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Pharyngeal Mucosal Pressure and Perfusion

A Fiberoptic Evaluation of the Posterior Pharynx in Anesthetized Adult Patients with a Modified Cuffed Oropharyngeal Airway

Joseph Brimacombe, M.B., Ch.B., F.R.C.A., M.D., Christian Keller, M.D.,† Fritz Pühringer, M.D.‡*

Background: **Pharyngeal airway devices can exert substantial pressures against the pharyngeal mucosa. The authors assess the relation between pharyngeal mucosal perfusion and directly measured mucosal pressure (MP) in the posterior pharynx using a fiberoptic technique with a modified cuffed oropharyngeal airway (COPA). The authors also measure *in vivo* intracuff pressure (CP), airway sealing pressure and MP at four locations using an unmodified COPA.**

Methods: **Twenty adult patients, American Society of Anesthesiologists status I or II, undergoing general anesthesia were allocated randomly to receive either (1) a COPA with a millimeter microchip sensor fixed on the external cuff surface to record distal posterior pharyngeal MP or (2) a COPA with a fiberoptic scope inserted inside the cuff to record digitized images of the distal posterior pharyngeal mucosa. MP and digitized images were obtained at the same location over an *in vivo* CP range of 10–160 cm H_2O in 10- to 20-cm H_2O increments. The digitized images were scored according to blood vessel caliber and mucosal color by two investigators blinded to MP and CP. In an additional 20 matched patients, *in vivo* CP, airway sealing pressure, and MP was measured at four different cuff locations (corresponding to the anterior, lateral, and posterior pharynx and the distal oropharynx) with increasing cuff volume.**

Results: **Blood vessel caliber and mucosal color was normal in all patients when the mean mucosal pressure was 17 cm H_2O. Blood vessel caliber was first reduced when the mean mucosal pressure was 34 cm H_2O. There was a progressive incremental reduction in blood vessel caliber and mucosal color when the mean mucosal pressure increased from 34 to 80 cm H_2O ($P \leq 0.05$). Complete blood vessel collapse and mucosal paling first occurred with the mean mucosal pressure was 73 cm H_2O and was present in 90% of patients when the mean mucosal pressure was 80 cm H_2O. Mean MP was always higher in the posterior pharynx compared with the other locations when the cuff volume was 20 ml or greater ($P < 0.001$). *In vivo* CP is an excellent predictor of mucosal pressure. Mean (95% confidence interval [CI]) MP in the posterior pharynx was 35 (5–67) and 78 (50–109) cm H_2O when the airway sealing pressure was 10 (6–16) and 17 (13–21) cm H_2O respectively.**

Conclusion: **Pharyngeal mucosal perfusion is reduced progressively in the posterior pharynx when MP is increased from 34 to 80 cm H_2O with the COPA. CP provides reliable information about MP and should be less than 120 cm H_2O to prevent mucosal ischemia. (Key words: Anesthesia equipment; pharyngeal morbidity; pharyngeal physiology.)**

PHARYNGEAL airway devices can exert mucosal pressures greater than those considered safe for the tracheal mucosa.[1] Recent studies have shown that mucosal pressures for the cuffed oropharyngeal airway (COPA),[2] laryngeal mask airway,[2,3] and intubating laryngeal mask airway[3] vary from 4–53, 1–75 and 7–160 cm H_2O, respectively, depending on cuff volume and anatomic location. Tracheal mucosal perfusion in humans progressively decreases when mucosal pressures exceed 30 cm H_2O and ceases when pressures are 50 cm H_2O,[4] but there are no published data about pharyngeal mucosal perfusion. In the following study, we assess the relation between pharyngeal mucosal perfusion and directly measured mucosal pressure in the posterior pharynx using a fiberoptic technique[4] with a modified COPA. We also measure *in vivo* intracuff pressure (CP), airway sealing pressure (ASP), and mucosal pressure (MP) at four locations with an unmodified COPA.

Methods

Twenty adult patients, American Society of Anesthesiologists status I or II, undergoing general anesthesia for

* Clinical Professor, Department of Anaesthesia and Intensive Care, University of Queensland, Cairns Base Hospital.

† Consultant Anaesthetist, Department of Anaesthesia and Intensive Care Medicine, Leopold-Franzens University.

‡ Associate Professor, Department of Anaesthesia and Intensive Care Medicine, Leopold-Franzens University.

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Address reprint requests to Dr. Brimacombe: Department of Anaesthesia and Intensive Care, Cairns Base Hospital, The Esplanade, Cairns 4870, Australia. Address electronic mail to: 100236,2343@compuserve.com

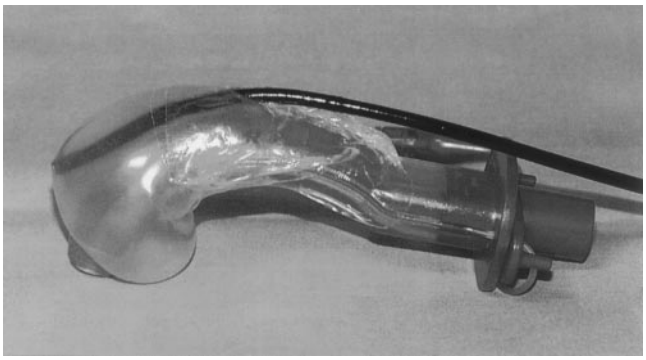

Fig. 1. Mucosal pressure sensor attached to the distal posterior cuff of the cuffed oropharyngeal airway.

minor surgery were allocated randomly (by opening a sealed envelope) to receive either (1) a COPA with a strain-gauge silicone microchip sensor fixed on the external surface of the distal posterior cuff (group 1) or (2) a COPA with a fiberoptic scope inserted into the cuff to provide a view of the mucosa approximately 1 cm in diameter from within the distal posterior cuff (group 2). Ethics committee approval and written informed consent were obtained. Patients were excluded if they were at risk of aspiration, had respiratory tract disease, or were otherwise unsuitable for the COPA.

Mucosal pressure was measured using a strain-gauge silicone microchip sensor (Codman MicroSensor; Johnson and Johnson Medical Ltd., Bracknell, UK) attached to the external surface of the COPA with a clear adhesive dressing 45 μm thick (Tegaderm; 3M, Ontario, Canada). The sensor tip had a diameter of 1.2 mm and a length of 6 mm; the sensor cable had a diameter of 0.7 mm, a length 100 cm, a functional pressure range of -50 to 250 mmHg, a temperature sensitivity of less than 0.1 mmHg/°C, a zero drift of less than 3 mmHg/24 h, a frequency response of 0–10 Hz, and was accurate to $\pm 2\%$ (manufacturer's specifications). Attachment of the sensor was performed manually by placing the sensor in the correct position on the distal posterior portion of the COPA cuff and then overlaying it with the adhesive dressing (fig. 1). The sensing element in the sensor tip was orientated such that its flat surface was parallel to and directed 90° away from the COPA surface. This ensured that the flat surface of the sensing element was directly facing the mucosa. The position (orientation) of the sensor was checked *in vitro* over the entire inflation range before and after use in each patient by visual inspection. The sensor was zeroed after attachment to the COPA. The accuracy of the measurement system was tested *in vitro* 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 mmHg) and 40.8 cm (30 mmHg) and noting the pressure readings from the sensor.

Digital images of the mucosa were obtained using a modification of a technique used by Seegobin and van Hassalt[4] to measure tracheal mucosal perfusion. The COPA cuff, which is transparent, was modified *in vitro* to accommodate a fiberoptic scope with an external diameter of 3.6 mm. A small hole was made in the proximal posterior cuff, the fiberoptic scope was inserted so that it was in position within the distal posterior cuff, and the hole was closed with an adhesive dressing (fig. 2). The fiberoptic scope was connected to a recording system that produced high-resolution digital images of the mucosa (including blood vessels) in contact with the distal posterior cuff. Both the sensor and the fiberoptic scope were located in identical positions on each COPA.

A standard anesthesia protocol was followed. Anesthesia was induced with 1 μg/kg fentanyl and 2.5 mg/kg propofol and maintained with oxygen in air (30% O_2) and a propofol infusion of 6 mg $\cdot$ kg^{-1} $\cdot$ h^{-1}. Muscle relaxation was with 0.6 mg/kg rocuronium. The train-of-four count was maintained at one or less. A No. 11 COPA device was used for all patients. The integrity of the cuff was checked preinsertion by inflation with 20-ml air and visual inspection. The cuff was then evacuated fully, and an experienced COPA user (C.K., $>$ 200 uses) inserted and fixed the device according to the manufacturer's instructions.[5]

Mucosal pressure, or the fiberoptic view, was documented at an CP of 10 cm H_2O and after each additional 10 cm H_2O, up to 80 cm H_2O, and then after each additional 20 cm H_2O, up to 160 cm H_2O. The CPs were adjusted using a Digital Cuff Pressure Monitor (Mallin-

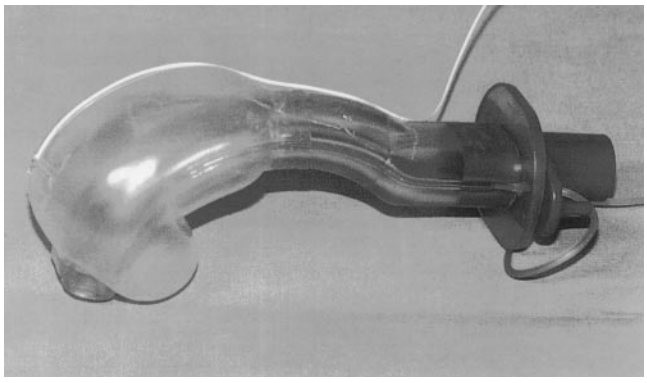

Fig. 2. Fiberoptic scope within the distal posterior cuff of the cuffed oropharyngeal airway.

Table 1. Physical Characteristics and Mean Blood Pressure during Measurements

	Group 1: Mucosal Pressure	Group 2: Fiberoptic Assessment	Group 3: Intracuff *versus* Mucosal Pressure
N	10	10	20
Age (yr)	37 (22–56)	39 (22–64)	34 (19–65)
Weight (kg)	71 (50–110)	70 (55–84)	72 (51–92)
Height (cm)	171 (158–188)	170 (152–183)	170 (150–185)
Male:female	5:5	4:6	10:10
Blood pressure (mmHg)	85 (75–94)	89 (77–99)	—

Data are mean (95% CI) or numbers.

ckrodt Medical, Athlone, Ireland) before each measurement. Care was taken to avoid displacement of the COPA during testing. Measurements were made at zero airway pressure with the head–neck in the neutral position, with the occiput resting on a firm pillow 7 cm in height and with chin lift applied. Between measurements, the patients' lungs were inflated manually with a lightweight circuit connected to the COPA. During measurements, the blood pressure was measured at 2-min intervals.

The digitized images were coded and scored by two observers blinded to the CP, the MP, and to each other's scores. Blood vessel caliber was scored as follows: 1: normal diameter; 2: first reduction in diameter; 3: $\geq$ 50% reduction in diameter; 4: completely collapsed (no vessels seen). Mucosal color was scored as follows: 1: uniform pink; 2: first pale areas detected; 3: $\geq$ 50% pale areas; 4: completely pale.

In an additional 20 paralyzed, anesthetized patients (matched with groups 1 and 2 for age, height, weight and gender), we measured *in vivo* CP, ASP, and MP at four cuff locations using an unmodified No. 11 COPA (group 3). Sensors were attached to (approximate corresponding mucosal areas): (1) the anterior middle part of the cuff (base of tongue); (2) the lateral cuff (lateral pharynx); (3) the proximal posterior cuff (distal oropharynx) and (4) the posterior cuff (posterior pharynx), as in group 1. The pilot balloon was attached *via* a three-way tap to a 10-ml syringe and a calibrated pressure transducer accurate to $\pm$5%. The CP was reduced to $-$55 cm H_2O *in vitro*. The COPA was inserted and fixed and the sensors applied and tested as described previously. *In vivo* CP, ASP, and MP were documented at zero volume and after each additional 10 ml, up to 60 ml.

Statistics

The distribution of data was determined using Kolmogorov-Smirnov analysis. Statistical analysis was with paired *t* test for demographic data. Multinominal logistic regression analysis was used for comparing MP with blood vessel caliber and mucosal color score. The relation between MP and *in vivo* CP was determined using Pearson product moment correlation coefficient. Interobserver reliability for blood vessel caliber and mucosal color was determined using a κ statistic. The reliability of cuff volume and *in vivo* CP to predict MP was determined with the intraclass correlation coefficient (ICC). Scores for statistical measurements with the κ statistic and intraclass correlation coefficient range from 0 to 1, in which the former shows no reliability and the latter shows perfect reliability. A score greater than or equal to 0.75 is considered excellent. Unless otherwise stated, data are presented as the mean (95% confidence intervals). Significance was taken as $P < 0.05$.

Results

There were no demographic differences among groups, and mean blood pressure was similar during measurements between the fiberoptic and MP groups (table 1). The position and orientation of the sensors were identical and the pressures were accurate before and after usage. Mucosal pressures, blood vessel caliber and mucosal color scores are presented in table 2. Interobserver reliability for blood vessel caliber and mucosal color was excellent at 0.94 and 0.9, respectively. For group 1, there was a significant correlation between *in vivo* CP and MP ($P < 0.001$). For group 2, there was a significant correlation between *in vivo* CP and blood vessel caliber ($P < 0.001$) and mucosal color ($P < 0.001$). Blood vessel caliber and mucosal color were normal in all patients when the mean MP was 17 cm H_2O. Blood vessel caliber was first reduced when the mean MP was 34 cm H_2O. There was a significant reduction in blood vessel caliber and mucosal color when the mean MP increased from 34 to 38 cm H_2O ($P = 0.05$), from 41 to 47 cm H_2O ($p = 0.05$), from 68 to 73 cm H_2O ($P \leq 0.04$), and from 73 to 80 cm H_2O ($P < 0.001$). Complete blood vessel collapse and mucosal paling first occurred with the mean MP was 73 cm H_2O and was

Table 2. Mucosal Pressure, Blood Vessel Caliber, and Mucosal Color Scores over the Intracuff Pressure Range 0–160 cmH_2O

Intracuff Pressure	Mucosal Pressure	Caliber Score (1/2/3/4; n)	*P*	Color Score (1/2/3/4; n)	*P*
10	9 (1–21)	10/0/0/0		10/0/0/0	
20	17 (3–32)	10/0/0/0	NS	10/0/0/0	NS
30	34 (4–65)	6/4/0/0	0.05	8/2/0/0	NS
40	38 (8–67)	1/9/0/0	<0.001	3/7/0/0	<0.01
50	41 (12–71)	1/9/0/0	NS	2/8/0/0	NS
60	47 (17–78)	0/5/5/0	0.05	0/8/2/0	0.05
70	54 (23–84)	0/2/8/0	NS	0/3/7/0	<0.01
80	59 (27–90)	0/1/9/0	NS	0/2/8/0	NS
100	63 (33–94)	0/1/9/0	NS	0/1/9/0	NS
120	68 (37–98)	0/0/10/0	0.04	0/1/9/0	NS
140	73 (42–104)	0/0/6/4	0.01	0/0/6/4	<0.001
160	80 (50–110)	0/0/1/9		0/0/1/9	<0.001

Data are mean (95% CI) or numbers. Pressures are in cmH_2O. Blood vessel caliber scores: 1, normal diameter; 2, first reduction in diameter; 3, ≥50% reduction in diameter; 4, complete collapse (vessels not seen). Mucosal color scores: 1, uniform pink; 2, first pale areas detected; 3, ≥50% pale areas; 4: completely pale. NS = not significant.

present in 90% of patients when the mean MP was 80 cm H_2O. *In vivo* CP, ASP, and MP at the four cuff locations are presented in table 3. Mucosal pressure was always significantly higher in the distal pharynx compared with the other locations when the cuff volume was 20 ml or more ($P < 0.001$). There was a significant correlation between *in vivo* CP and MP at all mucosal locations (table 4). *In vivo* CP is an excellent predictor of MP.

Discussion

These data show that mucosal perfusion is reduced progressively in the posterior pharynx when MP is increased from 34 to 80 cm H_2O. These values are higher than those obtained for the tracheal mucosa by Seegobin and van Hassalt[4] (30–50 cm H_2O) using a similar technique. We measured MP directly, whereas Seegobin and van Hassalt measured *in vivo* CP and assumed that MPs were similar.[4] Directly measured tracheal MP tends to be lower than *in vivo* CP.[6,7] The CP at which tracheal mucosal blood flow is reduced in humans using the fiberoptic technique[4] is similar to the value obtained in dogs using the radioactive microsphere technique.[8]

We measured mucosal perfusion in the posterior pharynx. This location was selected because positioning the fiberoptic scope at other intracuff locations was difficult technically. It has been shown in the rabbit[9] and in humans[4] that tracheal mucosal blood flow is less over the tracheal rings compared with the membranous portion.[9] It is possible that blood flow might be different in mucosa overlaying protruding bony or cartilaginous pharyngeal surfaces. Ideally, we would have measured MP and perfusion in each patient. However, during a pilot study, we found that the adhesive necessary to fix the pressure probe impeded the quality of the images. We also were concerned that the pressure probe or adhesive might influence mucosal perfusion.

We found that MP for the COPA is greatest in the posterior pharynx. This supports the findings of our previous study[2] and suggests that if perfusion to the

Table 3. *In Vivo* Intracuff Pressure, Airway Sealing Pressure, and Mucosal Pressures at Four Cuff Locations with Increasing Cuff Volume (ml)

Cuff Volume	*In Vivo* Intracuff Pressure	Airway Sealing Pressure	A: Base of Tongue	B: Lateral Pharynx	C: Distal Oropharynx	D: Posterior Pharynx
0	−28 (−40–−12)	4 (1–5)	2 (0–6)	0	4 (0–9)	0
10	8 (−5–15)	7 (4–10)	4 (0–14)	5 (0–16)	1 (0–6)	7 (2–19)
20	37 (20–52)	10 (6–16)	9 (2–23)	9 (1–21)	2 (0–5)	35 (5–67)
30	74 (51–92)	12 (7–18)	11 (3–28)	12 (2–26)	3 (0–7)	56 (22–87)
40	106 (86–129)	14 (8–20)	21 (5–39)	19 (9–44)	5 (0–12)	65 (35–99)
50	145 (125–167)	16 (9–22)	31 (12–45)	24 (15–51)	10 (2–23)	70 (40–105)
60	217 (180–248)	17 (13–21)	39 (15–55)	30 (17–55)	13 (3–25)	78 (50–109)

Data are mean (95% CI). Pressures are in cmH_2O.

Table 4. Pearson Product–Moment Correlation Coefficient (PPCC) and Intraclass Correlation Coefficient (ICC) for Directly Measured Mucosal Pressures at Four Locations with *In Vivo* Intracuff Pressure

	PPCC	*P*	ICC
A: Base of tongue	0.889	0.01	0.85
B: Lateral pharynx	0.924	0.001	0.92
C: Distal oropharynx	0.909	0.01	0.90
D: Posterior pharynx	0.856	0.01	0.83

PPCC: +1 = perfect positive correlation; 0 = no correlation; −1 = perfect negative correlation. ICC: ≥0.75 = excellent reliability; 0.41–0.74 = moderate reliability; ≤0.40 = poor.[12]

NS = not significant.

posterior pharynx is adequate, it probably will be adequate in other parts of the pharynx. We also found that MP is high even when the ASP is relatively low (10 cm H_2O). We speculate that this accounts for the high incidence of sore throat (35%) found in a recent double-blind trial in which the mean CP was 72 cm H_2O and the ASP was 16 cm H_2O.[10] There are no published studies assessing the relation between pharyngeal MP, duration of application, and mucosal damage. However, Nordin[11] showed that tracheal mucosal damage increases with increasing MP and, to a lesser extent, duration of application, although this finding predates the use of biocompatible cuff materials.

Finally, our data show that *in vivo* CP with the COPA is an excellent predictor of directly measured pharyngeal MP. By contrast, *in vivo* CP with the tracheal tube is only a moderate predictor of tracheal MP.[7] We found that mucosal perfusion is reduced in the posterior pharynx in approximately 30% of patients when the CP is 30 cm H_2O and stops in approximately 40% of patients when the CP is 140 cm H_2O. We recommend that CP should be monitored and maintained at 120 cm H_2O or less to prevent mucosal ischemia. Ideally, CP should be less than 30 cm H_2O, but the effectiveness of the seal is inadequate for most clinical purposes at this CP.

We conclude that pharyngeal mucosal perfusion is reduced progressively in the posterior pharynx when MP is increased from 34 to 80 cm H_2O with the COPA. Intracuff pressure provides reliable information about MP and should be less than 120 cm H_2O to prevent mucosal ischemia.

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References

1. Lewis FR, Schlobohm RM, Thomas AN: Prevention of complications from prolonged tracheal intubation. Am J Surg 1978; 135:452–7

2. Keller C, Brimacombe J: Mucosal pressures for the cuffed oropharyngeal airway versus the laryngeal mask airway. Br J Anaesth 1999; 82:922–4

3. Keller C, Brimacombe J: Pharyngeal mucosal pressures, airway sealing pressures and fiberoptic position with the intubating versus the standard laryngeal mask airway. ANESTHESIOLOGY 1999; 90:1001–6

4. Seegobin RD, van Hasselt GL: Endotracheal cuff pressure and tracheal mucosal blood flow: Endoscopic study of effects of four large volume cuffs. Br Med J 1984; 288:965–8

5. Cuffed Oropharyngeal Airway Instruction Manual. St Louis, Mallinckrodt, Critical Care Division, 1997

6. Dobrin P, Canfield T: Cuffed endotracheal tubes: Mucosal pressures and tracheal wall blood flow. Am J Surg 1977; 133:562–8

7. Brimacombe J, Keller C, Giampalmo M, Sparr HJ, Berry A: Direct measurement of mucosal pressures exerted by cuff and non-cuff portions of tracheal tubes with different cuff volumes and head and neck positions. Br J Anaesth 1999; 82:708–11

8. Bunegin L, Albin MS, Smith RB: Canine tracheal blood flow after endotracheal tube cuff inflation during normotension and hypotension. Anesth Analg 1993; 76:1083–90

9. Nordin U, Lindholm C, Walgast M: Blood flow in the rabbit tracheal mucosa under normal conditions and under the influence of tracheal intubation. Acta Anaesthesiol Scand 1977; 21:81–94

10. Brimacombe JR, Brimacombe JC, Berry A, Morris R, Mecklem D, Clarke G, Barry J, Kirk T: A comparison of the laryngeal mask airway and cuffed oropharyngeal airway in adult patients. Anesth Analg 1998; 87:147–52

11. Nordin U: The trachea and cuff induced tracheal injury. An experimental study on causative factors and prevention. Acta Otolaryngol Suppl (Stockh) 1976; 345:1–71

12. Fleiss JL: Reliability of measurements, The Design and Analysis of Clinical Experiments. New York, John Wiley and Sons, 1986