Cadaver study of oesophageal insufflation with supraglottic airway devices during positive pressure ventilation in an obstructed airway

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Editor’s key points
- Oesophageal insufflation can occur with a supraglottic airway when high ventilatory pressures are used.
- This cadaver study compared oesophageal leak with four devices during simulated airway obstruction.
- No oesophageal or gastric insufflation occurred in this model at an inspiratory pressure of 20 mbar.
- Insufflation occurred at pressures >40 mbar, with significant differences between devices.

Background. Supraglottic airway devices (SADs) play an increasing role in airway management in clinical anaesthesia and emergency medicine. Until now, no data exist concerning the extent of oesophageal insufflation when oropharyngeal leak pressures are exceeded.

Methods. Laryngeal masks LMA-Supreme™ and LMA-ProSeal™, laryngeal tubes LTS-D and LTS II, Combitube™, and I-Gel were inserted into unfixed human cadavers. The oesophagus was connected to a volumeter, while the trachea was closed surgically to simulate complete airway obstruction. Volumes of oesophageal insufflation resulting from pressure-controlled ventilation at inspiratory pressures of 20, 40, and 60 mbar were measured.

Results. No oesophageal insufflation could be detected at a ventilation pressure of 20 mbar in any device. Using inspiratory pressures of 40 and 60 mbar, oesophageal insufflation occurred in all devices, with significantly higher volumes of intraoesophageal air for both laryngeal tubes.

Conclusions. The use of SADs with inspiratory pressures of 20 mbar appears to be safe regarding the risk of intragastric insufflation. Higher inspiratory pressures should be strictly avoided.

Keywords: airway management; airway obstruction; inspiratory positive pressure ventilation; insufflations; laryngeal mask airways

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The use of supraglottic airway devices (SADs) has been steadily increasing in modern anaesthesia and emergency medicine, since the laryngeal mask and Combitube were introduced in the mid-1980s.1,2 Advantages over the tracheal tube are easy techniques of insertion, the possibility to insert these airway devices during continuous chest compressions,3 and their high effectiveness in securing the difficult airway as a backup for failed tracheal intubation.2

Important considerations for the use of SADs are the ease of airway maintenance, the quality of seal of the airway, and the incidence of complications such as pulmonary aspiration or damage to soft tissue. In patients with increased airway resistance due to bronchoconstriction or airway obstruction, the behaviour of the ventilation gas is of special interest.

While a tracheal tube seals the trachea even when high airway pressures occur, the usefulness of SADs may be limited. All SADs allow an air leak when inspiratory pressure exceeds the airway leak pressure, which defines the maximum tolerable ventilation pressure of the specific supraglottic device. The airway leak pressure primarily depends on the type of the SAD, correct size selection, and correct placement. The quality of oesophageal seal of various supraglottic devices to prevent aspiration of gastric contents is a key concern, especially when using SADs in emergency settings. Previous investigations of our group focused on this aspect, to evaluate the safety of different SADs.3,4

The aim of this study was to judge to what extent ventilation gas leaking from SADs may enter the oesophagus.
leading to gastric distension and subsequently increasing the risk of pulmonary aspiration.

Methods

Cadaver model

After approval by the local Institutional Ethics Committee of Charité—Universitätsmedizin Berlin, the trachea and oesophagus from eight unfixed human cadavers (head–neck preparations) were dissected. While the distal end of the exposed oesophagus was connected to a volumeter (Dräger, Lübeck, Germany), the dissected trachea was closed by suturing to establish a closed airway, thus simulating extreme airway obstruction.

Five female and three male cadavers (aged 67–84 yr, weight 60–100 kg, height 158–174 cm) were used. Six SADs were inserted by the same experienced anaesthesiologist (>1000 SAD uses). We investigated LMA-Supreme™ (LMS, Laryngeal Mask Company, Jersey, Channel Islands), LMA-ProSeal™ (LMPS, Laryngeal Mask Company), Laryngeal Tube Suction reusable (LTS II, VBM Medizintechnik GmbH, Sulz a. N., Germany), Laryngeal Tube Suction single-use (LTS-D, VBM Medizintechnik GmbH), Combitube™ (CT, Cividien plc, Dublin, Ireland), and I-Gel (Intersurgical, Berkshire, UK). All investigated SADs incorporate an oesophageal lumen. The sizes of the SADs were selected according to the height of the cadavers, after the manufacturer's recommendations. The cuffs of all investigated SADs were blocked in accordance with the manufacturer's instructions.

The correct placement of all SADs was evaluated by performing four different tests as follows: first, the correct position was functionally tested by using the emergency respirator Oxylog 3000® (Dräger). After the SAD had been connected, a constant airway pressure was built up by using the function inspiration hold in the pressure-controlled ventilation (PCV) mode with 15 mbar for 10 s. A correct position was postulated when no air leak escaped during this manoeuvre and the pressure was maintained. Before the start of the constant pressure phase, a soap membrane was established on the drain tube port of the LMS, LMPS, LTS II, LTS-D, CT, and I-Gel to detect leaking air as an indicator for malposition (bubble test). In addition, the anatomically correct position was verified through the respiratory lumen by means of fibreoptic pharyngoscopy (Bronchoscope BF Type 1T40, Olympus, Tokyo, Japan). The position was evaluated according to the per cent of glottic opening (POGO) scale: 1, the glottis fully visible; 2, more than 50% of the glottis visible; 3, <50% of the glottis visible; 4, the glottis not visible (Table 1).

As a last step, the correct position of SADs was corrected or the size was changed until all tests performed were passed and the conditions required for correct position were completely met.

For the duration of the tests, the respective airway device was fastened to the face. To prevent the cadaver models from cooling, the tests were carried out at a room temperature of 32°C. The measurements have been performed uniquely for each device in every situs.

Pressure-controlled ventilation

The pressure within the system of the cadaver model and SAD was increased by providing PCV with a respiratory rate of 10 bpm and three different inspiratory pressures (20, 40, and 60 mbar).

Measurements

The volume of ventilation gas that was pressed into the oesophagus during the third inspiration of ventilation with the respective inspiratory pressures was measured.

Statistical analysis

Differences in inflated oesophageal volumes between the six SADs were analysed using the Kruskal–Wallis test at inspiratory pressures of 20, 40, and 60 mbar, respectively. In the case of significant differences, the Mann–Whitney test was performed for post hoc analyses and corrected for repeated measurements. Significant differences were assumed for \( P < 0.05 \).

Results

During the performance of PCV with an inspiratory pressure of 20 mbar, no gas flow into the oesophagus was observed with any of the devices. With inspiratory pressures of 40 and 60 mbar, all devices lost their ability to avoid oesophageal insufflation and the Kruskal–Wallis tests detected significant differences between the devices \( (P < 0.0001 \) at both pressures). In comparison with LMS, LMPS, CT, and I-Gel at 40 and 60 mbar, significantly higher oesophageal volume insufflation was measured for LTS II and LTS-D in post hoc analysis. For the Combitube, the least amounts of oesophageal insufflation were detected. For the two laryngeal tube models, the oesophageal insufflation volume increased significantly with an inspiratory pressure of 60 mbar compared with 40 mbar (Fig. 1). Differences of oesophageal seal between laryngeal tubes compared with four other devices become especially obvious regarding the ratio of volume loss over pressure (Fig. 2).

Discussion

The aim of this study was to investigate the risk of oesophageal insufflation during mechanical ventilation via different SADs when tracheal ventilation is impaired or impossible. The scenario chosen simulates situations with maximal airway resistance which may occur in patients with massive bronchoconstriction or airway obstruction.

A relationship was found between the volume of oesophageal insufflation and different inspiratory pressures for the SADs tested under these extreme circumstances. Elevated inspiratory pressures may occur in clinical practice when SADs are used for airway maintenance during cardiopulmonary resuscitation with continuous chest compressions.
backup during emergency airway management, or for ventilation during laparoscopic surgery, when the compliance of the respiratory system is reduced.

If inspiration pressure exceeds the leak pressure of the specific SAD, the airway system starts leaking inspiratory gas into the pharynx. Clinical trials on the SADs included in this study found predominantly oropharyngeal leakage, while gastric insufflation was rare or not documented. Airway leak pressures documented range from below 20 mbar to over 40 mbar, depending on the airway devices and study design. In general, the risk and amount of leakage in SADs increases with increasing inspiratory pressures.

In these situations, it is decisive for the safety of ventilated patients whether the leaking gas is able to escape completely via the mouth or whether the gas is partially trapped within the oropharynx, partially entering the oesophagus. When the gas is pressed into the alimentary tract, the risk of gastric dilation and subsequent aspiration increases. The risk of gastric insufflation increases if ventilation is performed forcefully: fatal gastric perforation has been reported after initially successful cardiopulmonary resuscitation. In one case of cardiac arrest, gastric rupture could be linked to a laryngeal mask without oesophageal drain tube that did not prevent air from entering the alimentary tract, which went unnoticed by the rescuers performing chest compressions. However, in severe airway obstruction, the use of an SAD might be inadequate when high proximal airway pressures are required to overcome resistance to gas flow. The varying oesophageal insufflation volumes may be linked to differences in the design of the specific SADs. The form of the cuff, ratio of oropharyngeal and oesophageal seal, position of the SAD in relation to the glottic inlet, but also correct positioning of the device are among the influencing factors that need to be considered when ventilation is difficult after insertion of an SAD. A possible explanation of the significantly high oesophageal volume during the use of LTS is a better seal of the oropharyngeal cuff compared with the second oesophageal cuff.

The limitations of this study in unfixed human cadavers have to be considered before making any recommendations for clinical practice. While the anatomical features are correct, no factors which might influence the position of the SAD (respiration, swallowing, or retching movements) occur in this model. To minimize the potential influence of rigor mortis on the results, only fresh cadavers were used. All measures were taken to prevent cadavers from cooling into the pharynx.

### Table 1: POGO scores of the SADs (POGO, per cent of glottic opening)

<table>
<thead>
<tr>
<th>Cadaver model</th>
<th>Sex</th>
<th>POGO score</th>
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<tbody>
<tr>
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<tr>
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<td>8</td>
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*Fig 1* Oesophageal insufflations with different SADs during positive pressure ventilation at (a) 40 and (b) 60 mbar. LMS, LMA-Supreme; LMPS, LMA-ProSeal; LTS II, Laryngeal Tube Suction (reusable); LTS-D, Laryngeal Tube Suction (single-use); CT, Combitube; **P < 0.0001 between LTS II or LTS-D and all other devices in post hoc analyses, *P = 0.015 between CT and I-gel.*
to avoid possible distortion of the thermoplastic features of some SADs. Overall, the relevance of anatomical model to live humans is limited, but we feel that this is the best scientific method available to our question without endangering patients’ safety.

However, based on the findings of this study, the use of SADs with inspiratory pressures of 20 mbar seems safe. Higher inspiratory pressures must be critically monitored, if they cannot be avoided. As all devices investigated allow the passage of a gastric tube, this measure should be performed routinely to allow release of any gas pressed into the alimentary tract when increased inspiratory pressures occur with a partially obstructed or blocked airway. Forceful ventilation should be avoided, as leakage may occur towards the oesophagus before oropharyngeal leakage demonstrates that the sealing capacity of the specific device has been surpassed in the individual patient.

Authors’ contribution

W.S., H.G., and T.K. designed the study and wrote the manuscript drafts. W.S. and H.G. performed the investigations. W.S., O.A., and H.P. were responsible for data processing and statistical analyses. All authors read and approved the final manuscript.

Declaration of interest

H.G. has received financial support in the form of research grants, lecture/travel fees, and consultancy honoraria from Ambu (manufacturer of laryngeal masks and other airway products) and lecture/travel fees from VBM (manufacturer of laryngeal tubes).

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