Tracheal Tube Cuffs and Tracheal Dilatation*

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Although tracheal tube cuffs are well known to injure the trachea, attempts to design safer cuff systems have been only partially successful. In 14 dogs, we compared three models of high residual volume, low pressure cuffs, which are considered to be among the safest. Two were air-filled cuffs — a maintained pressure cuff and a balloon reservoir cuff — and the third was foam-filled. Tracheal dilatation was considerably more severe with mechanical ventilation than with spontaneous breathing, but the foam cuff produced significantly less dilatation (p < .005) than the air-filled cuffs.

That tracheal tube cuffs cause tracheal injuries is a well-known phenomenon. The most frequently cited cause is excessive cuff-to-tracheal-wall (c-t) pressure.1-4 Although the critical pressure at which such injuries occur has not been determined, a number of investigators assume it to be approximately 20 mm Hg.5 Undoubtedly, several clinical factors (eg, hypoproteinemia, poor perfusion states, hypoxemia) influence the tissue response.

Various modifications of the tracheal tube cuff have been made to reduce its potential for injury. High residual volume, low pressure (“floppy”) cuffs, when carefully inflated, have been shown to be less injurious than the narrow, low residual volume variety. The designation, low pressure, does not, however, necessarily ensure the same residual volume. Measuring the volumes of “low pressure” cuffs of tubes of similar diameters made by four different manufacturers, we found the residual volumes to range from 6 to 28 ml, depending on the design. Our purpose in this investigation was to compare three types of the high residual volume, low pressure cuffs with respect to extent of injury caused by tracheal overdistilation in each case.

The Reservoir Air Cuff

McGinnis et al6 introduced an automatic or controlled-pressure device that takes advantage of the compliance characteristics of a latex reservoir balloon (the Lanz controlled cuff endotracheal tube made of polyvinyl chloride). Once the stretch point of this balloon is exceeded, the intraballoon pressure remains constant and is not increased by further inflation until it strikes a confining sheath (at approximately 60 ml). McGinnis et al employed this feature with a valve that allowed filling of the cuff either from the balloon (reservoir) or from the inflating syringe (Fig 1). Its mechanism for attempting to minimize if not eliminate tracheal injury was inflation by a constant, low-pressure source.

The Maintained Pressure Air Cuff

Ching et al3 reported on a maintained pressure air cuff that employed an inflation technique which allows the internal pressure in a high residual volume, low-pressure cuff to be measured by manometer. On the basis of these measurements, they recommended that the cuff not be inflated above 20 mm Hg. As we used it, this system was identical to the Lanz controlled pressure endotracheal tube, except that in this case the reservoir system was replaced by a maintained pressure system.

The Foam Cuff

Kamen and Wilkinson7 introduced a high residual volume cuff that is filled with polyurethane foam (the Kamen-Wilkinson Foam-Cuff endotracheal tube, with a silicone cuff sheath and tube). The foam-filled cuff is evacuated through a pilot tube. After insertion, the cuff self-inflates until the expansion is halted by the airway wall. With their original

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design, Kamen and Wilkinson obtained c-t pressures of approximately 5 mm Hg.

Nevertheless, injuries do occur even with high residual volume, low-pressure cuffs. The following case report illustrates such an instance.

**Case Report**

A 52-year-old decerebrate man was admitted to the intensive care unit, with a diagnosis of malignant hypertension with encephalopathy.

A nasotracheal intubation was performed using a 9F endotracheal tube with a reservoir air cuff. Thirty ml of air was introduced into the cuff-reservoir system. Ventilation was controlled by a volume respirator at a respiration rate of 16/min and a tidal volume of 900 to 1100 ml, with a recorded peak pressure of approximately 25 mm Hg. The patient died 22 hours after intubation.

On autopsy, among other findings, the trachea was seen to be moderately distended with gross malacia of the tracheal muscle and adjacent cartilage in the region of the cuff. The tracheal mucosa in the same area showed a slight pallor.

**Materials and Methods**

Fourteen dogs, premedicated with diazepam, 0.5 mg/kg, were studied. Each was anesthetized with 2.5 percent thiopental sodium, to the point of loss of lid reflex. Anesthesia was maintained by a 1 percent thiopental drip.

Three types of high residual volume, low-pressure cuffs were used: two of them air cuffs — the reservoir system and the maintained-pressure system — and the third, a foam cuff.

In nine of the dogs, a double-cuff system (Fig 2) was used to enable them to act as their own controls. Five of the dogs had only a single cuff. The placement of the cuffs is shown in Figure 3.

The residual volume of the air cuffs was 23 ml, and of the foam cuff, about 22 ml (not measuring the foam, which occupies about 2 ml in its compacted state). The residual-volume external diameter of both cuffs was 3.1 cm, while the respective lengths of the foam and air cuffs were about 4 and 4.5 cm. The external diameter of each tube (9F) was 1.3 cm. As recommended by Ching and colleagues, a 20 mm Hg was not exceeded in the maintained pressure cuffs.

The endotracheal tubes were lightly sprayed with compound benzoin tincture and then coated with fine Tantalum dust to allow easy roentgenographic visualization. The dogs were then intubated and the cuffs inflated. Thirty milliliters was used for the initial inflation of the reservoir cuff system, but additional amounts had to be added during the course of the experiment because of leakage through the valve system.

Lateral roentgenograms were taken before and after mechanical ventilation and after spontaneous ventilation (Fig 4).

Seven of the animals were immediately placed on mechanical ventilation. The remainder were allowed to breathe spontaneously for different time periods and then were also placed on a respirator. Mechanical ventilation was maintained for 8 to 26 hours, following which the animals were killed and autopsied.
RESULTS

Volume changes after four hours on mechanical ventilation are shown in Figure 3. None ever returned to residual volume. Although cuff volume changes continued after this arbitrary time, they were comparatively small and considered to be insignificant in every case. The average volume increase was 7.4 ml for the air cuffs and 1.0 ml for the foam cuff. These changes are highly significant ($P < .005$).

Spontaneously breathing animals showed inconsistent volume changes, which were not statistically
significant (Fig 5).

All cuff sites showed tracheal dilatation, but it was more marked in ventilated animals, and less severe in spontaneously breathing dogs. In the ventilated animals, both air cuffs produced significantly more dilatation than did the foam cuff. Figure 6 shows the trachea of a dog with a double cuff.

DISCUSSION

Hitherto, the amount of pressure exerted by a cuff against the tracheal wall has been considered the most important cause of tracheal damage. The role of volume changes has been slighted.

Air Cuffs

In the case of air cuffs, the c-t pressure is that of the intracuff pressure minus the compliance pressure of the cuff. When the cuff is large or floppy, not fully distended, and made of a thin-walled, very pliable material, the intracuff pressure may be assumed to be the c-t pressure. This was the case in the cuffs we tested. If, in low-volume cuffs, the residual volume is easily reached and the cuff suddenly becomes relatively nondistensible (low compliance), much higher intracuff pressures are registered with small additional increments of air. This did not occur in the cuffs we tested: they never reached residual volume in any of the experiments.

Foam Cuff

A different principle obtains for the foam-filled cuff, and pressure must be estimated differently. A negative force is necessary to evacuate the foam. As the cuff is progressively deflated, an increasingly greater negative pressure is required because the elastic force of the foam tending toward re-expansion increases.

This negative pressure becomes positive for that

Figure 5. Volume changes in spontaneously breathing dogs were inconsistent and not statistically significant.

Figure 6. Trachea of dog 5 at autopsy. Foam cuff was placed on the left, air cuff on the right.
portion of it that is external (i.e., that exerted by the trachea). As an example, if a negative pressure of 20 mm Hg is needed to evacuate a cuff to a volume of 6 ml, a mean positive c-t pressure of 20 mm Hg is needed to squeeze out all air to a volume of 6 ml. Consequently, the average c-t pressure can be approximated by determining the volume remaining in the foam cuff after intubation and self-inflation, and then referring to a preplotted chart.

Possible Causes of Tracheal Dilatation

Although the reasons for the results obtained in this study are not known, we postulate the following explanation, which is consistent with the findings. In the spontaneously breathing subjects, intratracheal pressure changes are rather low, with comparatively little tracheal expansion. Therefore, any tracheal dilatation caused by the cuff is a function of the c-t pressure only.

The intratracheal pressure of the ventilated animals were substantially higher (mean, 15 mm Hg), as were the tidal volumes (approximately 40 ml/kg). There was, therefore, considerable tracheal expansion with each inspiratory cycle. Where the c-t pressure was constant (air cuffs), the cuff volume increased to accommodate the greater tracheal diameter. If the air in the cuff could not readily escape during exhalation, the inspiratory cuff volume became fixed. During exhalation, when the tracheal diameter diminished, the cuff volume did not. As a result, the cuff became somewhat distended. This sequence repeated itself with each cycle until the stretch limit of the trachea was reached.

In our experiments, the greater part of tracheal dilatation appeared to occur during the first 30 minutes of ventilation.

The absence of marked tracheal dilatation with the foam cuff may be explained by the foam principle and the manner of use. As with the air cuffs, during the inspiratory cycle with a mechanical ventilator, the increase in tracheal diameter is matched by an increase in cuff diameter (unless the intratracheal pressure is high enough to compress the foam until it causes a leak). This expansion, however, would cause the c-t pressure to fall, for as the foam expands, the pressure it exerts decreases. In other words, the foam cuff does not “chase the trachea.”

Clinical Significance

The clinical significance of this dilatation is not known. One may suppose, however, that if the dilatation is sufficiently prolonged, lack of tone will eventually result, with loss of sealing effectiveness. This, in turn, may account for the reported instances of aspiration in the presence of cuffed tracheostomy tubes. Since the soft portion of the trachea overlies the esophagus, esophageal compression occurs, which may contribute to the incidence of aspiration, difficulty in swallowing, or to ulcerations caused by nasogastric tubes. Further investigations of clinical implications should be done.

Conclusion

All tracheal cuffs appear to cause tracheal dilatation. It is most pronounced with the use of air cuffs in combination with mechanical ventilation. It is greatly minimized with foam cuffs and spontaneous ventilation. Additional observations are needed to better define the clinical significance of the dilatation, since at present it is still not demonstrated.

References


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