Work of Breathing in Anesthetized Patients: Laryngeal Mask Airway versus Tracheal Tube

Girish P. Joshi, MB BS, MD, FFARCSI,* Stuart G. Morrison, FFARCSI,† Paul F. White, MD, PhD, FANZCA,‡ Christopher J. Miciotto, MD,§ C.C.W. Hsia, MD¶

Department of Anesthesiology and Pain Management, The University of Texas Southwestern Medical Center, Dallas, TX

Study Objective: To compare the work of breathing associated with the laryngeal mask airway (LMA) and tracheal tube (TT) in spontaneously breathing anesthetized patients.

Design: Randomized, prospective, controlled trial.

Setting: University teaching hospital.

Subjects: 20 ASA physical status I and II patients scheduled for elective peripheral surgery with general anesthesia.

Interventions and Measurements: A standardized anesthetic protocol was utilized, and patients were allowed to breathe spontaneously through a circle absorption system. Patients were randomly assigned to receive either LMA (n = 10) or TT (n = 10) for airway management. Work of breathing was determined after the patients’ ventilatory status had been allowed to stabilize for 15 minutes and before the onset of the surgical stimulus. Airflow and esophageal pressures were measured using a pneumotachograph and an esophageal balloon, respectively, and the values were subsequently integrated to determine work of breathing.

Main Results: The two groups were similar with respect to demographic characteristics and the end-tidal concentrations of carbon dioxide and isoflurane. Work of breathing per minute through the LMA (1.4 ± 0.3 J/min) was significantly lower than that through the TT (1.9 ± 0.4 J/min).

Conclusion: In healthy, anesthetized, spontaneously breathing patients, work of breathing is significantly lower through the LMA than the TT.

Keywords: Airway; work of breathing; anesthetic technique: general anesthesia; equipment: laryngeal mask airway, tracheal tube.

Introduction

The laryngeal mask airway (LMA) is a device that conforms to the shape of the laryngeal inlet, and it is intermediate in design and function between an
oropharyngeal airway and a tracheal tube (TT). The LMA has become a useful device for airway maintenance during general anesthesia and is a suitable alternative to the face mask and the TT for superficial surgical procedures.1 Spontaneous breathing is preferred with the LMA because positive pressure ventilation may cause gastric distention.2 Because the work of breathing is increased in spontaneously breathing, anesthetized patients,3,4 it is important to evaluate the effects of the LMA on work of breathing in this clinical situation. Although in vitro studies suggest that the LMA imposes less resistance and requires lower additional inspiratory work than that imposed by the tracheal tubes,5 to date, work of breathing imposed by the LMA has not been compared with the TT in vivo. This investigation was undertaken to compare work of breathing associated with the LMA and the TT in spontaneously breathing, anesthetized patients.

Materials and Methods

Twenty consenting ASA physical status I and II patients scheduled for elective peripheral surgery with general anesthesia were studied according to University of Texas Southwestern Medical Center at Dallas Institutional Review Board-approved protocol. Patients with pulmonary disease, anticipated airway difficulties, and those at increased risk of aspiration were excluded from the study. Patients were randomly assigned, using a computer-generated random number sequence, to receive either an LMA or TT for airway management.

After insertion of an intravenous (IV) cannula and placement of routine monitoring devices, all patients received a standardized anesthetic technique. General anesthesia was induced with IV administration of fentanyl 1 μg/kg and propofol 2 mg/kg. In the LMA group, an LMA device (size 3 or 4) was inserted according to the manufacturer’s instructions,6 and the correct position was confirmed by ease of assisted ventilation and absence of leak. If there were difficulties in placement of the LMA, the patient’s head was repositioned and a supplemental bolus dose of propofol 0.5 mg/kg was administered. In the TT group, IV succinylcholine 1 mg/kg was used to facilitate the placement of a TT (size 8, 24 cm long). Ventilation was manually assisted until a regular breathing pattern was established. In addition, the recovery of neuromuscular blockade (in patients receiving succinylcholine) was determined by stimulating the ulnar nerve at the wrist with train-of-four stimuli. Subsequently, the patients were allowed to breathe spontaneously through a standard circle absorption system (Ohmeda, BOC Health Care, Madison, WI). Anesthesia was maintained with isoflurane in a mixture of 70% nitrous oxide (N2O) in oxygen. The inspired concentration of isoflurane was adjusted to avoid purposeful movement and maintain hemodynamic stability. Heart rate and noninvasive arterial blood pressure (BP) were monitored at one-minute intervals during induction of anesthesia and subsequently at 2- to 5-minute intervals. Hemoglobin oxygen saturation (SpO2), end-tidal carbon dioxide (CO2), end-tidal isoflurane concentrations, respiratory rate (RR), and tidal volume were continuously monitored.

Prior to measuring work of breathing, we calibrated the flow and pressure signals using a 500 ml syringe and a mercury manometer, respectively. Work of breathing was measured after the patient’s ventilation was stable for 15 minutes and before the onset of the surgery. A pneumotachograph (Fleisch, No 2, Hewlett-Packard, Fullerton, CA) was placed between the LMA or TT and the Y piece of the breathing circuit to measure flow rates. The pneumotachograph was interfaced to a differential pressure transducer (MP 45; ±2 cm H2O, Validyne, Inc, Northridge, CA). An 18-gauge esophageal balloon (Mallinckrodt Inc., Glens Falls, NY) was inserted in the midesophagus after adequate depth of anesthesia was achieved. The esophageal balloon was connected to one side of a differential pressure transducer (MP 45; ±100 cm H2O, Validyne Inc., Northridge, CA) while the other side was kept open to the atmosphere. The position of the esophageal balloon was adjusted to maximize the inspiratory deflection on the esophageal pressure tracing. In addition, the appropriate position was verified with the “occlusion” technique.7 This action consisted of occluding the airway opening at end-expiration, allowing three to five respiratory efforts and repositioning the esophageal balloon to a point where the ratio of esophageal and mouth pressures was close to unity. All signals were amplified and displayed on a multichannel strip chart recorder (Hewlett Packard Inc., Andover, MA). Tidal work of breathing during the preincisional study period was derived using a respiratory integrator (8815A, Hewlett Packard Inc., Andover, MA). The esophageal pressures, inspiratory and expiratory flows, and integrated work of breathing were independently recorded on the strip chart recorder.

Work of breathing is the energy expended to move a volume of gas during respiration. It is the product of volume, (V) multiplied by esophageal pressure (Pes) and integrated over a single respiratory cycle (work of breathing = ∫ Pes · dV). The raw data, expressed as cm H2O · ml, were converted to millijoules (mJ). The work per minute (Joules per minute) was obtained by multiplying the work per breath by RR.7

Data were summarized as mean values ± standard deviation (SD). These data were analyzed using an unpaired t-test. A p-value of less than 0.05 was considered statistically significant.

Results

There were no statistically significant differences between the two study groups with respect to demographic data (Table 1). End-tidal CO2 and end-tidal isoflurane concentrations during the measurement of work of breathing were also similar in the two groups (Table 1). The hemodynamic and respiratory parameters remained stable throughout the measurement period. There were no statistically significant differences in ventilatory parameters (Table 2). However, the work per minute through the
The LMA was significantly lower (1.4 ± 0.3 J/min) than that through the TT (1.9 ± 0.4 J/min).

**Discussion**

The results of this study demonstrate that the work of breathing per minute (also known as the power of breathing) in anesthetized patients breathing spontaneously through the LMA is significantly lower than through a TT. It is more appropriate to compare the power of breathing through the two devices because breathing is a continuous process. In addition, in anesthetized patients without pulmonary disease, imposition of impedance is associated with respiratory compensation, which makes the power of breathing a more appropriate measure of work. *8*

In a preliminary study, Ooi and Soni* found that the power of spontaneous breathing through the LMA in anesthetized patients was similar to that with a face mask. Of note, the power of breathing through the LMA in spontaneously breathing anesthetized patients reported by Ooi and Soni* was similar to that observed in this study. Bhatt et al.* reported that the additional inspiratory work imposed by the LMA in vitro was less than that imposed by the corresponding sized TT. In contrast, other investigators have reported that in awake volunteers, the airway resistance (as measured by body plethysmography) when breathing through the LMA was significantly higher than the airway resistance without the LMA in situ;† leading these authors to suggest that the mean airway resistance during breathing through the LMA would be similar to the TT.

The LMA might be expected to impose less additional work of breathing compared with a TT because of its larger internal diameter (12 mm vs. 8 mm) and a shorter length (19 cm vs. 24 cm). In addition, work of breathing during spontaneous ventilation through a LMA may be lower because the vocal cords are free to move normally during respiration; as a result inspiratory dilatation and expiratory constriction of the glottis can still occur and maintain functional residual capacity (FRC).‡

On the other hand, the vocal cords represent a major constriction and a site of turbulent air flow in nonintubated patients. Turbulence at this level may increase work of breathing with the LMA compared with the TT. In addition, the two vertical bars at the laryngeal end of the LMA can also contribute to increased turbulence and resistance. *9,10* Furthermore, work of breathing also may increase due to distortion of the laryngeal inlet by the pressure exerted by the inflated cuff of the LMA (which may be further increased as a result of diffusion of N2O into the cuff). *10* Although the LMA does not bypass the glottis unlike the TT, a recent study reported no significant increase in the total respiratory resistance. *11* Shapiro et al. *12* demonstrated that work of breathing increased markedly when volunteers were required to breathe through a TT placed in the posterior pharynx. Work of breathing measured during the later study included an additional component of laryngeal resistance, which represented a clinical situation similar to that of a patient breathing through the LMA.

The current work of breathing values reported in anesthetized patients breathing spontaneously through an 8 mm TT attached to a standard anesthesia circle system were similar to those reported by Christie and Smith, *13* but greater than the previously reported in vitro values. *14* Similar to the studies with the TT, earlier reports of the in vitro work of breathing with the LMA device* were lower than the in vivo work of breathing value in this study. Recently, Righini and colleagues *10* reported that the values for resistance through the LMA were twice as great in vivo as those obtained in vitro. The differences between the in vitro and in vivo studies could be due to clinical factors that increase airway resistance and, thus, work of breathing. For example, induction of general anesthesia can result in a considerable increase in work of breathing because of increased airway resistance, reduced FRC, and decreased pulmonary compliance. *3,4* Other factors, such as secretions, turbulence, tube deformation, and head and neck positioning, also increase work of breathing. *13*

The methodology used to determine work of breathing assumes that the esophageal pressure measurements accur-

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**Table 1. Demographic and Clinical Data in the Two Airway Treatment Groups**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Laryngeal Mask Airway</th>
<th>Tracheal Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (n)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Gender (males: females)</td>
<td>7:3</td>
<td>8:2</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>31 ± 8</td>
<td>35 ± 10</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75 ± 8</td>
<td>75 ± 7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>167 ± 11</td>
<td>165 ± 11</td>
</tr>
<tr>
<td>End-tidal CO₂ (mmHg)</td>
<td>49 ± 6</td>
<td>47 ± 7</td>
</tr>
<tr>
<td>End-tidal isoflurane (%)</td>
<td>0.8 ± 0.2</td>
<td>0.9 ± 0.3</td>
</tr>
</tbody>
</table>

*Note: Values are means ± SD.*

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**Table 2. Respiratory and Work of Breathing Data for the Two Airway Treatment Groups**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Laryngeal Mask Airway</th>
<th>Tracheal Tube</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory rate (breaths per min)</td>
<td>15 ± 3</td>
<td>17 ± 4</td>
</tr>
<tr>
<td>Tidal volume (ml)</td>
<td>195 ± 65</td>
<td>212 ± 67</td>
</tr>
<tr>
<td>Esophageal pressure (mmHg)</td>
<td>3.8 ± 1.3</td>
<td>4.4 ± 1.1</td>
</tr>
<tr>
<td>Work of breathing (J/min)</td>
<td>1.4 ± 0.3</td>
<td>1.9 ± 0.4*</td>
</tr>
</tbody>
</table>

*Note: Values are means ± SD.*

* ‡Brain AIG: The Intavent Laryngeal Mask Airway Instruction Manual, 2d ed. Henley-on-Thames, UK: Intavent International, SA.*
rately reflect pleural pressure. With the patient in the supine position, esophageal pressure may be more positive than the pleural pressure due to the mediastinum pressing on the esophagus. However, the “relative esophageal pressure” measured in the supine position should be valid because the measurements would have been affected similarly in both study groups. Furthermore, valid measurements of pleural pressures have been obtained in the supine position by positioning the esophageal balloon according to the “occlusion test” technique.

Anesthetized patients without respiratory disease can maintain adequate minute ventilation in presence of moderate increases in work of breathing. Although the additional work of breathing imposed by these airway devices may not represent a clinically significant burden with respect to the total work of breathing in healthy patients, it may be of clinical significance in spontaneously breathing patients with underlying pulmonary disease.

In conclusion, work of breathing in healthy, anesthetized, spontaneously breathing patients is significantly lower through the LMA than the TT.

Acknowledgment

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References