Effects of Suctioning on Mucociliary Transport*

Jose F. Landa, M.D., F.C.C.P.; Mark A. Kwoka, M.D.; Gillette A. Chapman, M.D.; Miguel Brito, M.D.; and Marvin A. Sackner, M.D., F.C.C.P.

We previously have shown that the mucosa of the airways is injured after suctioning, but the effect of this damage on mucus transport has not been systematically investigated. We measured bronchial mucus velocity of conscious sheep after tracheostomy and bronchial mucous velocity after suctioning the bronchi with three different catheters (Bard side end-hole, Aero-Flo, and Tri-Flo catheters). Tracheostomy in sheep produced a significant depression of right and left bronchial mucus velocity three hours after surgery, but at 24 hours, this measurement returned to baseline and remained at this value seven to ten days later. Interrupted suction in a preselected bronchus every ten minutes for three hours after insertion in anesthetized dogs. Mucus transport might be preserved with less severe injury resulting from tracheobronchial instrumentation, despite histologic evidence of mucosal damage. The purpose of the present investigation was to ascertain whether suctioning procedures to the tracheobronchial tree would affect mucus transport.

**MATERIALS AND METHODS**

**Material and Preparation**

Thirteen female sheep, weighing from 24 to 45 kg, were selected. A tracheostomy was used to gain access into the tracheobronchial tree. The animals were placed into a modified metal shopping cart, and a metal sling was used to restrain the head. The eyes were occluded by a blinder to minimize apprehension. The shopping cart was tilted to permit exposure of the neck. The skin was shaved and scrubbed with a povidone-iodine solution (Betadine). Local anesthesia was achieved with a 1 percent solution of lidocaine. A vertical incision was made midway between the angle of the jaw and the sternal notch. The trachea was exposed, and part of the fourth or fifth cartilage was removed so that a plastic, fenestrated tracheotomy tube (Shiley No. 6) could be inserted. The orifice of the tube was occluded at all times except during the suctioning procedures, in order to permit the animal to breathe naturally. The cuff was inflated only for one hour after tracheostomy.

**Bronchial Mucus Velocity**

Bronchial mucus velocity was determined by a modification of a roentgenographic method previously described. Teflon was rendered radiopaque by mixing with 50 percent reagent-grade bismuth trioxide powder and was compressed into eight sheep caused significant decreases in bronchial mucus velocity at 3, 6, and 24 hours when the Bard catheter was employed but much less of a fall with the Aero-Flo catheter. Interrupted suction for six hours in five sheep produced less of a decrease in bronchial mucus velocity at six hours for the Aero-Flo catheter than for the Tri-Flo catheter. We conclude that suctioning catheters with tips designed to minimize mucosal contact are less injurious to mucus transport than conventional side end-hole suctioning catheters and that the Aero-Flo tip is superior in design to the Tri-Flo tip, which also incorporates features to minimize damage to the mucosa of the airways.

Although prolonged endotracheal intubation has been used since the early 1940s, the trauma to the mucosa which produces erosions, ulcerations, tracheal stenosis, and tracheomalacia has only been well recognized in the last decade. The vulnerability of the tracheobronchial mucosa to minimal trauma was emphasized by Hilding and Hilding, who reported extensive desquamation of the mucosa after light rubbing of the airway's mucosa with gauze and cotton swabs. Our laboratory has reported that suctioning catheters employed to aspirate secretions from the airway cause mucosal denudation, edema, and inflammatory exudates due to invagination of the mucosa into the holes of the catheter(s). The occurrence of such lesions is minimized by an improved design of the suctioning catheter to prevent contact of the holes of the catheter with the mucosa of the airways. In the Aero-Flo catheter, this is accomplished by an expanded tip on the catheter, with four small holes located immediately proximal to the tip.

The occurrence of mucociliary dysfunction probably depends on the severity and extent of mucosal damage; for example, inflated cuffed endotracheal tubes depress tracheal mucus velocity one hour

*From the Division of Pulmonary Disease, Department of Internal Medicine, Mount Sinai Medical Center, Miami Beach, FL.
Supported in part by grant HL-17816 from the National Heart, Lung, and Blood Institute and by Sherwood Medical Corp.
Reprint requests: Dr. Landa, Mount Sinai Medical Center, 4300 Alton Road, Miami Beach 33104

202 LANDA ET AL

CHEST, 77: 2, FEBRUARY, 1980
into tape 0.64 cm wide and 0.08 cm thick (Chemplast, Inc.). Disks 1 mm in diameter and 0.8 mm thick were manufactured with a hand-operated punch and were blown through the inner channel of a fiberoptic bronchoscope onto the bronchial mucosa. The bronchus containing the disks was visualized in the lateral projection with a television monitor (Conrac Corp.) connected to a portable image-intensifier unit (Toshiba Surgical X-Ray Television Unit SXT6). The motion of the disks was recorded on videotape (International Video Corp) while time from a digital clock (Vicon Industries) was also displayed.

One centimeter lengths of radiopaque Teflon tape were placed on the skin of the right and left hemithoraces overlying the bronchi. The mean of the two lengths of tape on the videotape image was used as the reference distance, in order to allow for the magnification by the fluoroscopic image-intensifier. A test for validity of this procedure was accomplished by placing a length of radiopaque tape within the bronchus and comparing this measurement to the value obtained by the calibration procedure. The agreement between the two methods was within 1 percent of the length of tape. The velocity of the disks was computed from the videotape by measuring distance traveled over 30 to 60 seconds at the position of functional residual capacity. Bronchial mucus velocity was calculated from the average of the velocities of 15 to 25 individual disks.

Procedure

In the first set of experiments, we set out to study the effects of tracheostomy on bronchial mucus velocity. Measurements were obtained in eight animals the morning immediately prior to tracheostomy and at 3, 24, and 30 hours and seven to ten days later.

In the second set of experiments (same eight animals), the effects of suctioning on bronchial mucus velocity of a No. 14F side end-hole suctioning catheter (Bard Inc.) were compared to a No. 14F beaded suctioning catheter (Aero-Flo; Argyle Division, Sherwood Medical) (Fig 1).

One of the two suctioning catheters was selected at random. It was inserted into the tracheostomy tube with a fiberoptic bronchoscope (Medi-Tech FO/2.5/83) within it, so that the suctioning catheter could be placed in a predetermined right or left main bronchus under direct visual observation. Between procedures and in order to minimize manipulation, the suctioning catheter was secured with adhesive tape to avoid displacement, and its position was checked immediately prior to each suctioning procedure with the fiberoptic bronchoscope.

The suctioning catheters were connected to a vacuum source in which 100 mm Hg of negative pressure was repetitively applied by occluding the proximal vacuum regulator of the catheter intermittently and advancing and retracting the catheter as in a clinical situation. This procedure was repeated every ten minutes for three hours. Bronchial mucus velocities were estimated prior to suctioning, at the end of suctioning, and 3 and 24 hours later in both the suctioned and nonsuctioned bronchi. After carrying out suctioning with one of the catheters, the sheep were allowed to recover for at least one week. The catheter to be compared was then inserted in the contralateral bronchus, and the procedure was repeated.

In the third set of experiments (five animals), the effects on bronchial mucus velocity of a Tri-Flo suctioning catheter (Pharmaseal, Inc) (Fig 1) were compared to the Aero-Flo suctioning catheter. A procedure similar to the one used for comparison of the Bard side end-hole catheter with the Aero-Flo catheter was followed. Interrupted suctioning was applied every ten minutes for six hours. Measurements of bronchial mucus velocity were estimated prior to the beginning of suctioning, at the end of the six hours of suctioning, and at 24 hours.

Statistical Analysis

An analysis of variance was performed as a two-factor (procedure; time of measurement) experiment, with repeated measurements on one factor (time). To test the null hypothesis of no difference between procedures, a pairwise comparison was made of the treatments at each level of the time factor using Duncan's new multiple range test.

Results

Right vs Left Main Bronchi

All baseline observations of bronchial mucus velocity (prior to tracheostomy) for the 13 sheep studied are shown in Figure 2. All but one of these values fell within 25 percent of the line of identity.

Figure 1. A, No. 14F Tri-Flo suctioning catheter. B, Bard No. 14F side end-hole suctioning catheter. C, No. 14F Aero-Flo suctioning catheter.
Effect of Tracheostomy

Baseline mean bronchial mucus velocity prior to tracheostomy was 12.5 mm/min in the right main bronchus and 12.7 mm/min for the left (Table 1). At three hours after tracheostomy, the average bronchial mucus velocity decreased to 8.2 mm/min in the right and to 7.2 mm/min in the left bronchus, a fall of approximately 38 percent (P < 0.05). At 24 hours, bronchial mucus transport had returned to baseline values and remained unchanged seven to ten days later. There were no significant differences between mucus velocities of the right and the left bronchus at any time during the experiment.

Bard vs Aero-Flo Catheters

Compared to the baseline and the nonsuctioned bronchus values, there was a significant fall in bronchial mucus velocity at the end of suctioning and at 6 and 24 hours after initiating suctioning when the Bard side end-hole catheter was employed (P <

Table 1—Tracheostomy and Bronchial Mucus Velocity in Right and Left Main Bronchi

<table>
<thead>
<tr>
<th>Time after Tracheostomy</th>
<th>Bronchial Mucus Velocity, mm/min*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Right Bronchus</td>
</tr>
<tr>
<td>Baseline</td>
<td>12.5±3.6</td>
</tr>
<tr>
<td>3 hr</td>
<td>8.2±4.5**</td>
</tr>
<tr>
<td>24 hr</td>
<td>13.5±4.5</td>
</tr>
<tr>
<td>30 hr</td>
<td>12.8±3.9</td>
</tr>
<tr>
<td>7-10 days</td>
<td>14.2±4.1</td>
</tr>
</tbody>
</table>

*Mean ± SD.  
**P<0.05, compared to baseline.

Table 2—Bronchial Mucus Velocity after Suctioning

<table>
<thead>
<tr>
<th>Group</th>
<th>0 hr</th>
<th>3 hr</th>
<th>6 hr</th>
<th>24 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 2**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aero-Flo catheter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control bronchus</td>
<td>14.3±5.1</td>
<td>13.3±5.9</td>
<td>13.2±4.6</td>
<td>14.5±3.7</td>
</tr>
<tr>
<td>Suctioned bronchus</td>
<td>13.1±4.0</td>
<td>8.7±3.8†</td>
<td>9.3±3.9†</td>
<td>12.5±3.2</td>
</tr>
<tr>
<td>Bard side end-hole catheter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control bronchus</td>
<td>15.0±4.2</td>
<td>14.3±3.9</td>
<td>13.3±4.5</td>
<td>14.2±3.8</td>
</tr>
<tr>
<td>Suctioned bronchus</td>
<td>15.9±4.3</td>
<td>6.0±2.7‡</td>
<td>6.9±2.7‡</td>
<td>9.6±4.4‡</td>
</tr>
<tr>
<td>Experiment 3§</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aero-Flo catheter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control bronchus</td>
<td>13.2±2.3</td>
<td></td>
<td>12.3±3.2</td>
<td>15.6±4.5</td>
</tr>
<tr>
<td>Suctioned bronchus</td>
<td>14.6±1.9</td>
<td></td>
<td>11.4±3.2†</td>
<td>14.5±4.9</td>
</tr>
<tr>
<td>Tri-Flo catheter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control bronchus</td>
<td>15.0±2.8</td>
<td></td>
<td>13.1±3.0</td>
<td>14.6±3.8</td>
</tr>
<tr>
<td>Suctioned bronchus</td>
<td>14.6±4.8</td>
<td></td>
<td>7.6±2.4†</td>
<td>11.5±0.8</td>
</tr>
</tbody>
</table>

*Mean ± SD. Times are hours after starting suctioning.  
†P<0.001, compared to baseline.  
**Eight sheep.  
†P<0.05, compared to baseline.  
§Five sheep.

204 LANDA ET AL  CHEST, 77: 2, FEBRUARY, 1980
ing that the nonsuctioned bronchus was related to the suctioned bronchus by multiplying the bronchial mucus velocity of the suctioned bronchus at a given time by the product of the bronchial mucus velocity of the nonsuctioned bronchus over the baseline value of bronchial mucus velocity of the nonsuctioned bronchus. The data thus obtained are shown in Figure 4. At all points of measurement after suctioning, the depressant effect on bronchial mucus velocity associated with the Aero-Flo catheter was significantly less than with the Bard side end-hole catheter (P < 0.05).

**Tri-Flo vs Aero-Flo Catheters**

Compared to the baseline values, there were significant falls in bronchial mucus velocity of 48 percent for the Tri-Flo catheter and of 22 percent for the Aero-Flo catheter at the end of the six-hour suctioning period (P < 0.05) (Table 2). There was a return to baseline for both catheters 24 hours after initiating suctioning. Normalizing the values of mucus velocity to the nonsuctioned bronchus as described herein revealed that the Aero-Flo catheter had a less depressant effect on mucus transport at six hours compared to the Tri-Flo catheter (P < 0.05) (Fig 5).

**Discussion**

Various types of tracheostomy cannulae have been used in sheep. We used a fenestrated tracheostomy tube that could be occluded while not making measurements, so that the animal could breathe through the nasopharynx. The main purpose of tracheostomy was to facilitate access to the tracheobronchial tree of the sheep during suctioning. It also avoided the potential effects of suctioning attempts producing irritation of the nasal mucosa and larynx, which might affect bronchial mucus velocity. Another advantage of using a fenestrated tracheostomy tube is that it avoids the deleterious effects of low humidity, which injures the tracheal mucosa.

Extensive histologic studies of the deleterious effects of tracheostomy on the tracheal mucosa have

---

**Figure 3.** Changes in bronchial mucus velocity produced by suctioning with Aero-Flo and Bard side end-hole suctioning catheters at 3, 6, and 24 hours. Values depicted are mean ± SD.

**Figure 4.** Changes in bronchial mucus velocity produced by Aero-Flo catheter, compared to Bard side end-hole catheter. Values for suctioned bronchus are normalized to nonsuctioned bronchus.

**Figure 5.** Changes in bronchial mucous velocity produced by Aero-Flo catheter, compared to Tri-Flo catheter. Values for suctioned bronchus are normalized to nonsuctioned bronchus.
been obtained in subjects requiring therapy with mechanical ventilation and have focused primarily on morphologic considerations, representing, in fact, the results of cuff inflation and pressures required to maintain a seal with appropriate ventilation.\textsuperscript{1,12-14} We measured bronchial mucus velocity to determine the functional consequences of tracheostomy in airways distal to the site of surgery. Bronchial mucus velocity decreased to 38 percent of baseline values at three hours, returned to baseline by 24 hours, and remained near baseline one week to ten days later (Table 1). This decrease might have been related to disruption of normal patterns of transport as a result of the surgical incision or the aspiration of small amounts of blood which may have occurred during surgery. In order to minimize the latter possibility, the cuff was inflated with a minimal amount of air (2 to 3 ml) and was left inflated for one hour to prevent further aspiration of blood immediately after the tube had been inserted. Sackner et al\textsuperscript{4} found a decrease of 26 percent in tracheal mucus velocity in anesthetized dogs one hour after inflation of the cuff. These investigators\textsuperscript{4} attributed the slowing to damping of mucus or possibly to a neurogenic reflex due to mechanical contact. Therefore, part of the fall in bronchial mucus velocity which transiently occurred after tracheostomy might have been due to pressure on the tracheal walls by the inflated cuff. The effects of tracheostomy itself are transient and do not play a long-term role in the depression of mucus transport.

In 1956, Plum and Dunning\textsuperscript{15} reported that uninterrupted vacuum during tracheobronchial suctioning might lead to severe mucosal trauma. Amikam et al\textsuperscript{9} conducted a prospective fiberoptic bronchoscopic study of tracheobronchial damage associated with prolonged endotracheal intubation and reported areas of hemorrhage and erosion distal to the tip of the endotracheal tube in both the trachea and right bronchus within hours of intubation. Since straight suctioning catheters invariably enter the right bronchus,\textsuperscript{16} Amikam et al\textsuperscript{9} concluded that the location of lesions was consistent with damage by the suctioning catheter, as reported by Plum and Dunning.\textsuperscript{15} In 1973, Sackner et al\textsuperscript{12} investigated the pathogenesis and prevention of these previously reported mucosal hemorrhages and erosions. Interrupted suctioning was applied to the tracheobronchial tree of anesthetized dogs using conventional, commercially available side end-hole catheters and a newly designed Aero-Flo suctioning catheter. Histologic examination of the tracheobronchial mucosa of the animals suctioned with conventional side end-hole catheters showed varying degrees of mucosal denudation and edema of the lamina propria, extra-
EFFECTS

Plan to attend the

INTERNATIONAL CONFERENCE ON BYSSINOSIS

April 14-16, 1980

Birmingham Hyatt House
Birmingham, Alabama

Scientific Program Chairmen: Hans Weill, M.D., FCCP
Richard Schilling, M.D.

For further information, please contact Department of Education, AMERICAN COLLEGE OF CHEST PHYSICIANS, 911 Busse Highway, Park Ridge, IL 60068 (312) 698-2200