Second-generation laryngeal mask airway as an alternative to endotracheal tube in prolonged laparoscopic abdominal surgery: a comparative analysis of intraoperative gas exchanges

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Abstract

Introduction: Laryngeal mask airway (LMA), which is used in difficult airway maintenance conditions during emergencies, is rarely used in prolonged surgery despite its advantages over endotracheal tube (ETT). In this study, we conducted a comparative analysis of intraoperative gas exchanges between second-generation LMA and ETT during prolonged laparoscopic abdominal surgery.

Methods: Prolonged surgery was defined as a surgery lasting more than 2 h. In total, 394 patients who underwent laparoscopic liver resection via either second-generation LMA or ETT were retrospectively analysed. The following parameters were compared between the two groups of patients: end-tidal pressure of carbon dioxide (ETCO₂), tidal volume (TV), respiratory rate (RR), peak inspiratory pressure (PIP), arterial partial pressure of carbon dioxide (PaCO₂), pH and ratio of arterial partial pressure of oxygen to fractional inspired oxygen (PFR) during surgery. In addition, the incidence of postoperative pulmonary complications (PPCs), including pulmonary aspiration, was compared.

Results: The values of ETCO₂, TV, RR and PIP during pneumoperitoneum were comparable between the two groups. Although PaCO₂ at 2 h after induction was higher in patients in the LMA group (40.5 vs. 38.5 mmHg, P < 0.001), the pH and PFR values of the two groups were comparable. The incidence of PPC was similar.

Conclusion: During prolonged laparoscopic abdominal surgery, second-generation LMA facilitates adequate intraoperative gas exchange and may serve as an alternative to ETT.

Keywords: Laparoscopic liver resection, laryngeal mask airway, prolonged abdominal surgery

INTRODUCTION

Laryngeal mask airway (LMA) is widely used in many clinical scenarios requiring airway maintenance. It has several advantages over endotracheal tube (ETT), including ease of insertion, haemodynamic stability at insertion and removal, low pharyngolaryngeal morbidity and reduced need for anaesthetics.[1-3] However, LMA covering the glottis without direct insertion into the trachea is a structural limitation that increases the possibility of inadequate ventilation and oxygenation and the risk of aspiration. Moreover, prolonged use of LMA may trigger gastric dilatation, which leads to inadequate ventilation and oxygenation.[4,5] Therefore, LMA is indicated for short operations that can be completed within 2 hours.[6] The second-generation LMA is a new device designed to compensate the structural shortcomings of classic LMA (CLMA), the initial model of LMA.[2,6,7] It carries an
additional port for the gastric drainage tube to reduce gastric insufflation and improve airway sealing as compared to CLMA.\\(^{[6,7]}\)

Laparoscopic liver resection (LLR) has become a popular treatment option for liver cancer, and it is widely performed in many clinical centres now. We have used second-generation LMA with gastric drainage tube for LLR since the end of October 2017. Although several reports of second-generation LMA during short laparoscopic abdominal surgery such as cholecystectomy are available,\\(^{[8,9]}\) few studies have evaluated the use of such LMA in prolonged laparoscopic abdominal surgery. Therefore, we aimed to investigate whether second-generation LMA facilitated adequate intraoperative gas exchange during LLR.

**METHODS**

This study was a retrospective analysis of electronic medical records. The Institutional Review Board of Samsung Medical Center approved this study (SMC 2018-11-093) and waived the requirement for written informed consent. We used PLMA without gastric drainage tube between 30 May 2017 and 30 October of 2017. We have been using LMA-Protector (PLMA) (LMA® Protector™ Airway, Teleflex, Wayne, PA, USA) in LLR since 31 October 2017. Before 30 May 2017, ETT was inserted in all patients undergoing LLR.

We screened 564 consecutive patients who underwent elective LLR between 1 July 2014 and 7 December 2018 in a single tertiary hospital. We defined prolonged surgery based on surgical duration > 2 h. The study included only patients who were administered anaesthesia or supervised by the corresponding author. Patients who underwent LLR from 1 June 2017 to 30 October 2017 were excluded. We further excluded two patients whose LMA was switched to ETT during surgery, two patients with failed LMA insertion, five patients whose surgery was switched to laparotomy and nine patients with incomplete electronic medical records. Among the remaining 394 patients, we compared those who underwent LMA (Group LMA) to those who were treated with ETT (Group ETT).

All patients fasted for at least 8 h before the surgery. Anaesthesia was induced with thiopental sodium 5 mg/kg, vecuronium 0.1 mg/kg and sevoflurane. The arterial blood pressure of all patients was monitored, while no central venous line was secured. The insertion of PLMA was performed only by the corresponding author. The size of PLMA was selected according to the manufacturer’s weight-based recommendations. We used LMA size 3, 4 and 5 for patients weighing 30–50 kg, 50–70 kg and >70 kg, respectively. An ETT measuring 7 mm and 8 mm in internal diameter was used for women and men, respectively. Effective ventilation was defined based on the following criteria: (a) symmetrical breath sounds; (b) typical square wave pattern of capnography curve; (c) absence of audible leak; and (d) tidal volume (TV) 8 mL/kg (ideal body weight) with a peak airway pressure <30 cmH\(_2\)O. The PLMA was removed and ETT inserted in the absence of effective ventilation.

Volume-controlled ventilation and positive end-expiratory pressure at 6 cmH\(_2\)O were used for all patients. Fractional inspired oxygen was set to approximately 0.5. The respiratory rate (RR) was adjusted to maintain the end-tidal pressure of carbon dioxide (ETCO\(_2\)) at 35–40 mmHg. We inserted a gastric drainage tube into all patients to ensure adequate LMA insertion and prevent gastric insufflation during surgery. Vecuronium was continuously infused for muscle relaxation during surgery. Anaesthesia was maintained with isoflurane, and anaesthetic depth was adjusted to maintain a bispectral index of between 40 and 60. The ETCO\(_2\) and ventilator parameters such as TV, RR and peak inspiratory pressure (PIP) were automatically recorded every 10 min electronically. Arterial blood gas analysis (ABGA) was performed every 2 h after induction of anaesthesia. Most patients were transferred to the postanaesthesia care unit after surgery.

We reviewed data pertaining to ETCO\(_2\), TV, RR and PIP after induction of anaesthesia (T1), after initiation of pneumoperitoneum (T2), before the end of pneumoperitoneum (T3) and at the end of surgery (T4). The partial pressure of carbon dioxide (PaCO\(_2\)), pH and partial pressure of oxygen (PaO\(_2\)) were also reviewed based on ABGA results. The ratio of PaO\(_2\) to fractional inspired oxygen (PFR) was calculated to compare the oxygenation levels. Postoperative pulmonary complications (PPC) including pulmonary aspiration were reviewed for 7 days after surgery and defined based on a previous published study.\\(^{[10]}\) Postoperative pulmonary aspiration was a composite of pleural effusion, atelectasis and respiratory infection. Pulmonary aspiration was defined as pulmonary infiltration on chest X-ray associated with regurgitation of gastric contents.\\(^{[11]}\) The primary outcome was the difference in ETCO\(_2\) during surgery between the two groups according to airway device.\\(^{[12,13]}\) Ventilator parameters, ABGA results during pneumoperitoneum and PPC were also compared between the two groups according to airway device.

Continuous variables were summarised as mean ± standard deviation or median (interquartile range), and categorical variables were presented as frequency (%). The distribution of continuous variables was analysed using Kolmogorov–Smirnov test. Demographics and perioperative parameters were compared using Student’s t-test or Mann–Whitney test for continuous variables and chi-square test or Fisher’s exact test for categorical variables. Baseline differences in the duration of anaesthesia and pneumoperitoneum in the two groups were adjusted via analysis of covariance or linear mixed models using age, body mass index, albumin, crystalloid infusion rate (mL/kg/h), and duration of anaesthesia and pneumoperitoneum.
as covariates. The linear mixed model was used with time, group and the time × group interaction as fixed factors and patients as random factors. All reported P values were two-sided, and P values <0.05 were considered statistically significant. Analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp, Armonk, NY, USA).

RESULTS

Two patients were switched from LMA to ETT during surgery, as they developed an air leak that suppressed the expiratory TV to less than 4 mL/kg following pneumoperitoneum and a change in the surgical posture. A total of 394 patients were analysed — Group LMA (n=170) and Group ETT (n=224). Patients’ demographics and preoperative clinical features are presented in Table 1. Mean anaesthesia time and duration of pneumoperitoneum were significantly prolonged in Group ETT.

The ETCO$_2$ and ventilator parameters recorded during surgery are presented in Table 2. The ETCO$_2$ at T2 and T3 were comparable between the two groups. However, ETCO$_2$ at T1 and T4, as well as the highest ETCO$_2$ during surgery were higher in Group LMA. There was no difference in TV between the two groups except at T1. The RR at T1 was higher in Group LMA, but remained unchanged at T2, T3 and T4 in both groups. All ETCO$_2$ values during surgery in Group LMA were within the physiological range (< 45 mmHg), and RR remained below 19 breaths/min during surgery. There was no difference in PIP between the groups at every time point except T4. The proportion of patients showing PIP >25 mmHg did not differ between the two groups. The linear mixed model

| Parameter | Median (range) [IQR] | P |
|-----------|----------------------|---|
| ETCO$_2$ (mmHg) | | |
| T1 | 36 (29–41) [35–37] | 35 (30–41) [34–37] | <0.001 |
| T2 | 38 (31–43) [36–39] | 38 (30–47) [36–39] | 0.822 |
| T3 | 38 (32–45) [36–40] | 37 (30–44) [36–39] | 0.149 |
| T4 | 38 (31–42) [36–40] | 37 (30–44) [35–38] | <0.001 |
| Highest ETCO$_2$ | 40 [38–41] | 39 [38–40] | 0.002 |
| Tidal volume (mL) | | |
| T1 | 457 (280–624) [406–502] | 430 (249–578) [371–481] | <0.001 |
| T2 | 444 (256–638) [388–487] | 432 (250–656) [371–477] | 0.190 |
| T3 | 446 (259–666) [404–499] | 437 (257–644) [383–484] | 0.086 |
| T4 | 447 (252–588) [403–488] | 439 (247–602) [388–481] | 0.119 |
| Respiratory rate (breaths/min) | | |
| T1 | 10 (6–13) [8–10] | 9 (5–13) [8–10] | <0.001 |
| T2 | 10 (7–19) [9–12] | 10 (7–15) [9–12] | 0.629 |
| T3 | 12 (8–16) [11–13] | 12 (8–22) [10–13] | 0.279 |
| T4 | 11 (6–16) [9–12] | 10 (6–17) [10–12] | 0.672 |
| Peak inspiratory pressure (mmHg) | | |
| T1 | 16 (10–24) [15–17] | 16 (9–22) [15–17] | 0.742 |
| T2 | 21 (16–28) [20–23] | 21 (15–28) [20–23] | 0.859 |
| T3 | 22 (16–27) [21–23] | 22 (16–30) [20–23] | 0.672 |
| T4 | 17 (13–26) [16–19] | 18 (12–26) [17–19] | <0.001 |

*Data presented as median [IQR]. *Data presented as n(%). ETCO$_2$: end-tidal pressure of carbon dioxide, ETT: endotracheal tube, IQR: interquartile range, LMA: laryngeal mask airway, T1: after induction of anaesthesia, T2: after initiation of pneumoperitoneum, T3: before the end of pneumoperitoneum, T4: at the end of surgery.
revealed no significant group and time interaction for PIP during surgery ($P = 0.070$).

A total of 216 patients underwent ABGA at 2 h after anaesthesia induction, and the results are presented in Table 3. At 2 h after induction, PaCO$_2$ was higher in Group LMA (40.5 vs. 38.5 mmHg, $P < 0.001$), whereas the proportion of patients with PaCO$_2$ >45 mmHg was comparable between the groups; pH and PFR at 2 h after induction were also comparable. There was no significant difference in the proportion of patients with PFR <200 and PFR <300 during surgery.

For comparison of PPCs, we included four patients who were initially excluded (two patients whose LMA was switched to ETT during surgery and two patients with failed LMA insertion) in Group LMA. Postoperative pulmonary complications occurred in 87 (21.9%) patients, with no difference between the groups. Pulmonary aspiration did not occur in any of the patients. Pleural effusion and atelectasis occurred in 57 (14.3%) and 42 (10.5%) patients, respectively, with no difference between the groups. Respiratory infection occurred in one patient in Group LMA. The patient had a history of pneumonia involving the right lower lobe 2 weeks before surgery, and pneumonia recurred 5 days after surgery.

**DISCUSSION**

Our results reveal that PLMA ensures adequate intraoperative gas exchange in patients undergoing LLR. Although a few intraoperative variables of ventilation differed between the LMA and ETT groups, the values were within the physiological range and the pH and PFR did not differ 2 h after induction. In addition, no statistically significant differences in ETCO$_2$, RR and PIP were found between the groups at most of the time points. For the time points at which there were statistically significant differences, the difference was small and might not be clinically significant [Table 2]. Increased intra-abdominal pressure during laparoscopic surgery leads to early closure of small airways, resulting in inadequate ventilation and oxygenation. Our results show that adequate ventilation and oxygenation were maintained in patients with LMA even during pneumoperitoneum. Taheri et al.\textsuperscript{[15]} reported a retrospective study of LMA used in major ear surgery involving 2,000 patients with a mean surgical time of about 200 min. Haemodynamic instability during surgery was not related to the duration of the surgery, and no gastric distension was observed in any patient. However, their study was observational and did not compare LMA and ETT. Their study also did not use second-generation LMA or investigate variables related to intraoperative gas exchange. Although a few case reports\textsuperscript{[16,17]} and one retrospective study\textsuperscript{[18]} described the prolonged use of second-generation LMA, our report is the first of its kind to suggest that intraoperative gas exchange may be effective even with LMA in prolonged laparoscopic abdominal surgery.

The initial model of LMA and CLMA showed a temporal variation associated with the increased risk of inadequate ventilation due to structural limitations.\textsuperscript{[6,5]} Therefore, CLMA is considered safe for short and simple operations only, and anaesthesiologists appear reluctant to use CLMA in prolonged surgery.\textsuperscript{[5,19]} However, LMA has evolved since its first development in 1981.\textsuperscript{[6,7]} Second-generation LMA is specifically designed to overcome the disadvantages of CLMA.\textsuperscript{[6,7]} Several studies have shown that the second-generation LMA enhances the sealing capacity, which might be key when used for a prolonged period.\textsuperscript{[13,20,21]} Also, incorporating a gastric drainage tube with the second-generation LMA minimises the likelihood of gastric insufflation. With these structural improvements, PLMA ensures adequate intraoperative gas exchange even in prolonged laparoscopic abdominal surgery, as shown in the current study.

Laryngeal mask airway is faster and easier to insert than ETT and is used as an alternative to ETT under conditions where tracheal intubation is difficult.\textsuperscript{[2,3,22]} However, when ETT insertion is difficult during prolonged surgery, most clinicians are not clear whether ventilation and oxygenation can be safely maintained with LMA until the end of the surgery. Based on

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**Table 3. Intraoperative arterial blood gas analysis.**

| Variable          | Median (range) [IQR] | $n$ (%) | $P$ |
|-------------------|----------------------|--------|-----|
| PaCO$_2$ (mmHg)   |                      |        |     |
| 2 h after induction| 40.5 (30.9–56.3) [38.2–44.2] | 109    |     |
| PaCO$_2$ >45      | 25 (22.9)            |        |     |
| pH                | 7.36 (7.25–7.45) [7.33–7.39] |        |     |
| 2 h after induction| 7.38 (7.24–7.46) [7.34–7.40] |        |     |
| PFR               | 542 (188–799) [438–610] |        |     |
| 2 h after induction| 551 (288–769) [465–616] |        |     |
| PFR <300          | 3 (2.8)              |        |     |
| PFR <200          | 1 (0.9)              |        |     |

ETT: endotracheal tube, IQR: interquartile range, LMA: laryngeal mask airway, PaCO$_2$: arterial partial pressure of carbon dioxide, PFR: ratio of arterial partial pressure of oxygen to fractional inspired oxygen.
our results, a switch from the second-generation LMA to ETT during prolonged laparoscopic surgery is not necessary for patients who had LMA placed due to difficulties with intubation.

Pulmonary aspiration is one of the major concerns associated with LMA use. Even small amounts of pulmonary aspiration increase the risk of pneumonia or respiratory failure. However, previous studies reported that LMA with accurate positioning is not associated with increased risk of pulmonary aspiration.[2,24,25] Our study reveals no difference in PPC between the two groups, suggesting the absence of clinically significant microaspiration with PLMA. Nonetheless, it is unclear whether the use of PLMA is associated with an increased risk of pulmonary aspiration due to the small sample size of the current study. A very large sample size is required to demonstrate the difference in pulmonary aspiration under PLMA.[7]

This study has several limitations. First, as a retrospective study, we could not exclude the possibility of bias due to unmeasured or unmeasurable variables. For instance, we did not measure values that represent air leakage, such as oropharyngeal leak pressure,[26] leak fraction[27] or cuff pressure.[28] Also, a possible selection bias may exist due to differences in the duration of surgery between the two groups. We also could not compare pharyngolaryngeal complications such as sore throat and hoarseness. Second, although no symptoms or signs of aspiration were detected in Group LMA, the small sample size prevented estimation of the risk of pulmonary aspiration.[7] Third, since LMA insertion was performed by a single anaesthesiologist, it may be difficult to generalise to all physicians. Fourth, a significant difference was found in the duration of anaesthesia and pneumoperitoneum between the two groups, which may have influenced the outcome of PIP. If there was no difference in duration, there might be a possibility that PIP was similar between the two groups at the end of surgery. Fifth, the proportion of patients who underwent ABGA varied between the two groups. To overcome these limitations, well-controlled clinical trials are needed in the future. Finally, since only a single model of second-generation LMA was used, our results may not be generalisable to other second-generation LMAs.

We conclude that during LLR, properly positioned PLMA ensures adequate intraoperative gas exchange compared to ETT. During prolonged laparoscopic abdominal surgery, second-generation LMA may be an appropriate alternative to ETT.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.
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