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The laryngeal mask airway in infants and children

Purpose: To compare the effectiveness of various laryngeal mask airway (LMA) sizes and their performance during positive pressure ventilation (PPV) in paralyzed pediatric patients.

Methods: Pediatric patients (n=158), < 30 kg, ASA 1 or 2 were studied. After paralysis, an LMA of the recommended size was inserted and connected to a volume ventilator. Fibreoptic bronchoscopy (FOB) was performed and graded: 1, larynx only seen; 2, larynx and epiglottis posterior surface seen; 3, larynx, and epiglottis tip or anterior surface seen—visual obstruction of epiglottis to larynx: < 50%; 4, epiglottis down-folded, and its anterior surface seen—visual obstruction of epiglottis to larynx: > 50%; 5, epiglottis down-folded and larynx not seen directly. Inspiratory and expiratory tidal volumes (V_T), and airway pressure were measured by a pneumo-tachometer, and the fraction of leakage (F_L) was calculated. In 79 cases, LMA was used for airway maintenance throughout surgery.

Results: Successful LMA placement was achieved in 98% of cases: three failures were due to gastric insufflation. For LMA # 1, 1.5, 2, and 2.5, FOB grades [median (range)] were 3(1-5), 3(1-5), 1(1-5) and 1(1-3) respectively. In smaller LMAs, the cuff more frequently enclosed the epiglottis ($P <$ .001). F_L of LMA # 1 was higher than those of LMA # 1.5 and LMA # 2.5 ($P <$ .05), and F_L of LMA # 2 was higher than that of LMA # 2.5 ($P <$ .05). In the 79 patients, the number of patients experiencing complications decreased as LMA size increased ($P <$ .05).

Conclusion: Use of the LMA in smaller children results in more airway obstruction, higher ventilatory pressures, larger inspiratory leak, and more complications than in older children.

Objectif : Comparer l'efficacité de masques laryngés (ML) de tailles différentes et leur performance pendant la ventilation à pression positive (VPP) chez des enfants curarisés.

Méthode : On a étudié 158 patients pédiatriques, de moins de 30 kg et d'état physique ASA I ou II. Après la curarisation, un ML de taille appropriée a été inséré et raccordé à un ventilateur volumique. La fibroscopie bronchique (FB) réalisée a été graduée : 1, vision du larynx seulement ; 2, vision du larynx et de de la surface postérieure de l'épiglotte ; 3, vision du larynx, de la pointe et de la surface antérieure de l'épiglotte—vision du larynx obstruée par l'épiglotte : < 50 %; 4, épiglotte repliée vers le bas et vision de sa surface antérieure—vision du larynx obstruée par l'épiglotte : > 50 %; 5, épiglotte repliée vers le bas et vision indirecte du larynx. On a mesuré les volumes courants inspiratoire et expiratoire (VT) et la pression des voies aériennes avec un pneumotachomètre et on a calculé le pourcentage de fuite (PF). Dans 79 cas, le ML a été utilisé pour maintenir la perméabilité des voies aériennes tout au long de l'intervention.

Résultats : La mise en place réussie du ML a été réalisée dans 98 % des cas : trois échecs étaient liés à une insufflation gastrique. Les grades [médiane (intervalle)] de FB ont été, pour les ML 1, 1,5, 2 et 2,5 de 3(1-5), 3(1-5), 1(1-5) et 1(1-3) respectivement. Dans le cas des ML plus petits, le ballonnet couvrait fréquemment l'épiglotte (P < 0,001). Le PF du ML 1 a été plus élevé que ceux des ML 1,5 et 2,5 (P < 0,05); le PF du ML 2 a été plus élevé que celui du ML 2,5 (P < 0,05). Parmi les 79 patients, plus la taille du ML était grande, moins nombreux étaient ceux qui présentaient des complications (P < 0,05).

Conclusion : L'utilisation du ML chez les jeunes enfants entraîne davantage d'obstruction des voies aériennes, des pressions ventilatoires plus élevées, une fuite inspiratoire plus grande et plus de complications que chez les enfants plus âgés.

ALTHOUGH the laryngeal mask airway (LMA) has been recommended in situations, where positive pressure ventilation (PPV) is necessary, there are few investigations of its utility in this situation.[1–8] We were unable to find any studies about LMA insertion, its positioning, and/or its effect on controlled ventilation in paralyzed pediatric patients. No LMA study has been performed with the recommended sizes in large numbers of infants and young children.

Several LMA studies of infants have been reported.[7–12] In some,[7,9,10] only a few infants weighing > 5 kg were included. Size # 1 LMA (LMA 1) was used for 33 infants, but the mean weight was 5.6 kg.[11] In a

study of 50 infants, whose weight range was 3.8-10.0 kg, only the LMA 1 was used.[12] These previous studies were performed in spontaneously breathing patients. Since size # 1.5 LMA (LMA 1.5), the recommended body weight of which is 5 - 10 kg, became available recently, a study of LMA 1, 1.5 or size # 2 LMA (LMA 2) was warranted.

There were three objectives for this study: first, to assess the position of the LMA when it is inserted in paralyzed pediatric patients; second, to evaluate the competence of PPV when the LMA is used to maintain airway patency in paralyzed pediatric patients; third, to compare the efficacy of the various LMA sizes using the above measures.

Materials and methods

After institutional ethics board approval and informed parental consent, pediatric patients (n=158; 110 male, 48 female) weighing < 30 kg and of ASA physical status 1 or 2 were studied during elective surgical procedures. Patients with lung disease, upper airway abnormality or infection, or undergoing intra-abdominal surgery were excluded. In the operating room, anesthesia was induced with thiopental iv or via a face mask with O_2-N_2O- halothane and, if not already in place, an intravenous line was established. Three minutes after 0.15 mg·kg^{-1} vecuronium iv, neuromuscular blockade was assessed with train-of-four stimulation. Anesthesia was maintained with O_2-air-isoflurane, and paralysis was maintained with repeated administration of vecuronium iv.

An LMA 1 was used for infants < 5 kg; an LMA 1.5 for 5 - 10 kg; an LMA 2 for 10 - 20 kg; and a size # 2.5 LMA (LMA 2.5) for 20 - 30 kg. An experienced investigator inserted all the LMAs following the manufacturer's recommendations.[13] The leak pressure was measured by auscultation after the cuff was inflated with air to 80% of the maximum recommended inflation volume, and again after injecting an additional 10%. If there was a decrease in leak pressure after injecting an additional 10%, 80% of the maximum inflation volume was used unless, another 10% more would achieve 100% of the maximum volume. If leak pressure at 100% was lower than that at 90%, 90% was selected. Otherwise, 100% of the maximum recommended inflation volume was used. Namely, the inflation volume at a higher leak pressure was selected. All parameters including tidal volume (V_T) and peak inspiratory pressure (PIP) were measured after the end-tidal CO_2 partial pressure ($P_{ET}CO_2$) was stable. The LMA was connected to a volume ventilator (Dameca A/S, Copenhagen, Denmark) incorporated into the anesthesia machine, and PPV with inspiratory to expiratory

ratio of 1:2 was instituted. The V_T was set at about 10 ml·kg^{-1} and, depending on age, a respiratory rate of 20-40 ·min^{-1} was chosen to maintain the $P_{ET}CO_2$ at 30 - 35 mmHg. On a randomized basis, using odd or even hospital numbers, patients were assigned to LMA use throughout surgery or to endotracheal intubation. For infants < 10 kg, the LMA was connected to the ventilator via an infant circle system (Aika Medical Corp., Tokyo, Japan). A CP-100 neonatal pulmonary monitor (Bicore Monitoring Systems, Irvine, California, USA) with a disposable VarFlex® flow transducer was used to measure inspiratory and expiratory V_T. For children > 10 kg, a CP-100 adult pulmonary monitor (Bicore Monitoring Systems, Irvine, Calif.) was used. The CP-100 pulmonary monitor is a pneumo-tachometer, the flow transducer of which is inserted between the patient's LMA adapter and Y-connector. Measurements were taken over 10 breaths. The PIP was recorded from the pulmonary monitor reading. The fraction of leakage (F_L) (%) was defined as:

$$F_L = [(\text{inspiratory } V_T - \text{expiratory } V_T) / \text{inspiratory } V_T] \times 100.$$

The position and effectiveness of the LMA were assessed using the folllowing techniques and, once the position was clinically acceptable, no further adjustment to the LMA position was made. First, manual ventilation was possible with regular ETCO$_2$ display without gastric distention; second, bilateral breath sounds as heard by auscultation over axillae. If not acceptable, the LMA was removed and re-inserted. It was regarded as a failure if the positioning of LMA was not clinically acceptable after three attempts. The larynx was inspected through the self-sealing diaphragm of an elbow connector, using a fibreoptic bronchoscope (FOB; Olympus LF-P, Olympus Optical Co., Tokyo, Japan) located just proximal to the aperture bars, while an assistant prevented the LMA from moving. The FOB findings were defined as Grade 1, larynx only seen; Grade 2, larynx and epiglottis posterior surface seen; Grade 3, larynx, and epiglottis tip or anterior surface seen—visual obstruction of epiglottis to larynx: < 50%; Grade 4, epiglottis down-folded, and its anterior surface seen—visual obstruction of epiglottis to larynx: > 50%; Grade 5, epiglottis down-folded and larynx cannot be seen directly.

By placing a stethoscope on the stomach, gastro-esophageal insufflation at 30 cmH$_2$O airway pressure was qualitatively assessed by an independent observer. The observer measured the leak pressure by using a stethoscope placed on the neck, while the lungs were manually inflated at 5 cmH$_2$O intervals until an air leak was audible.

TABLE I PIP, V_T, F_L and leak pressure at each LMA size

	Age (months)	Body Weight (kg)	PIP (cmH₂O)	Inspiratory V_T (ml)	Expiratory V_T (ml)	F_L (%)	Leak Pressure (cmH₂O)
LMA # 1 (*n*=25)	1.6 ± 1.2	4.2 ± 1.0	18 ± 3*	32 ± 5	28 ± 5	12.0 ± 3.4	21 ± 10
LMA # 1.5 (*n*=41)	7.3 ± 5.6	7.5 ± 1.5	18 ± 3†	74 ± 29	69 ± 28	7.8 ± 3.6‡	21 ± 8
LMA # 2 (*n*=68)	39 ± 20	15 ± 3	16 ± 3	198 ± 41	174 ± 31	11.4 ± 7.6	21 ± 8
LMA # 2.5 (*n*=21)	81 ± 17	24 ± 3	14 ± 3	283 ± 36	263 ± 36	7.2 ± 2.4‡§	21 ± 11

LMA = laryngeal mask airway, PIP = peak inspiratory pressure, V_T = tidal volume, F_L = fraction of leakage.
Data are mean ± SD.
*$P < .05$, compared with PIP for LMA 2.5; †$P < .05$, compared with PIP for LMA 2 & 2.5.
‡$P < .05$, compared with F_L for LMA 1; §$P < .05$, compared with F_L for LMA 2.
F_L (%) = [(inspiratory V_T - expiratory V_T) / inspiratory V_T] × 100.

If $P_{ET}CO_2$ increased, but was still < 45 mmHg, head flexion,[14] head extension or mandibular elevation was tried. If all procedures failed, the cuff volume was changed. When $P_{ET}CO_2$ increased to > 45 mmHg, the LMA was removed and changed to an endotracheal tube. At the end of surgery, FOB was performed to recheck the position of the LMA.

Statistical analysis
The PIPs were compared with Kruskal-Wallis test. Analysis of variance (ANOVA) with Duncan's test for multiple comparisons was used to compare the F_L of each LMA size. FOB findings of each LMA size were compared with ridit test. The duration of PPV was compared with ANOVA. While maintaining PPV through LMA, the number of patients with problems among the groups of each LMA size was compared using Fisher's exact test. A *P*-value < .05 was considered significant.

Results
Successful LMA placement was achieved at the first attempt in 97% (153/158) of cases. Two of the remaining cases were successful at the second attempt. There were three failures due to gastric insufflation: one each in LMA 1, 1.5 and 2. Continuous leakage was found in seven cases: two in LMA 1, three in LMA 1.5 and two in LMA 2. Cuff volumes used were 80% (16/155), 90% (16/155) or 100% (123/155) of the maximum recommended volumes.

The PIP varied with the LMA size (*P* < .001) (Table I): PIP of smaller LMAs was higher than that of larger LMAs. The F_L of LMA #1, 1.5, 2, and 2.5 (mean ± SD) was respectively 12.0 ± 3.4, 7.8 ± 3.6, 11.4 ± 7.6, and 7.2 ± 2.4; F_L of LMA 1 was higher

TABLE II LMA size and fibreoptic bronchoscopic finding when LMA was inserted after paralysis

	Bronchoscopic Grade				
	1	2	3	4	5
LMA #1 (*n*=25)	5	2	11*	5	2
LMA#1.5 (*n*=41)	7	1	16*	9	8
LMA #2 (*n*=68)	35*	13	10	8	2
LMA #2.5 (*n*=21)	15*	5	1	0	0

LMA = laryngeal mask airway
Fibreoptic bronchoscopic finding was defined as Grade 1, larynx only seen; Grade 2, larynx and epiglottis posterior surface seen; Grade 3, larynx, and epiglottis tip or anterior surface seen—visual obstruction of epiglottis to larynx: less than 50%; Grade 4, epiglottis down-folded, and its anterior surface seen—visual obstruction of epiglottis to larynx: more than 50%; Grade 5, epiglottis down-folded and larynx cannot be seen directly.
$P < .001$, ridit test. *data of the median.

than those of LMA 1.5 and LMA 2.5 (*P* < .05), and F_L of LMA 2 was higher than that of LMA 2.5 (*P* < .05) (Table I). In smaller LMAs, the cuff more frequently enclosed the epiglottis than in larger LMAs (*P* < .001) (Table II).

Among 79 patients in when an LMA was used for airway maintenance throughout the operation, there were nine cases of continuous $P_{ET}CO_2$ increase (Table III); the FOB grade was 3 in six patients, 4 in two and 5 in one. Their FOB findings at the end of surgery did not change when compared with the initial findings. When we attempted to solve the problem, the mandibular elevation worked well in two of the nine only while elevating the mandible with both hands. Because of high $P_{ET}CO_2$, the LMA was removed in two of the nine (LMA 1.5 and 2 each). One of the nine

TABLE III Duration of PPV through LMA and incidence of complications while maintaining PPV through LMA

	Duration of PPV (min)	Complications Laryngo-spasm	Vomiting	$P_{ET}CO_2$ increase	Number of patients with more than one complication*
Total (n=79)	45 ± 23 (15-165)	3	1	9	12 (15%)
LMA #1 (n=10)	53 ± 14 (40-80)	0	0	3	3 (30%)
LMA #1.5 (n=27)	44 ±14 (15-80)	2	0	5	7 (26%)
LMA #2 (n=31)	47 ±31 (20-165)	1	1	1	2 (7%)
LMA #2.5 (n=11)	42 ±11 (30-60)	0	0	0	0 (0%)

Values are mean ±SD (range).

Duration of PPV was not different (P=.91).

*The number of patients, who had more than one complication, was different depending on the LMA size (P< .05)

PPV = positive pressure ventilation, LMA = laryngeal mask airway

vomited during emergence, while the LMA was still in place (Table III). There was no evidence of aspiration. The other LMAs were removed after reflexes had returned. There was no case of hypoxia, SpO_2 < 95%. The number of patients experiencing complications decreased as LMA size increased (P < .05) (Table III).

Discussion

In this study using appropriately sized LMAs in infants and children, older children had better LMA position and less leakage around the LMA during PPV. Also, older children had fewer complications while maintaining PPV through LMA. The LMA can be used safely for PPV during surgery of short duration in older children but cannot be recommended for infants.

Because of individual variation in the size of the larynx, the LMA sometimes encloses the epiglottis, even when the tip of its cuff correctly occupies the hypopharynx.[15] In the majority of correctly placed LMAs in children, the epiglottis lies within the confines of the mask.[9,11,12] However, optimal position of the LMA (FOB grade 1) was achieved in a comparatively large proportion of infants (29%[11] or 44%[12]), where smaller-size LMAs than recommended were used. In our study, the FOB grade was higher in neonates and infants, so that a satisfactory position was more difficult to achieve in those age groups as suggested by Wilson.[16] In children who weighed > 10 kg, the FOB finding was improved. This was comparable to our clinical impression that LMA > 2 is easier to use than smaller LMAs. This may be partly because the LMA was designed after cadaveric examination of the adult larynx, and the small LMA is a scaled-down version of the adult LMA.[17] Although the anatomy regarding the LMA is reported to be comparable in infants,[18] the anatomy of the larynx of infants differs from that of children. Thus, it might be more difficult to achieve a good position with an infantile size LMA than with a pediatric size.

Even though the airway diameter of the LMA is larger than that of a comparable endotracheal tube and the LMA does not occupy the narrowest portion of the upper airway (the cricoid cartilage), PIP through the small LMA was not particularly low. Incorporation of the epiglottis into the LMA cuff and its deflection (higher FOB grades) caused higher PIP especially in the smaller LMA. By comparing PIP and leak pressure, we know that PIP of the smaller LMAs was sometimes higher than the leak pressure. Because the leak through the LMA may increase at airway pressure > 25 cmH_2O,[19] ventilation may be lost during inspiration.

In nine of 79 patients whose airways were maintained with a LMA throughout the surgery, the $P_{ET}CO_2$ slowly increased. Although this sign occurs late, we could find no other earlier and reliable sign during the surgery. If surgery had continued longer, we may have had to abandon the LMA in more cases. Even if we could not hear an air leak with a stethoscope on the stomach, at the end of operation the abdomen appeared inflated or tympanic on percussion, so subclinical gastric insufflation might be a cause of the increased $P_{ET}CO_2$.

Compared with other reports without paralysis,[8,10] some problems related to insertion such as airway obstruction, coughing, laryngospasm, and difficulty with placement[8,10] were bypassed. Even though the complications during insertion were excluded, our overall complication rate was higher than in previous studies.[8,10] Since this study group consisted of small children, the complication rate was high as was suggested by another study.[8] Insertion of an LMA in paralyzed patients may affect the LMA position that cannot be detected by FOB. Thus it may have a high-

er complication rate than when paralyzed after LMA insertion.[8] Slowly increasing $P_{ET}CO_2$ might be a particular complication of LMA insertion and maintaining PPV in paralyzed pediatric patients.

The pharyngeal, laryngeal and genioglossus muscles are relaxed under general anesthesia,[20] and upper airway anatomy therefore changes when muscle relaxation is achieved. However, there has been no well-controlled study of LMA position in pediatric patients without paralysis. Furthermore, large variations in LMA position have been reported even in adults. Latorre and colleagues[6] stated that the ideal position (FOB grade 1) was achieved in 70% of cases, but Fullekrug and colleagues[5] reported that this figure was only 13%. Thus it is difficult to say that, from the results of this study, whether muscle relaxation has some definite effect on LMA position.

From our clinical impression, higher PIP and more frequent occurrence of $P_{ET}CO_2$ increase with small LMAs, we think that the larger the LMA, the less the leakage was around the LMA. However, in our study, the F_L of LMA 2 was not different from that of LMA 1 or 1.5. In patients weighing < 10 kg, we used the infantile breathing circuit and ventilator bellows, and neonatal pulmonary monitor, which has a lower dead space volume. As stated earlier, more ventilation was lost during inspiration through small LMAs. For the small LMAs such as # 1 and # 1.5, F_L was calculated to be relatively lower than it should be.

Because of the common occurrence of partial airway obstruction by the epiglottis while using the LMA in young children, the risk/benefit ratio should be carefully evaluated before using an LMA with paralysis and PPV in this age group.

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