Work is needed on the place of such herds in the ecology of campylobacters, the endemicity of the infection within herds, and the factors leading to contamination of milk.

We believe that the evidence points to thermophilic *Campylobacter sp* being an occasional but important contaminant of milk, which, under certain circumstances, may give rise to considerable outbreaks of enteritis in man. As with salmonella contamination it is probably only important where unpasteurised milk is consumed, but so long as there is a public demand for unpasteurised milk and the law allows such milk to be widely distributed, we believe that there is a risk that outbreaks will continue to occur.

We express our gratitude to all concerned in investigating these outbreaks and particularly to the Environmental Health Department, South Lakeland District Council, Cumbria; the Environmental Health Division, City of Bradford Metropolitan Council; and the laboratory staff at Preston and Leeds Public Health Laboratories and the Department of Medical Microbiology, Bradford Royal Infirmary. We also thank Dr M B Skirrow and the laboratory staff at Worcester Royal Infirmary for biotyping the isolates.

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Pressure on the tracheal mucosa from cuffed tubes

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Summary and conclusions

During cuffed intubation, damage to the trachea is least likely when the lateral wall pressure exerted by the cuff does not exceed the mean capillary perfusion pressure of the mucosa. A study was carried out of eight different types of endotracheal tubes. At the seal point the traditional red rubber tube and the armoured latex and Softway tubes exerted pressures above the mean systemic arterial pressure. Although the Portex and Mallinckrodt tubes exerted pressures close to the mean capillary perfusion pressure, much higher pressures resulted if they were overinflated. The Lanz tube, however, with its over-pressure safety balloon, maintained a lateral wall pressure below the mean capillary perfusion pressure even when inflated considerably beyond the seal point.

Endotracheal cuffs are often overinflated in clinical practice. Since cuff-induced tracheal damage is most influenced by the lateral wall pressure, these results suggest that the use of Lanz-type tubes should be mandatory in intensive care units or when a cuffed tracheostomy tube is required and they should also be considered for use in more routine anaesthetic practice.

Introduction

Excessive pressure exerted on the tracheal mucosa is an avoidable factor that has been implicated as a cause of damage after intubation of the trachea with cuffed tubes. The relatively stiff, traditional, low-volume rubber cuff requires a pressure above systolic blood pressure to make it expand to meet the tracheal wall. Part of this pressure is transmitted to the tracheal mucosa once contact has been made. Mucosal damage, cartilaginous necrosis, and eventual tracheal stenosis may result from using such low-volume, high-pressure cuffs. To prevent this several high-volume, low-pressure cuffs have been developed over the past few years, though these are still apt to exert excessive pressure on the tracheal wall when overinflated or when nitrous oxide diffuses into them from an anaesthetic mixture.

To mitigate this a revolutionary principle has been incorporated into the design of the Lanz tube,[1] which has only recently become available in Britain. This new tube has a high-volume, low-pressure cuff but the innovation is that the pilot balloon has a pressure-control valve and is a high-capacity latex structure. Thus any overinflation merely results in an expansion of the latex balloon so that the pressure within the system remains constant. Since in clinical practice all endotracheal cuffs probably tend to be overinflated, we consider this concept to be so important that we have evaluated the Lanz tube against other available equipment both in vitro and in vivo.

Methods

An East Radcliffe ventilator was used to ventilate a BOC model lung via an adult model trachea (National Catheter Corporation). At constant settings of the ventilator and model lung eight different types of No 9 tubes were inserted into the model trachea after lubrication with KY jelly. The following tubes were tested: Portex Blue Line, Kamen-Wilkinson, Lanz, armoured latex, Mallinckrodt, Portex Profile, red rubber, and Softway. The cuff was inflated and the seal point determined with great care. The airway pressure, intracuff pressure, and lateral wall pressure exerted by the cuff on the model trachea were determined at the seal point. The pressures were sensed using Bentley Trantec model 800 transducers: the airway pressure via a T junction; the intracuff pressure via a miniature T junction in the pilot-balloon line; and the lateral wall pressure via a flat balloon inserted between the cuff and the model trachea wall. This balloon had a diameter of 17 mm and maximal thickness (at its centre) of 3 mm. The display and recordings were achieved using a Spacelabs (Novamed Ltd) type 3204 Alpha 9 display unit and model 1060 hot-stylus recorder. In each experiment a constant tidal volume was verified using an electronic Wright respirometer (BOC).

Results

In-vitro studies—Figure 1 summarises the results of the in-vitro experiments. Only the Kamen-Wilkinson tube lies to the left of the

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line of identity, because the pressure exerted by its foam-filled cuff against the tracheal wall exceeded the air pressure within the cuff. Only the Lanz, Mallinckrodt, and Portex Profile tubes exerted lateral wall pressures at or below the mean capillary blood pressure at the seal point. The rest of the tubes grossly exceeded this, and most exceeded the mean arterial pressure. When the Mallinckrodt and Portex Profile tubes were overinflated by 5 and 10 ml the lateral wall pressures exerted by the cuffs increased dramatically. Overinflation of the Lanz tube by 20 and 40 ml of air, however, made virtually no difference to the intracuff and lateral wall pressures—that is, the excess volume was merely taken up by expansion of the pilot balloon.

In-vivo studies—Figure 2 shows in-vivo recordings obtained from two adult patients under clinical conditions during intermittent positive-pressure ventilation with a Cape ventilator. The Lanz tube inflated to 10 ml beyond a clinical seal point was compared with a red rubber tube inflated to the seal point. At comparable airway pressures the intracuff pressures were respectively 19 and 225 mm Hg while the lateral wall pressures were 17 and 87 mm Hg. The lateral wall pressure found with the red rubber tube was lower than in the in-vitro study

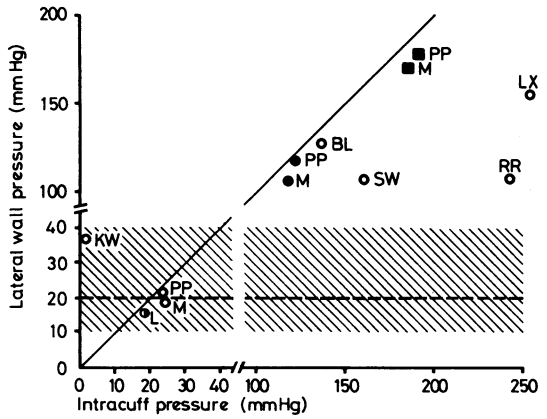

FIG 1—Intracuff pressure plotted against lateral wall pressure during in-vitro evaluation of eight cuffed No 9 tubes. Dashed line represents mean capillary pressure and shaded area theoretical limits of venous capillary pressure.

○=Tubes at seal-point pressure. ●=Tubes inflated 5 ml beyond seal point. ■=Tubes inflated 10 ml beyond seal point. ◑=Lanz tube at seal point and overinflated by 20 and 40 ml.

BL=Portex Blue Line. KW=Kamen-Wilkinson. L=Lanz. LX=Armoured latex. M=Mallinckrodt. PP=Portex Profile. RR=Red rubber. SW=Softway.

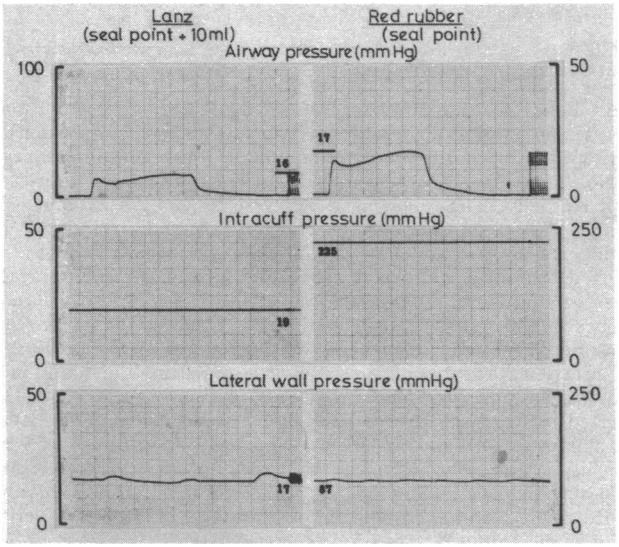

FIG 2—In-vivo recordings made in two adults during intermittent positive-pressure ventilation with a Cape ventilator, comparing Lanz tube inflated to 10 ml beyond clinical seal point with red rubber tube inflated to the seal point. Lateral wall pressure exerted by cuff of Lanz tube remained below mean mucosal capillary pressure, whereas that exerted by red rubber cuff approached mean systemic arterial pressure.

and must reflect the greater compliance of the real trachea. Nevertheless, it was well above mucosal capillary perfusion pressure.

Discussion

To prevent ischaemic damage the cuff should exert a pressure no greater than the capillary perfusion pressure of the mucosa. Although the mean capillary blood pressure is about 20 mm Hg, the venous end of a capillary has a pressure of about 12 mm Hg. Therefore, obstruction of flow will occur when the lateral wall pressure exerted by a cuff on the trachea is greater than this figure. Venous capillary outflow obstruction causes a rise in arteriolar pressure to overcome its effect. The limits of this rise are uncertain for some human tissues, but venous capillary pressure in the tracheal mucosa overlying the cartilages probably cannot exceed 40 mm Hg. In rabbits this figure is 30 mm Hg.[2] Hence the lateral wall pressure exerted by a cuff on the tracheal mucosa should preferably be less than 20 mm Hg and not exceed the upper limits of perfusion pressure. Clearly the red rubber and latex tubes exert unacceptably high lateral wall pressures at the seal point. The low-pressure cuffs tested could also exert pressures of a similar order unless carefully inflated to the seal point—such inflation is difficult to achieve and certainly difficult to maintain under clinical conditions. The Lanz tube, however, with its over-pressure safety balloon, cannot be overinflated under clinical conditions.

The studies of cuff-induced tracheal damage by Nordin and his colleagues are summarised in his monograph.[2] Damage is greatly influenced by the product of the lateral wall pressure and the duration of intubation, of which the pressure has by far the greater importance. Superficial damage to the mucosa occurs within 15 minutes at a lateral wall pressure of 20 mm Hg but is not progressive. At a pressure of 50 mm Hg damage may similarly be detected within 15 minutes and is more extensive with partial denuding of the basement membrane. Within 15 minutes at a pressure of 100 mm Hg the basement membrane begins to disintegrate and the mucosal stroma becomes exposed; and after four hours the damage penetrates virtually down to the cartilage and is accompanied by bacterial invasion. Thus if the lateral wall pressure is kept below 20 mm Hg then the trachea can resist long periods of cuffed intubation. According to our results, only the Lanz cuffed tube could satisfy this basic requirement with certainty under clinical conditions.

Our findings raise questions about routine anaesthetic practice. Should the traditional red rubber tube be abandoned even for short operations in favour of carefully used high-volume, low-pressure tubes? And should a tube fitted with an over-pressure safety balloon such as the Lanz be used for all intubations? Based on figures given by the Office of Health Economics[3] the number of anaesthetics given in hospitals in England and Wales is now about three million per year. Even if only 750 000 of these patients are intubated with cuffed tubes this must represent a risk of damage to each. The answer is likely to be economic so far as routine anaesthetic practice is concerned. The case is quite clear, however, when the patient is in intensive care or needs a cuffed tracheostomy tube. This study shows that the use of a tube of the Lanz type should be mandatory under such circumstances. It would also seem prudent to use such tubes during lengthy surgical procedures and when the airways are already known to be diseased, such as in chronic bronchitis.

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