Failure of a High-Compliance Low-pressure Cuff to Prevent Aspiration

E. G. PAVLIN, M.D.,* D. VANIMWEGAN, M.D.,† T. F. HORNEIN, M.D.‡

Tracheal intubation with a cuffed tube permits effective positive-pressure ventilation and protects the lungs from aspiration. Ulceration of the tracheal wall, occasionally with hemorrhage or perforation, can occur with time when cuffs are inflated so that appreciable pressure is applied to surrounding tissues.¹ ² Tubes sheathed with high-volume cuffs have been recently introduced. With these cuffs a seal can be created at low internal cuff pressures, minimizing the pressure that can be transmitted to tracheal mucosa.² The following case report and supporting experimental observations indicate that large-volume cuffs, while affording an effective seal for positive-pressure ventilation, may not protect against aspiration in the spontaneously breathing patient.

REPORT OF A CASE

A 43-year-old Indian woman with a long, flamboyant history of alcoholism underwent operation for bleeding esophageal varices. A portacaval shunt was performed. Postoperatively the patient continued to vomit blood and started to bleed copiously from her nose as well. She was somewhat obtunded, with a depressed gag reflex. When blood was aspirated from the trachea, the trachea was intubated with a 9.0-mm I.D. Lanz endotracheal tube. This tube had a high-volume, high-compliance cuff which was inflated as recommended by the manufacturer so that the pilot balloon was approximately two thirds full, yielding a balloon cuff pressure of approximately 20 cm H₂O. The patient was allowed to breathe spontaneously. Large amounts of blood continued to be suctioned from the endotracheal tube until the cuff was further inflated to pressures greater than 30 cm H₂O, whereupon the ability to retrieve blood upon suctioning ceased. With deflation of the cuff to recommended pressures, blood was again obtainable by endotracheal suctioning. Positive-pressure ventilation at recommended cuff inflation pressures also prevented the appearance of blood in the trachea.

The tube was replaced by a standard #9.0 Portex tube with a low-volume, high-pressure cuff. The bleeding was brought under control, and the trachea was extubated on the fifth postoperative day.

METHODS

Sizes #6 and #9 Lanz endotracheal tubes with large-volume cuffs were inserted into various models of the trachea, including excised dog tracheas of 20- and 30-mm diameter, as well as a glass cylinder of 20-mm diameter. Cuffs were inflated as recommended by the manufacturer and intra-cuff pressures were continuously monitored with a water manometer. Leakage of...
heparinized blood from a dog was measured for each combination of tube size and trachea model. Use of a glass cylinder allowed observation and photographing of any leak past the cuff (fig. 1). In one experiment using the glass cylinder with a #9 endotracheal tube, 10 cm H₂O negative pressure was applied distal to the cuff. Two other types of high-compliance cuffed tubes (Portex and American Hospital Supply) were studied in a similar way.

**RESULTS**

Significant leakage of blood past a cuff of this design can occur (fig. 1, table 1). The leak is minimized when the endotracheal tube size is small relative to the size of the trachea. The leak can also be eliminated simply by overfilling the cuff to pressures in excess of 50 cm H₂O. Although the rate of leakage is a function of the hydrostatic gradient across the cuff, the resistance to leak is so low that flow occurred even when there was virtually no pressure head (fig. 2). The calculated conductance for blood was approximately 1.8 cm/min/cm H₂O for the #9 tube in the glass conduit.

Blood passes readily through channels formed by invaginations of the cuff because the inflated diameter of the cuff appreciably exceeds that of the tube into which it is

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**FIG. 1 (left).** Lanz endotracheal tube of 9-mm I.D. with a high-volume low-pressure cuff inflated to 20 cm H₂O in a 20-mm I.D. glass cylinder. Blood in glass cylinder 5 cm above the top of the cuff immediately starts pouring through involutions in the cuff.

**FIG. 2 (right).** Three minutes after the start of the experiment, 8 ml have passed the cuff. Involutions continue to empty blood, indicating their patency even when there is no head of pressure above the cuff.
TABLE 1. Rate of Leakage of Blood Past a High-volume Cuffed Endotracheal Tube with Intra-cuff Pressure = 20 cm H₂O

<table>
<thead>
<tr>
<th>Tube Size</th>
<th>Rate of Leak at a Mean Pressure of 4 cm H₂O Blood above Top of Cuff</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Excised Dog Trachea 20 mm Diameter</td>
</tr>
<tr>
<td>Lanz #6</td>
<td>0 trace</td>
</tr>
<tr>
<td>Lanz #9</td>
<td>trace</td>
</tr>
<tr>
<td>Lanz #9 with negative pressure distal to cuff</td>
<td>trace</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Rate of leak at a mean pressure of 1 cm H₂O blood above top of cuff = 1.7 ml/min.
† Negative pressure (~10 cm H₂O) applied distal to cuff to simulate spontaneous inspiration against a closed airway.

TABLE 2. Rate of Leak of Heparinized Dog’s Blood Past a Low-pressure Cuff with 1 cm H₂O Blood above the Top of the Cuff and with Intra-cuff Pressure = 20 cm H₂O

<table>
<thead>
<tr>
<th>Tube</th>
<th>Excised Dog Trachea 20 mm Diameter</th>
<th>Glass Tube 20 mm Diameter</th>
<th>Cuff Pressure Necessary to Stop Leak Completely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanz #9</td>
<td>2.1 ml/min</td>
<td>1.7 ml/min</td>
<td>52 cm H₂O</td>
</tr>
<tr>
<td>Lanz #6</td>
<td>Trace</td>
<td>Trace</td>
<td>128 cm H₂O</td>
</tr>
<tr>
<td>Portex #9</td>
<td>10.8 ml/min</td>
<td>23.0 ml/min</td>
<td>117 cm H₂O</td>
</tr>
<tr>
<td>Portex #8</td>
<td>13.2 ml/min</td>
<td>7.3 ml/min</td>
<td>123 cm H₂O</td>
</tr>
<tr>
<td>Portex #7</td>
<td>4.5 ml/min</td>
<td>11.3 ml/min</td>
<td>123 cm H₂O</td>
</tr>
<tr>
<td>American Hospital Supply #9</td>
<td>0.4 ml/min</td>
<td>0.5 ml/min</td>
<td>42 cm H₂O</td>
</tr>
<tr>
<td>American Hospital Supply #8</td>
<td>0.4 ml/min</td>
<td>0.4 ml/min</td>
<td>58 cm H₂O</td>
</tr>
</tbody>
</table>

placed (fig. 2). When inflated cuff diameter approximates tracheal diameter (e.g., the #6 in a 20-mm I.D. trachea or the #9 in a 30-mm I.D. trachea), no infoldings occur and leaks are minimized. Also, if the cuff is inflated to high pressures sufficient to compress the channels, leaks will cease. Sustaining such pressures in patients during long-term ventilatory support would result in tissue necrosis,\textsuperscript{1,2} while matching of cuff size precisely to the unknown caliber of the trachea is impractical.

The cuff diameter/tracheal diameter ratio of the Portex tube is smaller than that of the Lanz tube, and hence fewer infoldings are formed. However, because the cuff material is both thicker and less pliable, the internal diameters of the invaginations are larger and hence are associated with larger leaks, requiring higher cuff pressures to eliminate them. The cuff pressure required to stop leakage was about twice as high for the Portex tube as for the Lanz model (table 2).

The American Hospital Supply tubes have a cuff made of a thin pliable material that formed involution on inflation in our tracheal models but showed lower rates of leak (table 2). The invaginations formed were collapsed by the cuff pressure, and hence leakage was less.

When these tests were repeated using water instead of blood, the rate of leak was increased approximately two to three times for all tubes and tracheal models. One might presume that the lesser viscosity of gastric fluid compared with blood would result in a greater rate of leakage.

In our patient, placement of a 9.0-mm Lanz tube into a trachea with an estimated diameter of 17–20 mm should be closely emulated by the data shown for the 9.0-mm Lanz tube in a 20-mm dog trachea or glass tube (table 1). Negative pressure distal to the cuff during spontaneous inhalation enhances the leak. Continuous positive-pressure ventilation prevents leaks, as was observed in our pa-
tient. However, if a patient were breathing asynchronously with a ventilator, large pressure gradients could be generated and leaks might be enhanced. To minimize aspiration in this patient while she was breathing spontaneously, the cuff had to be hyper-inflated, increasing the hazard of underlying tissue necrosis.

In summary, we have observed that high-volume, low-pressure tracheal cuffs properly inflated may not prevent aspiration of oropharyngeal contents if the net hydrostatic gradient is appropriate for lungward migration of fluid. Characteristics of cuff design contributing to this problem are an overly large cuff diameter relative to tracheal diameter, producing invaginations in the cuff, and cuff materials so stiff and thick that the invaginations formed do not collapse from the cuff pressure surrounding them. Patients particularly at risk are those whose tracheas are intubated while they are breathing spontaneously or are breathing asynchronously with a ventilator, creating a negative pressure distal to the cuff. What is apparently needed is a smaller-diameter high-compliance cuff that will fill the trachea at low inflation pressures without invaginations.

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REFERENCES

Percutaneous Radial-artery Cannulation—Increased Safety Using Teflon Catheters

ROBERT F. BEDFORD, M.D., MAJOR, M.C.*

Percutaneous cannulation of a radial artery is now a commonplace procedure attended by minimal risk. The most common complications are occlusion of the artery and the formation of emboli, both of which result from the deposition of thrombotic material on the cannula while in situ. While it has been shown that the frequency of thromboembolic complications increases with the duration of cannulation,1,2 there have been no studies evaluating the incidences of these complications when catheters made of different materials are used. The purpose of this study was to evaluate, prospectively, the incidence of radial-artery thrombus formation following a standard 24-hour period of cannulation, using both Teflon† and polypropylene catheters.

METHODS AND MATERIALS

Twenty consecutive patients, ranging in age from 21 to 80 years (mean 54 years), underwent percutaneous cannulation of a radial artery as previously described2 for monitoring during and after major surgical procedures. At the preoperative visit, the patients were

* Chief, Anesthesia Service, U.S. Walter Army Hospital, Fort Dix, N.J. 08640. Present address: Department of Anesthesia, Mary Imogene Bassett Hospital, Cooperstown, New York 13326.

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