A STUDY OF INTRACUFF PRESSURE MEASUREMENTS, TRENDS AND BEHAVIOUR IN PATIENTS DURING PROLONGED PERIODS OF TRACHEAL INTUBATION

L. JACOBSON AND R. GREENBAUM

SUMMARY
Intracuff pressure (c.p.) was measured continuously in 12 patients during prolonged periods of tracheal intubation. High residual volume–low pressure (floppy) and low residual volume–high pressure (conventional) cuffs were studied. The mean baseline c.p. at minimal occluding pressure was significantly smaller in floppy cuffs than in conventional cuffs. With coughing, the peak pressures in both cuff types were much greater than the baseline pressures but did not differ significantly from each other. On the basis of our observations, we recommend a simplification of the test methods for cuffs and tube collapse. We believe universal testing to 300 mm Hg (40 kPa) to be reasonable and to incorporate a realistic safety factor. Intracuff pressure tends to diminish with time, but there is a poor correlation between the rate of pressure decrease and elapsed time. As this decrease is not accurately predictable, gas should be added to the cuff as required, rather than at regular intervals. Other features of cuff behaviour are discussed and suggestions made to explain some anomalies occasionally observed in the cuff pressure behaviour pattern.

The value of endotracheal and tracheostomy tube cuffs in reducing the risk of erratic ventilation of the lungs and of aspiration has been appreciated since the poliomyelitis epidemic in Copenhagen in 1952 (Lassen, 1953; Ibsen, 1954; Safar et al., 1962; Carroll, Heddon and Safar, 1969). However, cuffs may cause complications (Cooper and Grillo, 1972). Investigators, designers and manufacturers issued a joint statement recommending performance specifications for cuffed endotracheal and tracheostomy tubes (Carroll et al., 1973; Carroll, McGinnis and Grenvik, 1974), aiming for a product design which minimizes the possibility of misuse and provides for continued safe function. In an attempt to attain the requirements, the British Standards Institute and the International Organization for Standardization have been working to develop a standard for tracheal tubes and cuffs for prolonged use. Such a standard would incorporate methods of test for cuffs and tube collapse in an attempt to minimize the possibility of failure in clinical use.

The studies reported in this paper were undertaken to determine c.p. generated during prolonged tracheal intubation. Information on this subject has been sparse and difficulties have arisen in determining a test pressure which incorporates a realistically agreed safety factor.

METHODS
Commercially available tracheal and tracheostomy tubes (Portex) were studied. Intracuff pressures were measured in patients in an intensive therapy unit (ITU) over a variable period depending on the duration of intubation. Both high residual volume–low pressure (floppy) and low residual volume–high pressure (conventional) cuffs were assessed.

The apparatus consisted of a four-way stopcock attached to a fluid filled tube and connected to a SEM 4-88 strain gauge physiological pressure transducer, which was plugged into a SE-4000 multi-channel amplifier system. The pressures were recorded on a two-channel felt-tip pen recorder.

The stopcock was connected to the pilot tube of the cuff system. The expired gas mixture was used to inflate the cuff to the minimum occluding pressure (m.o.p.) as determined by the absence of breath sounds over the neck and at the mouth on auscultation with a stethoscope.

The transducer trolley was kept at the level of the manubrio–sternal junction. Intracuff pressure was measured continuously and recorded. All patients had relatively constant body temperatures in the normothermic range.
Sedative drugs were used in preference to neuromuscular blocking drugs to facilitate intermittent positive pressure ventilation of the lungs.

**RESULTS**

Mean baseline c.p. in conventional cuffs was 61 mm Hg (table I). This was significantly greater than in the floppy cuff tubes in which the mean pressure was 24 mm Hg (table II) \(P < 0.01\).

**TABLE I. Low residual volume, high pressure cuffs. Baseline pressures and peak intracuff pressures**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Baseline pressure (mm Hg)</th>
<th>Peak pressure (mm Hg)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>110</td>
<td>168</td>
<td>+ 58</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>105</td>
<td>+ 55</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>60</td>
<td>+ 30</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>170</td>
<td>+ 95</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>100</td>
<td>+ 50</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>170</td>
<td>+ 120</td>
</tr>
<tr>
<td>(\bar{x})</td>
<td>61</td>
<td>129</td>
<td>68</td>
</tr>
<tr>
<td>SD</td>
<td>26</td>
<td>43</td>
<td>30</td>
</tr>
<tr>
<td>SEM</td>
<td>10</td>
<td>18</td>
<td>12</td>
</tr>
</tbody>
</table>

**TABLE II. High residual volume, low pressure cuffs. Baseline pressures and peak intracuff pressures**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Baseline pressure (mm Hg)</th>
<th>Peak pressure (mm Hg)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>133</td>
<td>+ 110</td>
</tr>
<tr>
<td>2</td>
<td>45</td>
<td>120</td>
<td>+ 75</td>
</tr>
<tr>
<td>3</td>
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<td>115</td>
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<tr>
<td>4</td>
<td>34</td>
<td>80</td>
<td>+ 46</td>
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<td>5</td>
<td>15</td>
<td>56</td>
<td>+ 41</td>
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<td>6</td>
<td>13</td>
<td>155</td>
<td>+ 142</td>
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<tr>
<td>(\bar{x})</td>
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<td>110</td>
<td>+ 86</td>
</tr>
<tr>
<td>SD</td>
<td>12</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>SEM</td>
<td>5</td>
<td>13</td>
<td>15</td>
</tr>
</tbody>
</table>

The mean peak c.p. observed in conventional and floppy cuffs were 129 mm Hg and 110 mm Hg respectively (tables I and II). Both were significantly greater than the baseline pressures \(P < 0.01\). There was no significant difference between the peak pressures in the cuffs \(P > 0.1\) or between the differences between baseline and peak pressures for floppy and conventional cuffs \(P > 0.1\) (fig. 1).

C.p. decreased with time. However there was no significant correlation between the cuff pressure decrease and time. Tables III and IV show that...
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\[ r = -0.73 \] for conventional cuffs \((P > 0.1)\) and \(-0.65\) for floppy cuffs \((P > 0.05)\) respectively.

**DISCUSSION**

The study demonstrates significant transient increases in c.p. with coughing. Other manoeuvres, such as neck flexion, extension and rotation, have little effect. Peak pressures of 170 mm Hg and 155 mm Hg have been observed in conventional and floppy cuffs respectively.

A recommended test for cuffs and tubes involves the measurement of baseline m.o.p. with the tube in an artificial trachea. An inflation pressure of between 100 and 300 mm Hg is used, depending on m.o.p., and cuff asymmetry, herniation and tube collapse sought. However, we found no constant relationship between baseline c.p. and peak c.p. There was no significant difference between peak c.p. of conventional and floppy cuffs despite the marked disparity in their baseline pressures. On occasions, the peak c.p. exceeded that which would be anticipated for the baseline pressures observed, according to the approved test tables. This could result in tubes being tested at inflation pressures less than those which may be encountered clinically. We suggest the use of a standard inflation pressure test, irrespective of the cuff type. Universal testing to a pressure of 300 mm Hg should suffice.

We believe that this will include conditions likely to be encountered in clinical practice, provided certain elementary clinical rules are observed when selecting and managing cuffed tubes (Cooper and Grillo, 1972; Carroll, 1973; Carroll, McGinnis and Grenvik, 1974).

Intracuff pressures tend to decrease with time, probably as a result of a combination of slow movement ("creeping") of the plastic cuff material and diffusion of gases. By movement, the cuffs may stretch and increase their volume, thereby decreasing the pressure (McGinnis et al., 1971; Hill, 1976). Nevertheless there is no predictable rate of pressure decrease \((P > 0.05)\). The clinical implication is that, should c.p. decrease to less than 15–25 mm Hg, aspiration past the cuff would be a hazard (Carroll, 1973; Bernhard et al., 1979). A significant cuff leak in a patient receiving intermittent positive pressure ventilation may cause inadequate ventilation (Carroll, Heddon and Safar, 1969).

Cross (1973) and Crawley and Cross (1975) studied the relationships applicable to various inflatable cuff systems *in vivo*, and demonstrated the importance of cuff diameter and the stiffness of cuff material in the ultimate determination of both c.p. and tracheal wall pressure. They studied the applied physiology and physics of conventional and floppy cuff systems and their relationship to airway pressure. Our unpublished findings endorse their work. It is of interest to note that the mean baseline c.p. in conventional cuffs (61 mm Hg) was much greater than in the floppy type (24 mm Hg).

We have occasionally recorded c.p. values, in conventional cuffs, in the range associated with the low pressure variety. Several factors probably occur simultaneously. The moist warm environment in the trachea alters the consistency of the cuff material and promotes movement of the plastic. Repeated episodes of increased c.p. compress the cuff material and contribute to the movement phenomenon observed in plastic materials. The effect may resemble that encountered by prestretching cuffs (Geoffin and Pontoppidan, 1969). If an appropriately sized conventional cuffed tube is inserted, c.p. in the range seen in floppy cuffed tubes may be recorded, especially after a period of time.

Occasionally c.p. in floppy cuffs was greater than expected. This may be related to the formation of longitudinal folds along the length of the cuff because its circumference is greater than that of the trachea. Leakage may occur along these folds even when c.p. is equal to the inflation pressure. Thus the cuff may have to be inflated to the extent where the tracheal wall pressure exceeds the capillary pressure (Cross, 1973; Crawley and Cross, 1975). Also, the resting size of the cuff concerned may be too small for the trachea, requiring it to be over-expanded in the trachea in order to create a seal. Such a cuff has a low pressure only at a volume insufficient to form a seal and becomes a rigid high pressure cuff as it distends to the sealing volume.

The significant transient increases in c.p. that occur with coughing are unlikely to be exclusively a result of the cuff being compressed by the increased intrathoracic pressure. These peak pressures are usually generated when coughing is initiated by suction through the endotracheal tube, which is therefore open to the atmosphere at the time, thus precluding a large increase in intra-
thoracic pressure. More plausible is that a moderately increased intrathoracic pressure, generated by the cough, acts on the trachea, which is a dynamic organ, and causes it to alter its configuration and to constrict the cuff (Croteau and Cook, 1961; Scarpelli, Real and Rudolph, 1965; Carroll, McGinnis and Grenvik, 1974). These conditions of cuff compression approach those of nondistensibility and the pressure increases as the volume is diminished because of tracheal compression.

We observed no simple relationship between the strength of cough and the peak cuff pressure reached. This depends on other factors such as the tracheal compliance, degree of altered intrathoracic pressure, the extent of cuff inflation, the diameter of the cuff in relation to the trachea and the stiffness of the cuff material. Therefore it cannot be concluded that patients with the most active cough will generate the greatest peak pressures. These peak c.p. pose a potential hazard of tube collapse, cuff herniation and cuff asymmetry. Thus it is important that an agreed standard for tracheal tubes and cuffs for prolonged use be determined.

ACKNOWLEDGEMENTS
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REFERENCES

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ETUDE DE MESURES, DES TENDANCES ET DU COMPORTEMENT DE LA PRESSION INTRAMANCHON SUR DES PATIENTS SOUMIS A UNE INTUBATION TRACHEALE

RESUME
On a mesure d'une maniere continue, sur 12 patients et pendant des periodes prolonges d'intubation tracheale, la pression se trouvant a l'interieur du manchon (c.p.). On a etudie les manchons presentant un important volume residuel-basse pression (trop large) et les manchons ayant un faible volume residuel et une haute pression (normaux). La c.p. moyenne de base, a la pression d'occlusion minimale, a ete sensiblement plus faible dans les manchons trop larges que dans les manchons normaux. Lorsque les patients ont toussé, les pressions de pointe, dans les deux types de manchons, ont ete beaucoup plus importantes que les pressions de base mais elles n'ont tout de meme pas varie d'une maniere significative, les unes par rapport aux autres. En nous basant sur nos observations, nous pouvons recommender une simplification des methodes d'essai des manchons et des deformations de tubes. Nous estimons que les essais universels a 300 mm Hg (40 kPa) sont raisonables et comprennent un facteur de securite reeliste. La pression a l'interieur du manchon tend a diminuer avec le temps, mais la correlation entre le rythme de la baisse de pression et le temps ecoule est mauvaise. Comme cette baisse n'est pas previsible d'une maniere precise, il faudrait ajouter du gaz au manchon en fonction des besoins, plutot qu'a des intervalles reguliers. On expose dans ce document d'autres caracteristiques sur le comportement des manchons et on y fait des suggestions pour expliquer certaines anomalies que l'on a occasionnellement observes dans le modele de comportement de la pression du manchon.
ZUSAMMENFASSUNG