Calculated vs measured pharyngeal mucosal pressures with the laryngeal mask airway during cuff inflation: assessment of four locations

C. Keller\textsuperscript{1,2}, J. Brimacombe\textsuperscript{1,*} and A. Benzer\textsuperscript{2}

\textsuperscript{1}Department of Anaesthesia and Intensive Care, University of Queensland, Cairns Base Hospital, The Esplanade, Cairns 4870, Australia. \textsuperscript{2}Department of Anaesthesia and Intensive Care Medicine, Leopold-Franzens University, 6020 Innsbruck, Austria

*To whom correspondence should be addressed at: Department of Anaesthesia and Intensive Care, Cairns Base Hospital, The Esplanade, Cairns 4870, Australia

We have compared calculated with measured pharyngeal mucosal pressures at four different locations on the surface of the laryngeal mask airway (LMA) during cuff inflation in 10 anaesthetized, paralysed adult patients. Microchip sensors were attached to a size 5 LMA at the following locations: the anterior and lateral side, tip and backplate. Pressures were recorded during inflation of the cuff from 0 to 40 ml in 5-ml increments. Calculated pressures were determined by subtracting \textit{in vivo} from \textit{in vitro} intracuff pressures. Calculated pressures were greater than measured pressures at cuff volumes of 5 ml or greater at all locations ($P<0.003$). The greatest mean calculated and measured pressures were 118 and 14 cm H\textsubscript{2}O, respectively. We conclude that measured mucosal pressures at the four locations tested were less than calculated pressures and less than capillary perfusion pressure.

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The laryngeal mask airway (LMA) cuff sits in the pharynx where it forms an airtight seal with the adjacent mucosa. In theory, if transmitted pharyngeal mucosal pressure exceeds capillary perfusion pressure, mucosal ischaemia is possible. Transmitted pharyngeal mucosal pressures have been calculated\textsuperscript{1} and measured directly,\textsuperscript{2} but with inconsistent results, and the relationship between calculated and measured mucosal pressures has not been determined. Marjot\textsuperscript{1} and Asai and colleagues\textsuperscript{3} subtracted \textit{in vivo} from \textit{in vitro} intracuff pressures and calculated that pharyngeal mucosal pressures frequently exceeded capillary perfusion pressure, despite apparent pharyngeal accommodation of the mask. However, Hamakawa, Nakamura and Kawasaki,\textsuperscript{2} using a single pressure sensor placed between the cuff and lateral pharynx, showed that capillary perfusion pressure was not exceeded and remained stable during nitrous oxide–oxygen anaesthesia. In this study, we have compared calculated with measured pharyngeal mucosal pressures at four different locations during LMA cuff inflation.

\textbf{Patients and methods}

After obtaining approval from the Ethics Committee and informed patient consent, we studied 10 consecutive ASA I–II adult patients in whom the LMA was considered suitable. Pharyngeal mucosal pressures were measured using four strain gauge silicone microchip sensors (Codman MicroSensor, Bracknell, UK) attached to the external surface of the LMA with clear adhesive dressing, 45 $\mu$m thick (Tegaderm, 3M, Ontario, Canada). The sensors had a tip diameter of 1.2 mm, functional pressure range of –68 to 340 cm H\textsubscript{2}O, zero drift of $<4$ cm H\textsubscript{2}O/24 h, frequency response of 0–10 Hz and were accurate to $\pm2\%$. The accuracy of the measurement system (probes/adhesive) was $\pm1$ cm H\textsubscript{2}O. This was determined by submerging the LMA with attached probes in water to a standard depth of 13.6 cm and noting the pressure readings from each location before and after each case. The sensors were attached with the microchip sensing surface orientated towards the mucosal surface. The following locations on the LMA were used: (1) anterior middle part of the side (anterior side), (2) lateral middle part of the side (lateral side), (3) anterior tip (tip) and (4) middle of the backplate (backplate) (Fig. 1). All sensors were zeroed before insertion. The position/orientation of the sensors were checked after removal by visual inspection.

A standard anaesthetic was given and routine monitoring applied. Anaesthesia was induced with propofol 2.5 mg kg\textsuperscript{-1}
Fig 1 Location of sensors on the laryngeal mask airway (LMA): (a) anterior side; (b) lateral side; (c) tip; (d) backplate.

Table 1  

<table>
<thead>
<tr>
<th>Cuff volume (ml)</th>
<th>In vivo</th>
<th>In vitro</th>
<th>Calculated</th>
<th>Anterior side</th>
<th>Lateral side</th>
<th>Tip</th>
<th>Backplate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-27 (-35 to 22)</td>
<td>-0 (0)</td>
<td>13 (5–18)</td>
<td>11 (3–19)</td>
<td>3 (0–6)</td>
<td>1 (0–2)</td>
<td>4 (0–8)</td>
</tr>
<tr>
<td>5</td>
<td>-1 (–5 to 9)</td>
<td>-20 (–22 to –17)</td>
<td>21 (18–25)</td>
<td>12 (4–19)</td>
<td>2 (1–3)</td>
<td>1 (0–2)</td>
<td>5 (1–9)</td>
</tr>
<tr>
<td>10</td>
<td>17 (12–23)</td>
<td>-16 (–18 to –14)</td>
<td>33 (29–36)</td>
<td>12 (4–20)</td>
<td>3 (1–5)</td>
<td>1 (0–2)</td>
<td>6 (1–10)</td>
</tr>
<tr>
<td>15</td>
<td>33 (29–39)</td>
<td>-12 (–14 to –10)</td>
<td>45 (39–51)</td>
<td>14 (3–23)</td>
<td>3 (1–5)</td>
<td>2 (0–3)</td>
<td>6 (1–10)</td>
</tr>
<tr>
<td>20</td>
<td>60 (54–67)</td>
<td>-9 (–12 to –7)</td>
<td>69 (61–76)</td>
<td>10 (1–19)</td>
<td>4 (1–6)</td>
<td>2 (1–3)</td>
<td>6 (0–9)</td>
</tr>
<tr>
<td>25</td>
<td>92 (87–98)</td>
<td>-4 (–6 to –1)</td>
<td>96 (88–105)</td>
<td>14 (2–25)</td>
<td>4 (1–8)</td>
<td>2 (1–4)</td>
<td>5 (1–9)</td>
</tr>
<tr>
<td>30</td>
<td>116 (109–125)</td>
<td>2 (–2 to 5)</td>
<td>118 (106–130)</td>
<td>7 (3–11)</td>
<td>7 (1–13)</td>
<td>3 (2–5)</td>
<td>5 (2–7)</td>
</tr>
<tr>
<td>35</td>
<td>151 (144–159)</td>
<td>35 (30–38)</td>
<td>116 (102–128)</td>
<td>6 (1–11)</td>
<td>9 (1–16)</td>
<td>5 (3–8)</td>
<td>5 (2–8)</td>
</tr>
</tbody>
</table>

and maintained with 1–2% sevoflurane and 100% oxygen. Neuromuscular block was produced with atracurium 0.5 mg kg⁻¹. A single experienced LMA user (>1500 insertions) inserted/fixed the LMA according to the manufacturer’s instructions. A size No. 5 LMA was used for all patients. The pilot balloon was attached via a three-way tap to a 5-ml syringe and a calibrated pressure transducer with an accuracy of ±5%. Intracuff pressure was reduced to –40 cm H₂O. Pharyngeal mucosal pressures and intracuff pressures were documented at zero volume and after each additional 5 ml up to a maximum of 40 ml.

When the measurements were complete, airway sealing pressure and fibreoptic position were recorded at an intracuff pressure of 60 cm H₂O, as recommended by the manufacturer, to provide general information on LMA position. The fibreoptic position of the LMA was determined using an established scoring system (4 = only vocal cords visible; 3 = vocal cords plus posterior epiglottis; 2 = vocal cords plus anterior epiglottis; 1 = vocal cords not seen). Airway sealing pressure was measured by closing the expiratory valve of the circle system at a fixed gas flow of 3 litre min⁻¹, and noting the airway pressure at which an audible gas leak occurred in the mouth. The position of the anterior tip sensor was verified at the end of the procedure by observation of a pressure spike during application of cricoid pressure. Calculated pharyngeal mucosal pressures were determined by subtracting the in vivo intracuff pressure measurements from the in vitro intracuff pressure measurements, as described previously. Statistical analysis was performed using Friedman’s two-way analysis of variance. Significance was taken as P<0.05.

Results

Mean (range) age, height and weight were 40 (24–75) yr, 173 (150–187) cm and 79 (50–115) kg, respectively. The male:female ratio was 6:4. All LMA were inserted at the first attempt. Median (range) fibreoptic score was 3.0 (2–4) and mean (range) airway sealing pressure was 26 (10–45) cm H₂O. The pressure from the anterior tip probe increased to >100 cm H₂O when cricoid pressure was applied in all patients. The position/orientation of the sensors was identical before and after use. Calculated pressures were higher than measured pressures at cuff volumes of 5 ml or greater at all locations (P<0.003) (Table 1). The highest mean calculated and measured pressures were 118 and 14 cm H₂O, respectively.

Discussion

Several forces may be acting at a given point on the pharyngeal mucosa, including tension in the cuff, recoil
from the curved tube and elastic pharyngeal tissues, and pharyngeal muscle activity in non-paralysed patients. Not only do these forces vary from point to point, but the physical properties (hardness/softness) of the LMA (cuff/ backplate and tube) and pharynx (cartilage and bone/muscle and elastic tissue) are also variable. There may also be movement between the two surfaces when the cuff is inflated and possibly during respiration. In some patients the pressure decreased to zero, indicating little or no contact between the two surfaces. Our pressures were lower than those measured by Hamakawa, Nakamura and Kawasaki\(^2\) against the middle part of the outside of the LMA (33 cm H\(_2\)O). This may be related to our use of a small probe (less likely to create an artificial high pressure zone as it bulges into the pharyngeal tissues) or differences in the point of measurement, mask size and cuff volume. Our calculated pressures were greater for the size No. 5 compared with those documented by Asai and colleagues.\(^3\) This may be related to differences in patient morphology as our patients were of mixed sex and Asai and colleagues studied only males for the size No. 5.

We suggest that calculated pressures are an imprecise method of assessing localized transmitted pressures. Calculated pressures reflect the average pressure exerted by the cuff on surrounding structures, but not all structures surrounding the cuff are pharyngeal tissues. The proximal posterior cuff presses into the tube–backplate junction and, on occasions, the partially inflated cuff can press into the backplate or itself, if folded. In addition, calculated pressures cannot reflect pharyngeal mucosal pressures exerted by non-inflatable components of the LMA, such as the backplate and tube. Marjot considered that capillary perfusion pressure in the pharynx was similar to the conventionally accepted value of 40 cm H\(_2\)O for the tracheal mucosa.\(^1\) Our calculated pressures exceeded this value when cuff volume was 15 ml or greater, but the measured values remained substantially lower. Physical theory suggests that since the calculated values must reflect the average pressure on surrounding structures, there must be one or more high pressure areas not detected by our sensors. We speculate that these high pressure areas may be in the proximal end of the cuff as we had no sensors attached to this section. These high pressure areas could be mucosal or non-mucosal.

We conclude that measured mucosal pressures at the four locations tested were less than calculated pressures and less than capillary perfusion pressure.

References

1. Marjot R. Pressure exerted by the laryngeal mask airway cuff upon the pharyngeal mucosa. Br J Anaesth 1993; 70: 25–9