

A Comparison of Pharyngeal Mucosal Pressure and Airway Sealing Pressure with the Laryngeal Mask Airway in Anesthetized Adult Patients

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We measured pharyngeal mucosal pressures at six different locations on the laryngeal mask airway (LMA) and tested the hypothesis that the efficacy of the seal is not related to pharyngeal mucosal pressure. Twenty anesthetized, paralyzed adult patients were studied. Microchip sensors were attached to the size 5 LMA at locations corresponding to the lateral and posterior pharynx, the hypopharynx, the pyriform fossa, the base of tongue, and the oropharynx. Mucosal pressures and airway sealing pressures were recorded during inflation of the cuff from 0 to 40 mL in 10-mL increments. The highest mean mucosal pressure was in the oropharynx (26 cm H₂O), and the lowest was in the posterior pharynx (2 cm H₂O). Mucosal pressures increased with increasing intracuff pressure and cuff volume, but the rate of increase varied among locations. Airway sealing pressure increased with increasing intracuff volume from 0 to 10 mL ($P < 0.0001$) and 10 to 20 mL

($P = 0.0001$), was unchanged from 20 to 30 mL, and decreased from 30 to 40 mL ($P = 0.005$). The airway sealing pressure was higher than pharyngeal mucosal pressure until the intracuff volume was ≥ 30 mL. There was no correlation between mucosal pressures and airway sealing pressure at any location. We conclude that the efficacy of the seal is not related to pharyngeal mucosal pressure. Pharyngeal mucosal pressures are generally lower than those considered safe for the tracheal mucosa during prolonged intubation. **Implications:** We measured pharyngeal mucosal pressures at six different locations on the laryngeal mask airway and showed that the efficacy of the seal is not related to pharyngeal mucosal pressure. Pharyngeal mucosal pressures are generally lower than those considered safe for the tracheal mucosa during prolonged intubation.

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The cuff portion of the laryngeal mask airway (LMA) sits in the compliant, variable-shaped pharyngeal sack, where it forms a seal with the periglottic tissues and applies a pressure against the pharyngeal mucosa (1). There is evidence that airway sealing pressure is optimal at submaximal cuff volumes (2) and pressures (3), which suggests that it is the matching contours of the cuff and pharynx, rather than the transmitted pharyngeal mucosal pressure, which provides the airtight seal. In addition, if transmitted pharyngeal mucosal pressure exceeds capillary perfusion pressure, there is a possibility of mucosal ischemia, but only one group (4) has published data about pharyngeal mucosal pressures with the LMA. Hamakawa et al. (4) showed that capillary perfusion pressure was not exceeded, but they only used a single

pressure sensor placed between the cuff and lateral pharynx. In this study, we measured pharyngeal mucosal pressures at six different locations on the LMA and tested the hypothesis that the efficacy of the seal is not related to pharyngeal mucosal pressure.

Methods

Twenty consecutive ASA physical status I or II adult patients for whom the LMA was considered suitable were included in this study. Ethics committee approval and informed consent were obtained. Pharyngeal mucosal pressures were measured using six strain-gauge silicone microchip sensors (Codman®; MicroSensor™, Bracknell, UK) attached to the external surface of the LMA with clear adhesive dressing 45 μ m thick. The sensors have a tip diameter of 1.2 mm, a functional pressure range of -50 to 250 mm Hg, a temperature sensitivity of <0.1 mm Hg/°C, a zero drift of <3 mm Hg/d, and a frequency response of 0-10 Hz; they are accurate to 2%. The sensors were attached with

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the microchip orientated away from the surface of the LMA. The sensors were attached to the following locations on the LMA (corresponding mucosal area): anterior base of cuff (base of tongue); posterior tip of cuff (hypopharynx); posterior middle part of cuff side (lateral pharynx); posterior tube (oropharynx); backplate (posterior pharynx); and anterior middle part of the cuff side (pyriform fossa) (Figure 1). All sensors were zeroed in water 0.25 cm deep at 37°C before insertion.

A standard anesthesia protocol was followed and routine monitoring was applied. Anesthesia was induced with propofol 2.5 mg/kg and was maintained with 100% O₂ and sevoflurane 1%-2%. Muscle relaxation was achieved with atracurium 0.5 mg/kg. Two experienced LMA users (>1000 insertions) inserted/ fixed the LMA according to the manufacturer's instructions (5). A size 5 LMA was used for all patients (6). Measurements were made with the head and neck in the neutral position with the occiput rested on a firm pillow 7 cm in height. The pilot balloon was attached via a three-way tap to a 10-mL syringe and a calibrated pressure transducer accurate to 5%. The intracuff pressure was reduced to -55 cm H₂O *in vitro*. Pharyngeal mucosal pressures, intracuff pressures, airway sealing pressures, and fiberoptic position were documented at zero volume and after each additional 10-mL increase up to 40 mL (maximal recommended cuff volume). The fiberoptic position of the LMA was determined by using a proposed scoring system (7), and any displacement of the cuff from the periglottic tissues was noted. The airway sealing pressure was measured by closing the expiratory valve of the circle system at a fixed gas flow of 3 L/min and noting the airway pressure at which the dial on the aneroid manometer reached equilibrium. The position of the anterior tip sensor was verified at the end of the procedure by observation of a pressure spike during the

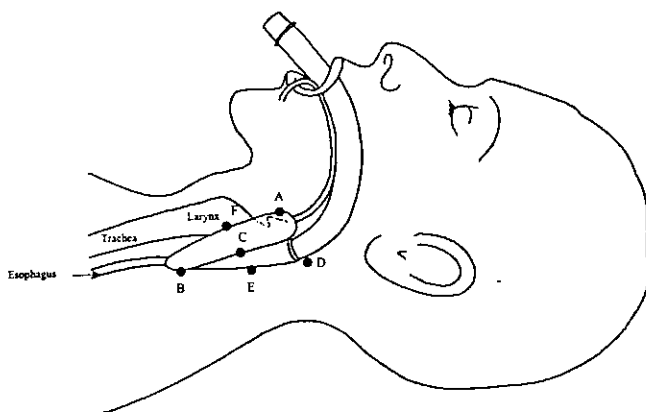


Figure 1. Location of sensors on laryngeal mask airway (corresponding anatomical area): A = anterior base of cuff (base of tongue); B = posterior tip of cuff (hypopharynx); C = posterior middle part of cuff side (lateral pharynx); D = posterior tube (oropharynx); E = backplate (posterior pharynx); and F = anterior middle part of the cuff side (pyriform fossa).

application of gentle cricoid pressure. The position and orientation of the sensors were checked after removal by visual inspection. The accuracy of the probes was tested before and after use in each patient by submerging the cuff portion in water at 37°C to a depth of 13.6 cm (10 mm Hg) and noting the pressure readings.

The distribution of data was determined by using Kolmogorov-Smirnov analysis. Statistical analysis was performed by using paired *t*-test (normally distributed data), Friedman's two-way analysis of variance (non-normally distributed data), and regression analysis. The relationship between mucosal pressure and other variables was determined by using the Pearson product-moment correlation coefficient. Unless otherwise stated, data are presented as mean (95% confidence intervals). Significance was taken as $P < 0.05$.

Results

The mean (range) age, height, weight, and body mass index were 46 (24-78) yr, 171 (150-185) cm, 70 (45-91) kg, and 24 (20-32) kg/m, respectively. The male to female ratio was 10:10. All LMAs were inserted at the first attempt and were positioned correctly as judged by fiberoptic laryngoscopy and the cricoid pressure spike. The position/orientation of the sensors was identical, and the pressures were accurate before and after usage. The median (range) fiberoptic score was 2.8 (1-4). There was no displacement of the cuff from the periglottic tissues. The highest mean mucosal pressure was in the oropharynx, and the lowest was in the posterior pharynx (Table 1). Mucosal pressures increased with increasing intracuff pressure and cuff volume, but the rate of increase varied among locations (Table 2). The airway sealing pressure increased with increasing intracuff volume from 0 to 10 mL ($P < 0.0001$) and 10 to 20 mL ($P = 0.0001$), was unchanged from 20 to 30 mL, and decreased from 30 to 40 mL ($P = 0.005$). The airway sealing pressure was higher than pharyngeal mucosal pressure until the intracuff volume was ≥ 30 mL. There was no correlation between mucosal pressures and airway sealing pressure at any location.

Discussion

Two studies by this group have demonstrated that the airway sealing pressure with the LMA are higher at low, rather than high, intracuff volumes (2) and pressures (3). The data from the current study confirm these findings and show that there is no correlation between airway sealing pressure and transmitted pharyngeal mucosal pressure. This supports the concept that it is the conformity of the LMA cuff with the

Table 1. Airway Sealing Pressures (ASP), Fiberoptic Scores (FOS), Intracuff Pressures (ICP), and Mucosal Pressures with Increasing Cuff Volume

Volume (mL)	ASP (cm H ₂ O)	FOS (4/3/2/1) ^a	ICP (cm H ₂ O)	A	B	C	D	E	F
0	14 (11 to 16)	0/12/6/1	-26 (-23 to 28)	2 (0 to 4)	3 (1 to 4)	2 (0 to 3)	4 (2 to 7)	1 (0 to 2)	6 (4 to 8)
10	20 (16 to 23)	2/10/6/1	29 (19 to 41)	7 (4 to 11)	5 (3 to 7)	4 (2 to 5)	7 (3 to 11)	2 (1 to 2)	8 (5 to 10)
20	26 (22 to 29)	4/11/3/1	69 (55 to 80)	16 (10 to 23)	11 (7 to 14)	5 (2 to 7)	23 (5 to 41)	2 (1 to 3)	9 (7 to 12)
30	26 (23 to 30)	6/6/6/1	120 (101 to 138)	24 (8 to 39)	17 (12 to 23)	5 (2 to 8)	44 (15 to 73)	2 (1 to 3)	9 (7 to 12)
40	24 (21 to 27)	5/5/7/2	190 (177 to 202)	27 (8 to 46)	25 (16 to 34)	5 (3 to 8)	54 (20 to 87)	2 (1 to 3)	9 (6 to 12)
Total	22 (20 to 24)	17/44/28/6	76 (61 to 92)	15 (10 to 21)	12 (9 to 15)	4 (3 to 5)	26 (16 to 36)	2 (1 to 2)	8 (7 to 9)

Data are mean (95% CI).
A = base of tongue, B = hypopharynx, C = lateral pharynx, D = oropharynx, E = posterior pharynx, F = pyriform fossa.
^a Fiberoptic score 4 = only vocal cords visible, 3 = vocal cords plus posterior epiglottis, 2 = vocal cords plus anterior epiglottis, 1 = vocal cords not seen.

pharynx, rather than the pressure the cuff exerts on the pharyngeal mucosa, that determines the efficacy of the seal. Our finding that airway sealing pressure was almost always higher than transmitted pharyngeal mucosal pressure further supports this hypothesis. Leak-free ventilation is possible with some high-volume, low-pressure cuffed tracheal tubes when the airway sealing pressure is higher than mucosal pressure (8). More recently, a tracheal tube in which the cuff was replaced by a no-pressure sealing system positioned within the larynx and made of 12-20 toroidal layers of thin polyurethane was shown to have an airway sealing pressure of 35-50 cm H₂O (9). We postulate that the soft, semiinflated cuff of the LMA can form a more effective seal because it is compliant enough to adapt to a variety of different pharyngeal geometries. Maximally inflated cuffs are less able to conform because they are too rigid to adapt.

We found that transmitted pharyngeal mucosal pressures are unevenly distributed across the surface of the LMA. Three forces may be acting on the pharyngeal mucosa: the tension in the cuff, elastic recoil or muscular activity of submucosal tissues, and elastic recoil from the curved tube. These forces vary not only with location, but also with the physical properties of the LMA and pharynx: the soft cuff, rigid tube, and backplate of the LMA versus the soft muscle, rigid cartilage, and bone of the pharynx. There may also be movement between the two surfaces when the cuff is inflated. We found that pharyngeal mucosal pressures increase at different rates or remain static despite increases in intracuff pressure/volume. This suggests that, as the cuff shape changes, the point of contact shifts or the adjacent tissue is highly distensible.

Pharyngeal capillary perfusion pressures have not been measured but are probably similar to those in the trachea. It has been recommended that tracheal mucosal pressures be <41 cm H₂O (30 mm Hg) for safe prolonged intubation (10). We have shown that mean mucosal pressure exceeded 41 cm H₂O only in the oropharynx and only when the cuff volume and intracuff pressure were >20 mL and >69 cm H₂O, respectively. At this location, the curved tube is adjacent to rigid vertebral body and is pressed firmly into it by the expanding cuff and its own elastic recoil. One study showed that lowering the cuff pressure reduces the incidence of sore throat (11), and another study showed that it has no effect (12). Two noncomparative studies in which cuff pressure was limited to 60 cm H₂O reported a very low incidence (5%) of sore throat (13,14).

We conclude that the efficacy of the seal is not related to pharyngeal mucosal pressure. Pharyngeal mucosal pressures are generally lower than those considered safe for the tracheal mucosa during prolonged intubation.

Table 2. The Relationship Among Leak Pressure, Intracuff Pressure, Intracuff Volume, and Mucosal Pressure

	Leak pressure		Intracuff pressure		Cuff volume	
	PPCC	P value	PPCC	P value	PPCC	P value
Base of tongue	-0.05	NS	0.32	0.001	0.36	0.0002
Hypopharynx	0.31	NS	0.56	<0.0001	0.60	<0.0001
Lateral pharynx	0.15	NS	0.28	0.04	0.24	0.02
Oropharynx	0.06	NS	0.40	<0.0001	0.39	<0.0001
Posterior pharynx	-0.16	NS	0.18	0.05	0.23	0.02
Pyramidal fossa	-0.04	NS	0.24	0.04	0.16	NS

NS = not significant, PPCC = Pearson product-moment correlation coefficient.

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