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PRESSURE EXERTED BY THE LARYNGEAL MASK AIRWAY CUFF UPON THE PHARYNGEAL MUCOSA

R. MARJOT

SUMMARY

Ten patients were studied for each of the sizes 2, 3 and 4 laryngeal mask airways (LMA) in order to calculate the pressure exerted by the cuff upon the pharyngeal mucosa. Using a non-invasive method of comparing intracuff pressures recorded both in vitro *and* in vivo, *the transmitted pharyngeal mucosal pressures were calculated over the clinical range of injection volumes. Cuff inflation with the "normal" injection volumes recommended resulted in the residual volumes of the cuffs being exceeded. The intracuff pressures recorded with the mask* in situ *at these normal injection volumes were in the range 103–251 mm Hg. The calculated transmitted mucosal pressures were substantial for all three sizes of cuff and potentially exceeded the capillary perfusion pressure of the adjacent pharyngeal mucosa, despite apparent pharyngeal accommodation to the mask.* (Br. J. Anaesth. 1993; **70**: 25–29)

KEY WORDS

Complications: mucosal pressure. Equipment. laryngeal mask airway.

The laryngeal mask airway (LMA) is an innovative new device for upper airway management. The prototype consisted of an elliptical cuff formed from the black rubber of a Goldman dental mask attached to a tracheal tube [1]. The currently manufactured model is constructed entirely from silicone rubber.

Inflation of the cuff orientates and positions the mask within the pharynx and creates a seal around the laryngeal inlet. This generates a pressure against the adjacent pharyngeal mucosa, sufficient to displace the thyroid and cricoid cartilages anteriorly [2] as the mask is "squeezed out of the triangular shaped base of the hypopharynx" [3].

It has been demonstrated that transmitted lateral wall pressure is the prime determinant of mucosal injury resulting from tracheal tube cuffs [4–6]. There has been one report of phayngeal trauma associated with repeated usage of an LMA within a short period [7]. The manufacturers currently recommend monitoring the LMA intracuff pressures to avoid postoperative throat discomfort [3].

The aim of this study was to determine the pharyngeal mucosal pressures generated by the sizes 2, 3 and 4 LMA with the cuff injection volumes used clinically.

PATIENTS AND METHODS

After Ethics Committee approval, informed written consent was obtained from 30 patients presenting for elective surgery for whom spontaneous ventilation via an LMA was appropriate [3].

The pilot tube of each LMA was attached via a three-way tap to a Spectramed pressure transducer (P10EZ) with a Physio Control VSM 1 recorder, and a Plastipak syringe (fig. 1). A 50-ml and a 10-ml syringe were used for the size 3 or 4 LMA and size 2 LMA, respectively. The same transducer was calibrated against a mercury column and the zero point determined before each study (non-linear error $< 2\%$). Each LMA was suspended in air and the cuff evacuated to a negative pressure of -20 mm Hg. The syringe volumes were adjusted so that they were equal for all the cases in each group of LMA. This was defined as the start point and, when set, this sealed system was not disrupted until the end of each study.

The pilot tube was clamped as it entered the cuff and a pressure–volume curve plotted to enable conversion of injected volume to cuff volume. This was necessary to account for the compression of the air within the inflating syringe, transducer, connecting tubing and pilot tube with pressurization of the system [8] (Appendix). The cuff was then inflated incrementally and the first pressure–volume curve of the cuff recorded (P1). The system was then aspirated back to the start point.

Anaesthesia was induced with propofol 1.5–3 mg kg^{-1} and spontaneous ventilation established with the patient breathing halothane and 67% nitrous oxide in oxygen. The laryngeal mask was inserted according to the manufacturer's instructions [3]. The patient's head and neck were then placed in a neutral position resting upon one pillow. The cuff was inflated incrementally *in situ* to record a second pressure–volume curve (P2).

At the end of surgery, the cuff was deflated *in situ* to record a third pressure–volume curve (P3). The laryngeal mask was removed from the patient and

R. MARJOT, M.B., B.S., F.R.C.ANAES., University Department of Anaesthetics, Leicester Royal Infirmary, Leicester LE1 5WW. Present address: Royal United Hospital, Combe Park, Bath BA1 3NG. Accepted for Publication: August 6, 1992.

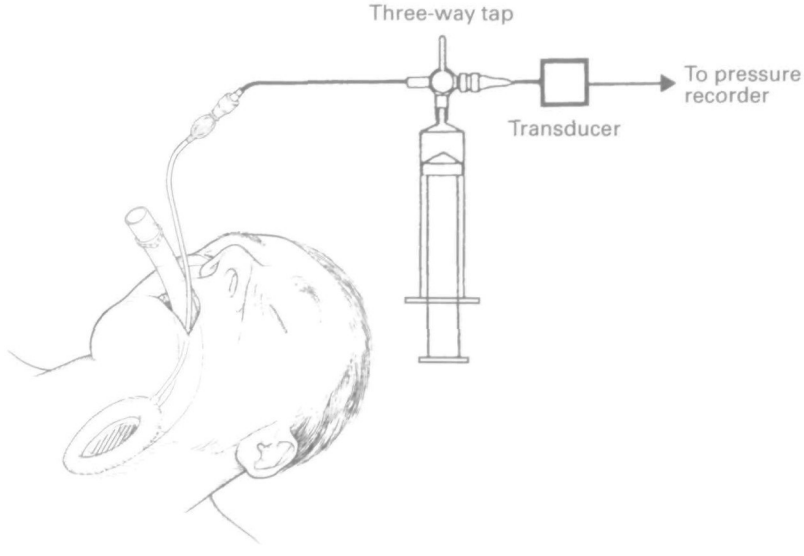

FIG. 1. Diagram of the pressure recording system connected to the laryngeal mask airway *in situ*..

TABLE I. *Patient data (mean (range or SD)) and the cuff characteristics for the sizes 2, 3 and 4 laryngeal mask airways*

	Laryngeal mask airways size		
	2	3	4
Age (yr)	3.9 (2–8)	39.1 (10–78)	60.8 (23–84)
Weight (kg)	18.7 (3.9)	57.4 (12)	74.1 (6.9)
Sex (M:F)	7:3	0:10	10:0
Normal injection volume (NIV) (ml)	10	20	30
Cuff volume with NIV (ml)	6.7 (0.2)	14.2 (0.7)	21.8 (1)
Cuff residual volume (ml)	5.5 (0.6)	12.9 (0.9)	17.8 (1.9)
Anaesthetic time (min)	23.2 (10.2)	37 (12.4)	41.5 (16.7)
Cuff volume increase (%)	9 (0.5)	15.4 (7.6)	17.6 (5.2)
Cuff N_2O concn (%)	4.2 (1.3)	10.3 (3.1)	13.1 (4.8)

the cuff immediately reinflated. A fourth pressure–volume curve was recorded with deflation of the cuff whilst it was suspended in air (P4). The cuff was then aspirated back to the start point and the final volume within the syringe recorded.

The pilot tube was again clamped as it entered the cuff and a final pressure–volume curve plotted to enable conversion of injected volume to cuff volume [8] (Appendix). The gas was then aspirated back into the syringe and analysed immediately using a Datex Cardiocap monitor.

Cuff volume was calculated for each injected volume. Each pressure–volume curve (P1–P4) was replotted against cuff volume. Data presented refer to cuff volume.

For each cuff volume, the pharyngeal mucosal pressures for the start ($P\text{pm}_s$) and end ($P\text{pm}_e$) of anaesthesia were calculated. The cuff residual volume is that volume in excess of which the cuff develops sufficient tension itself to generate an intracuff pressure [9]. This intracuff pressure is determined from the pressure–volume curves P1 and P4. In order to obtain the pressure that any given cuff exerts upon the pharyngeal mucosa ($P\text{pm}_s$ and $P\text{pm}_e$), the intracuff pressure resulting from the tension in the cuff itself as its residual volume is exceeded (P1 and P4) is subtracted from the intracuff pressure recorded *in situ* (P2 and P3). Thus:

$$P\text{pm}_s = \text{P2} - \text{P1}$$
$$P\text{pm}_e = \text{P3} - \text{P4}$$

Data were analysed using analysis of variance for repeated measures (MANOVA). Values of $P < 0.05$ were considered significant. Data are presented as mean (SEM).

RESULTS

Observations were recorded for 10 patients using each LMA size (table I). The LMA was inserted successfully at the first attempt in 86% of the cases, and the remainder upon the second attempt. A clinically patent airway was provided in all patients.

Pressure–volume curves

The intracuff pressure increased for all three sizes of LMA with cuff inflation (fig. 2). The pressures recorded were significantly greater with the LMA *in situ* compared with inflation of the cuff whilst it was suspended in air (P2 *vs* P1 and P3 *vs* P4: $P < 0.001$). The cuff itself tended to be more compliant by the end of anaesthesia, but this was not significant (P1 *vs* P4: $P = 0.07$).

The cuff volume resulting from the injection of the manufacturer's "normal" recommended volumes exceeded the cuff residual volume for all three sizes of LMA (table I).

Pharyngeal mucosal pressures

There was an initial increase, followed by a plateau in the calculated transmitted pharyngeal mucosal pressures with increasing cuff volume (fig. 3). The largest calculated mean pharyngeal mucosal pressures were 79.9 (7) mm Hg, 92.3 (6.9) mm Hg and

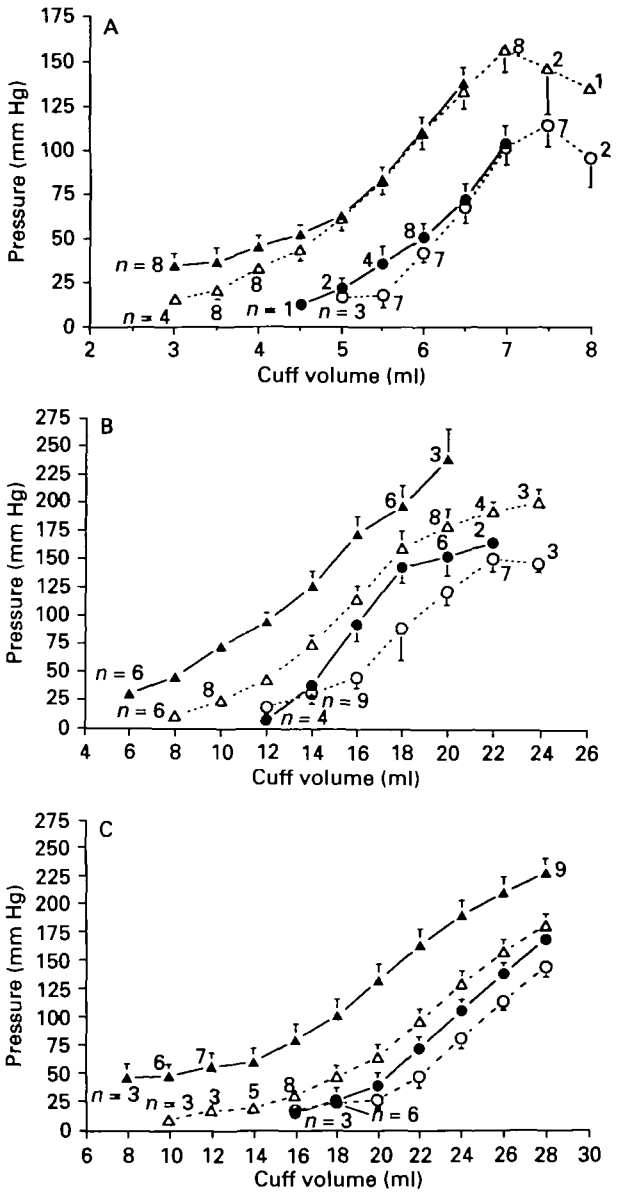

FIG. 2. The pressure–volume curves for P1 (▲), P2 (●), P3 (△) and P4 (○) for (A) size 2, (B) size 3 and (C) size 4 laryngeal mask airways, in 10 patients unless indicated otherwise.

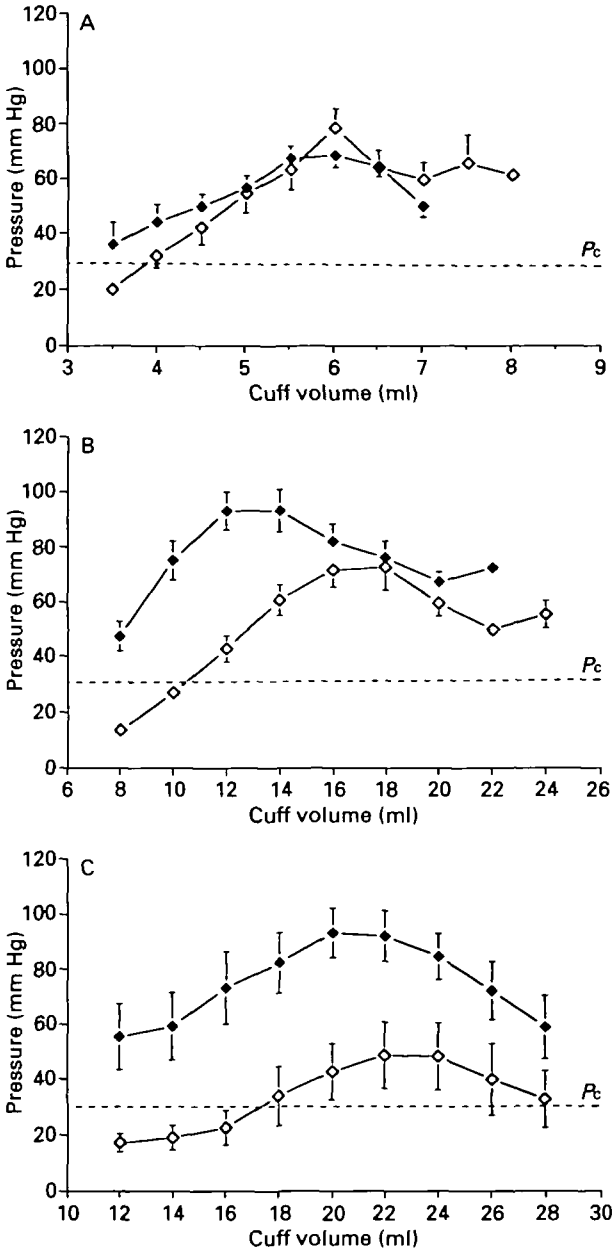

FIG. 3. The calculated pharyngeal mucosal pressures for the start (Ppm_s) (◆) and end (Ppm_e) (◇) of anaesthesia, for (A) size 2, (B) size 3 and (C) size 4 laryngeal mask airways. Pc is an estimate of mucosal capillary perfusion pressure.

93.1 (9.3) mm Hg for sizes 2, 3 and 4 LMA, respectively.

Using the size 4 LMA, a decrease in transmitted pharyngeal mucosal pressure occurred by the end of anaesthesia (Ppm_e) throughout the range of cuff volumes (fig. 3C). This reduction occurred only at the smaller range of cuff volumes with the sizes 2 and 3 LMA, with no reduction in the largest calculated mean mucosal pressures (fig. 3A, B).

The cuff volume increased in all three LMA groups by the end of anaesthesia. Nitrous oxide was detected in the gas aspirated from the cuffs (table I).

DISCUSSION

Laryngeal mask airway cuff inflation with the normal recommended injection volume [3] results in the residual volume of the cuff being exceeded. At these clinically used injection volumes, the features of a "low residual volume, high pressure cuff" were demonstrated.

The disadvantages of this cuff design have been described for tracheal tubes. Grimm and Knight [11] warned that the large intracuff pressure required to expand these cuffs to fill the trachea had the effect that an unknown pressure would be transmitted to the mucosa. Dobrin and Canfield [12] demonstrated that these cuffs, rather than conforming to the trachea, distort it, applying increasing pressure to the mucosa first encountered. McGinnis and colleagues [13] concluded that excessive lateral wall pressure was unavoidable if extensible occluding cuffs were used. This had led to the development of large-volume tracheal tube cuffs, enabling the maintenance of small intracuff pressure and therefore small lateral wall pressures.

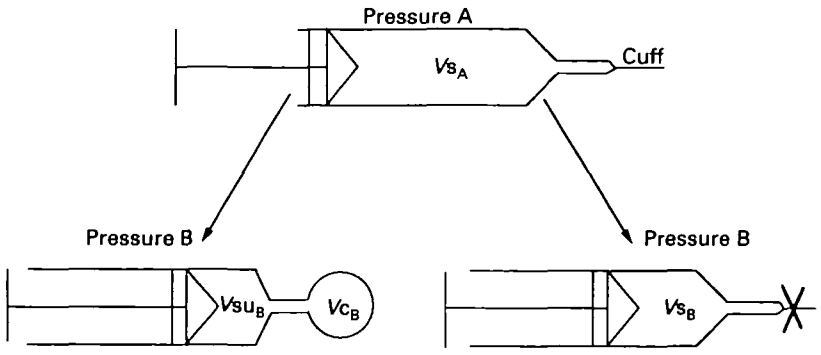

FIG. 4. Method of calculating cuff volume from injected volume.

Nordin [4] suggested that pressure was the principal determinant of cuff-induced tracheal mucosal morbidity, and demonstrated that cuff pressures exceeding 50 mm Hg, exerted upon the rabbit mucosa, resulted in partial denuding of the basement membrane. Seegobin and Van Hasselt [6] assessed fibreoptically the tracheal mucosa underlying the cuff in patients and observed that pressures exceeding 38 mm Hg resulted in total occlusion of mucosal blood flow.

Safe, prolonged tracheal intubation warrants a tracheal cuff that is compliant, deformable and inflated easily to a volume greater than the trachea with maintenance of the intracuff pressure less than 30 mm Hg [14].

For the cuffs of these sizes of LMA, the calculated transmitted lateral wall pressures were substantial when inflated with the recommended injection volumes and likely to exceed the pharnygeal mucosal capillary perfusion pressure (fig. 3).

Two features of the LMA cuff distinguish it from cuffs of tracheal tubes. First, there was not a sustained increase in transmitted lateral wall pressure with increasing cuff volume (fig. 3). Several factors could account for this. A degree of pharyngeal accommodation accompanying incremental cuff inflation might occur. Normally, there is cranial migration of the LMA in the hypopharynx as it is inflated [3], and the large intracuff pressure generated with the LMA *in situ* could result in configurational changes in the cuff, resulting in underestimation of the calculated transmitted pressure. In an evaluation of the methodology used in this study, Black and Seegobin [15] concluded that the derived pressures tended to be underestimates when the cuff became stretched, for this reason. The second distinguishing feature is that the transmitted lateral wall pressure decreased during the time the mask is *in situ* ($P\text{pm}_s$ *vs* $P\text{pm}_e$). Unlike the trachea, the pharynx is a fibromuscular tube which is capable of accommodating an object placed within it, such as an LMA. The apparent reduction in pharyngeal muscular tone with general anaesthesia [16] may also contribute to this decrease in pressure. The sizes 2 and 3 LMA demonstrated this phenomenon only at small cuff volumes. This could reflect a greater mask:pharyngeal size ratio which would limit any effect of pharyngeal accommodation.

An important advantage of the LMA is that insertion and removal do not require visualization of the airway. The incidence and degree of pharyngeal mucosal morbidity, therefore, remains undetermined; there has been one case report of trauma [7]. The incidence of postoperative sore throat with the LMA ranges between 7 and 12% [17–19]. Postoperative "dryness of the throat" was noted in 36% of patients in one study [19]. The aetiology of sore throat after general anaesthesia is multifactorial [20]. It correlates with the surface area of the cuff in contact with the mucosa, and not the lateral wall pressure generated by the cuff [21,22].

Cuff volume and intracuff pressure increased in all patients during anaesthesia. Nitrous oxide was detected in the gas from the cuffs. The gas concentrations recorded could be an underestimation as a result of the small sample volumes obtained for analysis by the Datex Cardiocap analyser. The 9–17.6% increases in cuff volume were less than the increases described previously for a range of tracheal tube cuffs exposed to nitrous oxide, even with consideration for the shorter anaesthetic time [23, 24]. The large intracuff pressure generated with the LMA *in situ* would increase the partial pressure of nitrous oxide within the cuff, decreasing the pressure gradient across the cuff wall, thereby limiting diffusion [23]. In addition, there may be a proportion of the cuff exposed to the air in the patient's upper pharynx, allowing nitrous oxide to diffuse back out of the cuff. Although nitrous oxide diffusion into the cuff increased cuff volume and intracuff pressure, this did not result in an increase in the pressure exerted upon the pharyngeal mucosa (fig. 3).

The site of the transmitted lateral wall pressure cannot be determined here. It is likely to differ in different parts of the pharynx, as the maximum cuff seal around the laryngeal inlet has been found to be only approximately 15 mm Hg [3].

The pharyngeal mucosal pressures demonstrated for the LMA are particularly unwarranted during spontaneous ventilation, as the cuff is not designed to secure the trachea from gastric aspiration, nor is it necessary for it to provide a high-pressure seal around the laryngeal inlet.

The pharyngeal mucosal pressures resulting from the LMA cuff depend, in a complex manner, upon the relative dimensions of the pharynx and LMA, the degree of accommodation by the pharynx and the inflation pressure required to extend the cuff sufficiently for its function as an airway. The morbidity resulting from this transmitted mucosal pressure is

undetermined. It may be an important consideration when prolonged or repeated LMA usage is anticipated. Pressure upon the pharyngeal mucosa could be limited by reducing the cuff inflation volumes sufficiently so as not to exceed the residual volumes of the cuff. The intracuff pressure could then be monitored and maintained at a value less than expected mucosal capillary perfusion pressure. Intracuff pressure monitoring is now recommended by the manufacturers "to avoid postoperative throat discomfort" [3], although no guidelines are given as to an acceptable intracuff pressure. Lumb and Wrigley have suggested the fitting of a pressure relief valve to the cuff of the LMA [25]. The substantial reductions in cuff volume required to reduce intracuff pressure to less than expected capillary perfusion pressure may interfere with the function of the LMA with its current cuff design.

APPENDIX

The LMA is supported with the syringe and pressure recording system attached and sealed (fig. 1).

Pressure A = −20 mm Hg vacuum within cuff, pilot tube and syringe at the start.

Vs_A = Volume of air in syringe at pressure A (constant at 40, 26 and 10 ml for sizes 4, 3 and 2 LMA, respectively).

Temperature is assumed constant when comparing the pressure–volume curves P1 with P2, and P3 with P4, as P2 was recorded *immediately* after insertion and P4 *immediately* after removal of the LMA.

Then (fig. 4):

The pilot tube is clamped as it enters the cuff and the system is inflated to pressure B.

Vs_B = volume remaining in the syringe at pressure B.

Then:

The pilot tube is unclamped and the cuff inflated to pressure B.

Vsu_B = volume remaining within the unclamped syringe at pressure B.

Vc_B = cuff volume at pressure B.

Applying the gas law, $\frac{PV}{T}$ = constant.

$$\text{Pressure A} \times Vs_A = \text{pressure B} \times Vs_B$$
$$= \text{pressure B} \times Vsu_B + \text{pressure B} \times Vc_B$$

Therefore:

$$Vc_B = Vs_B - Vsu_B$$

For example: the starting volume in the syringe for the size 4 LMA was 40 ml ($Vs_A = 40$). Injecting 30 ml caused an increase in pressure (pressure B) with a volume of 10 ml remaining in the syringe ($Vsu_B = 10$). Reinflating from the start point with the pilot tube now clamped to pressure B resulted in a volume of 32 ml remaining in the syringe ($Vs_B = 32$). Thus, with an injection volume of 30 ml, the cuff volume achieved was only 32 − 10 = 22 ml.

This process was repeated to determine the cuff volumes resulting over the range of intracuff pressure achieved. This procedure was performed at the start of each study for the calculations regarding the pressure–volume curves P1 and P2 and repeated again following the removal of the LMA at the end of the study for the calculations regarding the pressure–volume curves P3 and P4.

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