Journal of Clinical Anesthesia (2016) **31**, 124–130

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Journal of Clinical Anesthesia

Original Contribution

Intrinsic positive end-expiratory pressure during ventilation through small endotracheal tubes during general anesthesia: incidence, mechanism, and predictive factors☆,☆☆,★,★★

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Received 19 November 2014; revised 20 August 2015; accepted 20 January 2016

Keywords:
Mechanical ventilation;
Intrinsic PEEP;
Pulmonary dynamic hyperinflation;
Airflow obstruction;
Barotauma

Abstract
Study Objective: To assess the safety of mechanical ventilation and effectiveness of extrinsic positive end-expiratory pressure (PEEP) ($PEEP_e$) in improving peripheral oxygen saturation (SpO_2) during direct microlaryngeal laser surgery; to assess the incidence, amount, and nature (dynamic hyperinflation or airflow obstruction) of ensuing intrinsic PEEP ($PEEP_i$); and to find a surrogate $PEEP_i$ indicator.
Design: Quasiexperimental.
Setting: S. Raffaele Hospital (Milano), November 2009 to December 2010.
Patients: Fifty-two adults scheduled for direct microlaryngeal laser surgery. Exclusion criterion is pregnancy.
Interventions: Twenty-one percent O_2 mechanical ventilation through 4.5- to 5.5-mm internal diameter endotracheal tubes; in 29 patients, after measurement of $PEEP_i$, an identical amount of $PEEP_e$ was added; and $PEEP_i$.
Measurements: SpO_2, peak (Paw_{peak}) and plateau ($Paw_{plateau}$) airway pressure, and end-expiratory carbon dioxide were measured every 5 minutes. Respiratory compliance (C_{rs}) was computed. $PEEP_i$ was measured (end-expiratory occlusion method).
Main Results: $PEEP_i \geq 5$ cm H_2O occurred in 14 patients (27%) after intubation, in 16 (30%) at the beginning, and in 14 (27.3%) at the end of surgery. Thirty-one patients (59.4%) exhibited $PEEP_i \geq 5$ cm H_2O on at least 1 time point. $PEEP_i$ at the beginning of surgery was positively correlated with $Paw_{plateau}$, C_{rs}, tidal

☆ Assistance with the article: None.
☆☆ Financial support and sponsorship: None.
★ Conflicts of interest: None.
★★ Presentation: None.

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http://dx.doi.org/10.1016/j.jclinane.2016.01.029
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volume, and body mass index. Body mass index was the only predictor for the occurrence of $PEEP_i \geq 5$ cm H_2O. At the beginning of surgery, the $Paw_{plateau}$ receiver operating characteristic curve predicting $PEEP_i \geq 5$ cm H_2O had area under the receiver operating characteristic curve of 0.85; best cutoff value of 15.5 cm H_2O (sensitivity, 88.9%; specificity, 75%; correctly classified cases, 86.1%). When $PEEP_e$ was applied, in 23 cases (82.1%), total PEEP equaled $PEEP_e$+ $PEEP_i$; in 3 (10.7%), it was lower; and in 2 (7.1%), it was higher. Application of $PEEP_e$ increased SpO_2 (P< .05) and C_{rs} (P< .05).

Conclusions: During ventilation through small endotracheal tubes, $PEEP_i$ (mostly due to dynamic hyperinflation) is common. Hemodynamic complications, barotrauma, and O_2 desaturation (reversible with $PEEP_e$) are rare. $Paw_{plateau}$ provided by ventilators is useful in suspecting and monitoring the occurrence of $PEEP_i$ and allows detection of lung overdistension as $PEEP_e$ is applied.

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1. Introduction

In choosing the most appropriate endotracheal tube (ETT) caliber, the anesthetist is guided by nomograms and formulas that take into account patient's age, sex, and body mass index (BMI) [1]. The goal is to allow adequate ventilation while limiting laryngotracheal trauma.

Unfortunately, there are situations in which the ETT internal diameter (ID) has to be smaller than the optimal calculated value, for example, because of difficult intubation or upper airway trauma, malformation, or surgery [2-12].

Maintaining adequate ventilation in these cases may be challenging, particularly when dealing with patients affected by pulmonary disease or obesity [12-14].

Moreover, the respiratory mechanics during ventilation through relatively small ETTs have not yet been completely described.

In a previous study [2], we assessed the feasibility of mechanical ventilation during general anesthesia for direct microlaryngeal laser surgery (DMLS) with small ID laser safe ETTs and 0.21 inspired oxygen fraction (FIO_2). In this setting, a small ID ETT is preferred to warrant optimal surgical field view, and a low-oxygen gas mixture is required to prevent laser-related ignition hazards. A low incidence of oxygen desaturation together with high inspiratory pressure was observed. We hypothesized that high-resistance ETTs cause an increase in intrinsic positive end-expiratory pressure ($PEEP_i$) preventing the development of atelectasis [15]. Notably, when persistent desaturation occurs in this setting, anesthetists are reluctant to set any extrinsic PEEP ($PEEP_e$) because the $PEEP_i$ induced by the high-resistance ETTs is unknown.

In the present study, we aim to assess the safety of mechanical ventilation and the effectiveness of $PEEP_e$ in improving oxygen saturation due to potential pulmonary derecruitment during DMLS. In this setting, we also addressed the incidence, amount, and nature (dynamic hyperinflation or airflow obstruction) [16-20] of potentially ensuing $PEEP_i$.

A further end point of our study is to find a possible surrogate $PEEP_i$ indicator, as ventilators for anesthesia usually do not provide $PEEP_i$ measurement.

2. Materials and methods

Ethical approval for this study (GO/URC/ER/mm prot NE 9421 DG) was provided by the Ethical Committee NAC of San Raffaele Hospital, Milan, Italy (Chairperson Dr Gianna Zoppei) on December 3, 2009.

All the enrolled patients signed an informed consent form.

Patients scheduled to undergo DMLS in the Ear-Nose-Throat (ENT) Surgery Department of the S. Raffaele Hospital between November 2009 and December 2010 were sequentially involved in the study.

Pregnant and younger than 18 years patients were excluded.

Age, sex, and BMI were recorded together with the presence of clinical evidence of pulmonary disease (asthma, chronic obstructive pulmonary disease, hemoptysis, pulmonary hemorrhage, pulmonary hypertension, productive cough over 3 consecutive months of at least 2 years), smoking habits (nonsmokers, moderate smokers [<10 cigarettes/day and/or <5 years of smoking history], heavy smokers [>10 cigarettes/day and/or >5 years of smoking history]), physical activity (Metabolic Equivalent of Task), presence of any alteration on chest x-ray (CXR).

Anesthetic management reflected our standard practice. Before induction, baseline noninvasive blood pressure and peripheral oxygen saturation (SpO_2) were recorded. Thereafter, preoxygenation was performed by mask ventilation with 100% oxygen. Anesthesia was induced with intravenous (IV) fentanyl 1.0 μg/kg and propofol 2 mg/kg.

Muscle relaxation was achieved with cisatracurium besilate 0.20 mg/kg IV. Anesthesia was maintained with propofol 4 to 6 mg/kg per hour IV and remifentanil 0.1 to 0.3 μg/kg per minute IV (total intravenous anesthesia [TIVA]). Continuous neuromuscular block was maintained with cisatracurium besilate 1 to 2 μg/kg per minute IV.

Tracheal intubation was performed with the Laser-Flex ETT (Mallinckrodt). This sterile, single-use ETT consists of a flexible stainless steel hose with a soft plastic segment at its distal end that has 2 cuffs, each with an independent self-sealing valve and pilot balloon, which are completely filled with sterile isotonic saline after intubation and covered with moistened gauzes. A 4.5 to 5.5 ID ETT was selected by the attending anesthetist taking into account patient's BMI

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