15 $L \cdot min^{-1}$.

Observation of each trial (adult and paediatric) continued until either seepage occurred or 30 minutes had elapsed. In the adult study "minimal" seepage involved the presence of non-dripping blue solution localized to the distal cuff. "Moderate" leaks included slow dripping while "maximal" seepages were characterized by a rapid flow of fluid past the cuff.

In our paediatric study, an 8 mm ID nasopharyngeal airway (Argyle, St. Louis, MO.) simulated the trachea. A 5.5 mm ID (7.5 mm OD) uncuffed paediatric endotracheal tube (Mallinckrodt) was inserted 2 cm into the "trachea" without surgical lubricating jelly. A fabricated reservoir was filled, creating a 2 cm water column at the proximal end of the model trachea (Figure 2). The paediatric model endotracheal tube and "tracheal" sizes were chosen to provide a minimal air leak with a peak inspiratory pressure of 20 cm H_2O, simulating common clinical practice. Trials were conducted randomly with and without PEEP (Table II). Mechanical and spontaneous respiratory rates were 20 cycles/min with a tidal volume of 125 cc. Presence of *any* coloured fluid at the distal end of the endotracheal tube was defined as seepage. Significant differences between mean seepage rates were sought using analysis of variance.

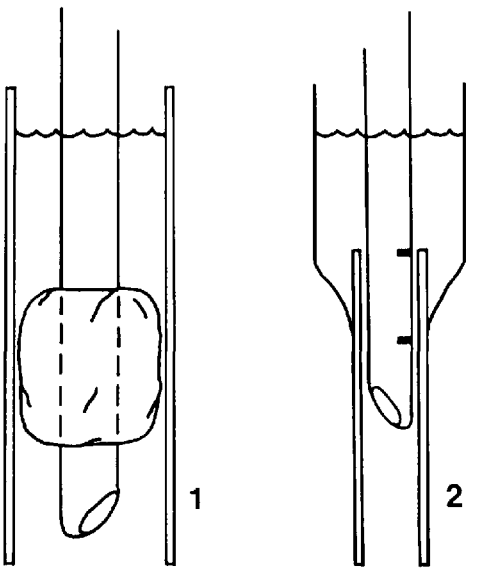

FIGURE 1 Schematic representation of adult model. ETT cuff supports column of indicator-tinted water within simulated trachea.

FIGURE 2 Paediatric model. Uncuffed paediatric ETT projects 2 cm into simulated trachea. Flexible plastic reservoir simulated hypopharynx and contains column of indicator-tinted water.

Results

In the adult model, seepage occurred during MV with PEEP in 3 of 20 (15 per cent) trials. Without PEEP, seepage occurred in 11 of 20 (55 per cent) trials ($p < 0.05$, Table I). All incidents of seepage occurring with PEEP were "minimal," whereas 64

TABLE I Conditions and results of the adult model trials

No. of trials	*Mode of ventilation*	*Peak airway pressure (cm H_2O)*	*PEEP level (cm H_2O)*	*% Showing seepage*	*Average time to seepage (min)*
10	MV	20	5	20	16.5 ± 9.5
10	MV	20	0	60*	8.3 ± 4.5
10	MV	25	5	10	4.0 (n = 1)
10	MV	25	0	50*	6.4 ± 7.8
10	SV	25	5	90	5.9 ± 8.1
10	SV	25	0	100 (NS)	3.8 ± 5.3

*Significantly different from trial *with* PEEP immediately above ($p < 0.05$).
NS = not significantly different from trial *with* PEEP immediately above ($p > 0.05$).

per cent of those leaks without PEEP were "moderate" or "maximal". Average elapsed time before seepage was 21 ± 12 min for trials with PEEP and 7 ± 6.3 min for trials without PEEP ($p < 0.05$).

During mechanical ventilation in the paedatric study, seepage occurred in all ten trials without PEEP, five of ten (50 per cent) with 2.5 cm H_2O PEEP, and none of the trials with 5 cm H_2O PEEP. As PEEP level increased, time to seepage increased and the degree of leak decreased.

Simulated SV in the adult and paediatric models resulted in nearly 100 per cent rates of seepage regardless of use of PEEP. Peak negative proximal airway pressures on inspiration reached an average of −10 and −1 cm H_2O for adult and paediatric models respectively.

Discussion

Undetected aspiration is a widespread phenomenon commonly resulting in delayed and non-specific pulmonary complications.[1–3,7–9,11,12] The high morbidity and mortality rates associated with aspiration underscore the importance of prevention.[6–8,16] Yet numerous attempts to prevent seepage around endotracheal tubes have not been successful.

Our results demonstrate that PEEP may provide some protection against seepage during mechanical ventilation. Compared to trials without PEEP, seepage occurred less frequently, was reduced in amount, and delayed in onset. The positive airway pressure of PEEP appeared to act as a pneumatic valve which allowed outward escape of air but restricted fluid leaks in.

In the adult model, seepage occurred through longitudinal channels formed from invaginations of the cuff wall. Such folding can occur in high-volume, low-pressure cuffs regardless of proper inflation.[5] During the respiratory cycle, lowered intratracheal pressures promoted progressive fluid descent. Intermittently increased airway pressures during mechanical inspiration resulted in upward displacement of the channeled fluid. Additional intratracheal pressure from MV with PEEP further elevated the fluid column.

Our results support the observations by Pavlin[13] and Mehta[2] that negative pressures distal to the cuff during spontaneous ventilation intensify the aspiration problem. Pavlin reported that a higher cuff pressure was needed to prevent aspiration in a spontaneously breathing patient. Comparison of results of MV plus PEEP trials with those of SV plus PEEP reveals the importance of a continuously positive airway pressure. Our SV trials resulted in rates of seepage nine to ten times greater than trials with MV.

It is probably not meaningful to compare our *in vitro* seepage rates with those determined from *in vivo* investigations. Use of an artificial trachea, its vertical orientation, our reduced intracuff pressure, and the low viscosity of the indicator compared to saliva may all favour increased seepage in our model. However, the *relative* PEEP-associated reductions of seepage rates within the different studies can be considered. In this respect, our results differ from the findings of Browning and Graves[12] who demonstrated no benefit from positive pressure ventilation. However, our study does confirm their obvious finding that uncuffed endotracheal tubes bear a higher risk of aspiration compared to those with cuffs.

The use of PEEP, or better CPAP, to reduce

TABLE II Conditions and results of the paediatric model trials

No. of trials	*Mode of ventilation*	*Peak airway pressure (cm H_2O)*	*PEEP level (cm H_2O)*	*% Showing seepage*	*Average time to seepage (min)*
10	MV	20	0	100	1
10	MV	20	2.5	50*	1.6 ± 1.7
10	MV	20	5	0*	—
10	SV	0	5	100	1
10	SV	0	0	100	1

*Significantly different from trials with PEEP = 0.

aspiration may help resolve concern over proper inflation of endotracheal tube cuffs. The intracuff pressure must be high enough to prevent aspiration, yet low enough to ensure adequate blood flow to the tracheal mucosa. In 1975, Pavlin determined that pressures in high-volume, low-pressure cuffs must be 28 to 38 mmHg to stop leaks.[13] Later, Leigh[5] and Nordin[17] advised that cuff pressures should stay below the mean capillary pressure of 20 mmHg. Considering both blood flow and risk of aspiration, Bernhard[4] recommended cuff pressures between 18 and 25 mmHg while Mehta[2] suggested pressures between 15 and 20 mmHg. Perhaps no single cuff pressure can provide both sufficient tissue blood flow and also guarantee absolute protection from aspiration. However, if PEEP and CPAP decrease the risk of aspiration, their use may allow lower cuff pressures, thus improving mucosal blood flow. At the same time, one must be mindful of the potential adverse haemodynamic effects of PEEP.[18,19,20] Future studies should examine clinically optimal cuff pressures to be used during mechanical ventilation with PEEP.

Acknowledgement

The authors thank Ms. Linda Furr for secretarial help in preparation of the manuscript.

References

1 *Spray SB, Zuidema GD, Cameron JL.* Aspiration pneumonia: incidence of aspiration with endotracheal tubes. Am J Surg 1976; 131: 701–3.

2 *Mehta S.* Performance of low pressure cuffs; an experimental evaluation. Ann Roy Coll Surg Eng, 1982; 64: 54–6.

3 *Macrae NJ.* Aspiration around high-volume, low-pressure endotracheal cuff. Br Med J 1981; 283: 1220.

4 *Bernhard WN, Cottrell JE, Sivakumaran C, Patel K, Yost L, Turndorf H.* Adjustment of intracuff pressure to prevent aspiration. Anesthesiology 1979; 50: 363–6.

5 *Leigh JM, Maynard, JP.* Pressure on the tracheal mucosa from cuffed tubes. Br Med J 1979; 1: 1173–4.

6 *LeFrock JL, Clark TS, Davies B, Klainer AS.* Aspiration pneumonia: a ten-year review. Am Surg 1979; 45: 305–9.

7 *Cameron JL, Zuidema GD.* Aspiration pneumonia – magnitude and frequency of the problem. JAMA 1972; 219: 1194–6.

8 *Cameron JL, Mitchel WH, Zuidema GD.* Aspiration pneumonia: clinical outcome following documented aspiration. Arch Surg 1973; 106: 49–52.

9 *Turndorf H, Rodis, ID, Clark TS.* Silent regurgitation during general anesthesia. Anesth Analg 1974; 53: 700–3.

10 *McCleave DJ, Fisher M.* Efficacy of high-volume low-pressure cuffs in preventing aspiration. Anesth Intensive Care 1977; 5: 167–8.

11 *Cameron JL, Reynolds J, Zuidema CD.* Aspiration in patients with tracheostomies. J Surg Gynecol Obstet 1973; 136: 68–70.

12 *Browning DH, Graves SA.* Incidence of aspiration with endotracheal tubes in children. J Ped 1983; 102: 582–4.

13 *Pavlin EG, VanNimwegan D, Hornbein TF.* Failure of a high-compliance low-pressure cuff to prevent aspiration. Anesthesiology 1975; 42: 216–9.

14 *Klain M, Keszler H, Stool S.* Transtracheal high frequency jet ventilation prevents aspiration. Crit Care Med 1983; 11: 170–2.

15 *Cox PM, Schatz EM.* Pressure measurements in endotracheal cuffs: a common error. Chest 1974; 65: 84–7.

16 *Arms RA, Dines DE, Tinstman TC.* Aspiration pneumonia. Chest 1974; 65: 136–9.

17 *Nordin U.* The trachea and cuff-induced tracheal injury. Acta Otolaryngol 1977 (suppl. 345).

18 *Manny J, Grindlinger G, Aleksander AM, Hechtman HB.* Positive end-expiratory pressure, lung stretch, and decreased myocardial contractibility. Surg 1978; 84: 127–33.

19 *Jardin F, Farcot JC, Boisante L, Curien N, Margairaz A, Boudarias JP.* Influence of positive end-expiratory pressure on left ventricular performance. N Engl J Med 1981; 304: 387–92.

20 *MacDonnell KF, Armand AL, Hyung SM, Daniel JD, Johnson RP.* Comparative hemodynamic consequences of inflation hold, PEEP, and interrupted PEEP. Ann Thorac Surg 1975; 19: 552–60.

Résumé

Malgré l'amélioration de la forme du tube endotrachéal, l'aspiration demeure une cause de complication pulmonaire. Cette étude in vitro *évalue l'efficacité de la pression positive en fin d'expiration (PEEP) afin de réduire l'incidence de fuite autour des tubes endotrachéaux pendant la ventilation mécanique et la ventilation spontanée. Deux trachées en plastique transparent avec des tubes endotrachéaux à ballonnets et sans ballonnets ont été pris comme modèle de voies aériennes adultes et d'enfants. Dix essais avec PEEP et dix sans PEEP à des niveaux différents ont été accomplis pour chaque modèle utilisant la ventilation spontanée ou la ventilation mécanique. La ventilation spontanée pour les deux modèles a été associées avec une fuite à chaque fois indépendamment du niveau du PEEP. Lors de la ventilation mécanique sans PEEP la fuite survint dans 55 pour cent des essais adultes et 100 pour cent des essais pédiatriques. En contraste, la ventilation mécanique avec 5 cm H_2O PEEP produit un taux de fuite de 15 pour cent pour le modèle adulte et 0 pour cent pour le modèle pédiatrique. Comparativement aux essais sans PEEP, la fuite survint moins fréquemment, a été réduite en quantité retardée à s'établir. La ventilation mécanique avec PEEP a significativement ($p < 0.05$) diminué l'incidence de fuite autour des tubes endotrachéaux.*