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Novel System for Complete Removal of Secretions within the Endotracheal Tube

The Mucus Shaver

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THE method normally used to clean endotracheal tubes (ETTs) in intubated patients is *via* a small, flexible, plastic suction catheter. The small-bore tube is inserted into the ETT and manipulated to remove mucus lodged within the ETT and this process is repeated as frequently as indicated.[1] This may not remove all secretions. With residual secretions retained on the surface, the ETT provides a fertile ground for bacterial proliferation and biofilm formation. Bacteria-laden biofilm promotes bacterial colonization of the lower respiratory tract and development of ventilator-associated pneumonia.[2] Moreover, any mucus accumulated within the ETT decreases its internal diameter,[3] increasing resistance to airflow and work of breathing.[4]

To overcome this problem, we devised the Mucus Shaver (National Institutes of Health, Bethesda, Maryland).‡ In one sweep, the Mucus Shaver removes all mucus from the lumen of the ETT, restoring the appearance of the lumen to that of a new, unused ETT.

Materials and Methods

This protocol was approved by the animal care and use committee of the National Institutes of Health.[5] To a 3.0-mm-OD, 2.0-mm-ID, 28-cm-long plastic tube (Hytrel®; E.I. DuPont, Wilmington, DE), we attached a 2-cm-long, one-piece, injection-molded silicone rubber (GE SE-4524) tube (ID, 3.5 mm; OD, 4.5 mm) (inflatable balloon) with two or more 1.0-mm-wide, 0.5-mm-thick silicone rubber "shaving rings" (fig. 1). For safety, we incorporated a radiopaque, stainless steel bead attached to a fine, braided stainless steel wire into the distal end. We used the wire to facilitate retrieval in the unlikely event that tearing, adhesive failure, or misuse caused loss of the inflatable Mucus Shaver.

To remove mucus, the balloon is inflated sufficiently to force the two shaving rings firmly against the wall of the ETT. The volume of air needed to inflate the balloon was determined from *in vitro* measurements; this depended on the size of the ETT, the silicone polymer, and the length of tubing used to inflate the balloon. For example, approximately 8 ml was used for an 8-mm-ID ETT. The shaft of the Mucus Shaver is supplied with an adjustable ring (not shown) that marks the depth to which the device can be advanced, that is, to the tip of the ETT or just beyond. When inflated, the Mucus Shaver is gently retrieved during a period of 3 to 5 s, followed by resumption of ventilation. In experimental animals, we immersed the Mucus Shaver sequentially into three graduated cylinders filled with aqueous antiseptic: the first to dislodge secretions, the second for rinsing, and the third to await reuse.

To explore the possible benefits of the Mucus Shaver, we conducted a study in eight anesthetized, paralyzed, adult female Dorset sheep (weight, 38.5 ± 2.0 kg) intubated with a standard 8-mm-ID ETT and mechanically ventilated for 72 h. Preparation of the sheep, measurement of physiologic parameters, mechanical ventilator settings, euthanasia, and autopsy were administered and monitored as previously described.[6]

Study Group

The study group included six sheep. Every 6 h, after routine suctioning, the Mucus Shaver was introduced through the connector piece of the ETT until its tip reached just beyond the end of the ETT. The balloon was then inflated with a 12-ml syringe (or connected to a reservoir of air at preset pressure) so that the shaving rings made contact with the lumen of the ETT (see second paragraph under Materials and Methods). The Mucus Shaver was then gently pulled out of the ETT during a period of 3 to 5 s, removing the remaining accumulated mucus from the lumen of the ETT.

Control Group

The control group included two sheep. Every 6 h or as needed, we performed routine suctioning of the trachea and ETT in a conventional manner. At the time of extubation and after autopsy, we examined the ETT and

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‡ Patent applied for by National Institutes of Health, on February 5, 2004, application number 10/773,570.

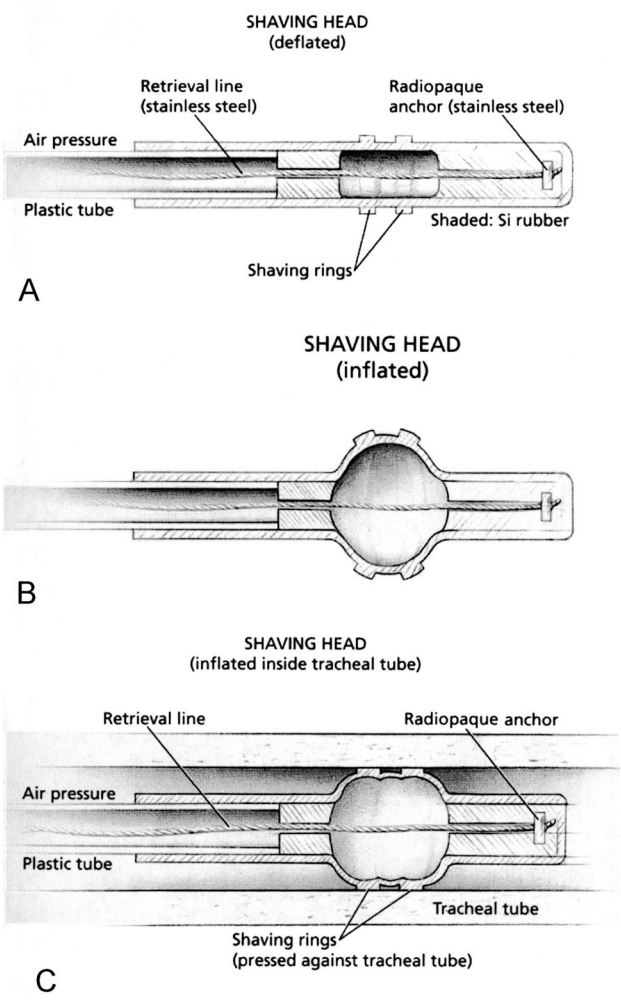

Fig. 1. (*A*) Schematic of the Mucus Shaver. (*B*) Mucus Shaver inflated. (*C*) Mucus Shaver inflated after being introduced into an endotracheal tube. *Shaded areas* = silicone rubber.

visually inspected the lumen. We removed a 1-cm section of ETT just proximal to the tip and studied the surface with scanning electron microscopy.

Results

No technical difficulties were encountered while using the Mucus Shaver. After using the device, the ETT was free of visible secretions. The force needed to pull the Mucus Shaver from within the ETT ranged from 170 to 310 g.

An average of 0.35 ± 0.29 g mucus was retrieved with each use. The peak inspiratory pressure during the course of the study in the Mucus Shaver group was lower (mean, 18.7 ± 1.39 cm H_2O) than that in the control group (mean, 21.4 ± 1.91 cm H_2O). In the study group, scanning electron microscopy of the internal lumen of the ETT showed no biofilm or proteinaceous material; in the control group, there was extensive biofilm formation (fig. 2).

Discussion

The Mucus Shaver was easy to use and effective in removing secretions from the ETT lumen. Inspection of the lumen of the ETT revealed no visible secretions. In laboratory studies, we reused a single Mucus Shaver many times and with no decrease in apparent efficacy. We noted no damage to the device with repeated use.

In the clinical setting, a new Mucus Shaver can be used one time and then discarded. The Mucus Shaver is limited to cleaning the ETT, and deep suctioning of the trachea in the conventional manner may also be re-

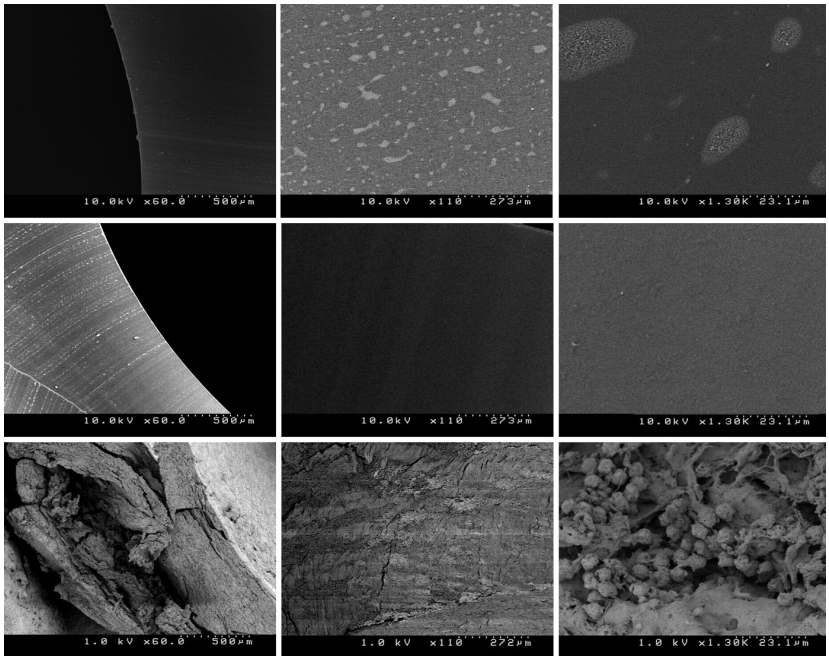

Fig. 2. (*Top row*) Scanning electron microscopy image of standard endotracheal tube (ETT) and using the Mucus Shaver after 72 h of mechanical ventilation. Note absence of bacteria. (*Middle row*) Scanning electron microscopy image of a new vinyl ETT, as received. (*Bottom row*) Scanning electron microscopy image of a standard ETT after 72 h of mechanical ventilation and standard ETT suctioning. Note confluence of erythrocytes and bacteria at highest magnification. (*Left column*) Oblique scanning of cut edges in ETT, ×60. (*Middle column*) Surface of ETT, ×110. (*Right column*) Surface of ETT, ×1,300.

quired. However, when the orientation of the ETT and trachea is maintained below horizontal (*e.g.*, in sheep and presumably also in humans, lying prone, or in either the right or the left semilateral position), we have found no need for deep tracheal suctioning.[6] Presumably, the benefit of the Mucus Shaver will be to limit the ETT of biofilm, to prevent possible distal aerosolization into the lungs, and to prevent increased resistance to inspiratory/expiratory gas flow. The simplicity of this design has allowed us to devise a Mucus Shaver suitable for many different-sized ETT. However, laboratory animal experience with a smaller, pediatric/neonatal-size Mucus Shaver is still lacking. Preliminary clinical results (Milan, Italy) in patients intubated and mechanically ventilated for up to 7 days indicate the device is effective (personal communication, Lorenzo Berra, M.D., Resident, Department of Anesthesia and Intensive Care, University of Milan, Milan, Italy, September 2004).

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