Rediffusion of nitrous oxide prevents increases in endotracheal tube cuff pressure

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An endotracheal tube designed to reduce nitrous oxide-induced intracuff pressure increases (Mallinckrodt Brandt rediffusion tracheal tube) and its relationship to nitrous oxide exposure was studied. Thirty-two subjects undergoing general anesthesia with endotracheal intubation used either a conventional endotracheal tube (Mallinckrodt Intermediate Hi-Lo) or a nitrous oxide rediffusion endotracheal tube (Mallinckrodt Brandt rediffusion). Intracuff pressures and nitrous oxide concentration were monitored continuously throughout surgery and recorded at 10-minute intervals for 50 minutes. The mean intratracheal cuff pressure in the rediffusion tube rose slightly from an initial 15.0 ± 0.0 mmHg (mean ± 1 SD) to 18.5 ± 2.2 mmHg, which was less than in the conventional tube, 15.0 ± 0.0 mmHg (initial) to 29.5 ± 3.8 mmHg (50 minutes). Mean nitrous oxide concentration measured near the pilot balloon was 19.57 ± 15.8 ppm with the conventional tube and 13.0 ± 20.7 ppm with the rediffusion tube. Mean nitrous oxide concentration measured near the anesthetist’s breathing area was 7.57 ± 5.8 ppm with the conventional tube and 3.57 ± 3.3 ppm in the rediffusion tube. All nitrous oxide concentration values remained within National Institute for Occupational Safety and Health recommendations (less than 25 ppm) and did not differ significantly between groups.

Key words: Adverse effect of anesthetics, inhalation anesthesia, intratracheal anesthetization, intratracheal intubation, nitrous oxide.

Introduction

Studies have implied that high pressures in the cuffs of endotracheal tubes may be associated with an increased incidence of complications.1,2 Morbidity is most commonly manifested as sore throat, followed by glottic or subglottic edema.3,4 Temporary paralysis of the recurrent laryngeal nerves may result from the edema.5 Diffusion of nitrous oxide into the cuff may increase intracuff pressure, compromising tracheal mucosal perfusion.1,2,7-10 Impairment of tracheal perfusion may be an important factor in tracheal morbidity associated with intubation.11,12

Nitrous oxide and oxygen diffuse into air-inflated cuffs of tracheal tubes, increasing their volume and pressure. The process is favored by increased exposure time, decreased cuff thickness, and increased inspired partial pressure of nitrous oxide. As a result, deflation to an intracuff pressure of less than 15 torr should be carried out approximately every 30 minutes when nitrous oxide is in use.2,6 Alternatively, the use of the anesthetic gas mixture to inflate the cuff can prevent or minimize the rise in cuff pressure, because the diffusion gradient for nitrous oxide is minimized.8,9-16 Unfortunately, if this technique is used and a higher inspired oxygen concentration is later chosen, nitrous oxide will diffuse from the cuff, which might result in an incompetent seal and aspiration.17,18
Another approach to limiting cuff pressure is a nitrous oxide rediffusing endotracheal tube (Mallinckrodt Brandt™ rediffusion endotracheal tube), which has a large, thin-walled pilot balloon (Figure 1). The gas within the pilot balloon is similar in composition to the gas within the intratracheal cuff, because of the rhythmic changes in pressure caused by ventilation. These changes cause a pumping effect that results in free gas exchange between the intratracheal cuff and the pilot balloon through the connecting tube. Because the partial pressure of nitrous oxide within the pilot balloon exceeds its partial pressure in room air, nitrous oxide “rediffuses” from the pilot balloon, attenuating pressure increases within the intratracheal cuff.

This study investigated the hypothesis that the use of a conventional endotracheal tube (Mallinckrodt Intermediate Hi-Lo™ tracheal tube) would result in greater endotracheal intracuff pressures compared with a nitrous oxide rediffusing endotracheal tube (Mallinckrodt Brandt rediffusion tracheal tube). The study also proposed to determine the concentration of nitrous oxide produced by nitrous oxide rediffusion, both at the pilot balloon and in the anesthesia provider’s breathing area.

Materials and methods
After institutional review board approval, written informed consent was obtained from all subjects. Patients were excluded from the study if:
1. Nitrous oxide was contraindicated.
2. They had an upper respiratory infection.
3. They had a history of chronic obstructive pulmonary disease.
4. They had a history of an allergic reaction to medication used in the study.
5. If, during laryngoscopy, it was determined that an 8.0-mm internal diameter endotracheal tube (in men) or a 7.0-mm internal diameter tube (in women) was an inappropriate size for the patient.
6. The duration of anesthesia was less than 45 minutes.

Random allocation of patients to study groups was performed with the aid of TrueEpistat® (Epistat Services, Richardson, Texas) statistical software.

The endotracheal tubes used were either 7.0-mm or 8.0-mm internal diameter Mallinckrodt Intermediate Hi-Lo tracheal tubes or Mallinckrodt Brandt rediffusion tracheal tubes (Figure 1). Intermediate high-volume, low-pressure cuffs with a self-sealing valve and attached pilot balloon are a feature of both types. Endotracheal tube cuff pressures were monitored by a National Catheter Company (a division of Mallinckrodt Anesthesia) manometer attached to the pilot balloon.

At 30 minutes postintubation, the area near the pilot balloon and the anesthetist’s breathing area (shirt) were sampled for nitrous oxide concentration using an infrared spectrophotometer (Wilks Miran), which was calibrated and operated according to the manufacturer’s instructions.

All patients received glycopyrrolate 0.2 mg intravenously. Narcotics and benzodiazepines were administered as needed in the preoperative holding area or in the operating room before induction of anesthesia. Patients were given d-tubocurarine 4.5 mg at least 2-3 minutes before the administration of succinylcholine. Following the administration of sodium thiopental 3-5 mg/kg and the control of ventilation by mask, succinylcholine 1.5 mg/kg was administered. After 1 minute or after a decreased response to peripheral nerve stimulation was evident, the trachea was intubated using either the conventional or the rediffusion-type tube. All men received an 8.0-mm internal diameter endotracheal tube, and all women received a 7.0-mm internal diameter tube. The intratracheal cuffs in both groups were inflated to 15 mmHg using the manometer, which was left connected to allow cuff pressure to be recorded every 10 minutes. A heat-and-moisture exchanger was employed within the circuit for all anesthetics. Inspired nitrous oxide concentration was maintained at 66% and inspired oxygen at 34%. Isoflurane and narcotics were titrated to effect. After 30 minutes of anesthesia, an infrared spectrophotometer reading was taken at the endotracheal tube pilot balloon and at the anesthetist’s breathing area. After
50 minutes of anesthesia, the final cuff pressure was recorded, and the cuff pressure manometer was disconnected.

Groups were compared on nominal variables (sex, number of smokers) with the Fisher exact test. Physical status was considered as ordinal data and analyzed with a Mann-Whitney U test. Age, height, and weight, as interval level data, were compared with Student's t test. Cuff pressures, as affected by the type of endotracheal tube and time of measurement, were analyzed with a split-plot analysis of variance (ANOVA). Data from the infrared spectrophotometer readings were analyzed using a two-way ANOVA, with site of measurement and type of endotracheal tube (group) as the independent variables. Computations were performed on an IBM® compatible computer, using CRUNCH® (Crunch Software, Oakland California), and TrueEpistat statistical software. All P values reported are two-tailed, and P values of less than .05 were accepted as significant throughout. All data are reported as mean ± 1 SD, unless noted otherwise.

### Table I

<table>
<thead>
<tr>
<th>Group differences</th>
<th>HiLo</th>
<th>Brandt</th>
<th>P</th>
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<tbody>
<tr>
<td>Number of males</td>
<td>4</td>
<td>11</td>
<td>&lt;.04</td>
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<tr>
<td>Age (years)</td>
<td>41.6 ± 16.4</td>
<td>51.5 ± 16.0</td>
<td>NS</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164 ± 11</td>
<td>171 ± 12</td>
<td>NS</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>71.8 ± 18.7</td>
<td>88.8 ± 19.7</td>
<td>.018</td>
</tr>
<tr>
<td>Number of smokers</td>
<td>3</td>
<td>10</td>
<td>.029</td>
</tr>
<tr>
<td>Physical status</td>
<td>1.5 ± 1</td>
<td>2 ± 0</td>
<td>NS</td>
</tr>
<tr>
<td>Nitrous oxide concentration:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pilot balloon</td>
<td>19.57 ± 15.8</td>
<td>13.0 ± 20.7</td>
<td>NS</td>
</tr>
<tr>
<td>Anesthetist's breathing area</td>
<td>7.57 ± 5.8</td>
<td>3.57 ± 3.3</td>
<td>NS</td>
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</table>

1. Values are median ± interquartile range
NS—Not significant, P > .05

### Table II

<table>
<thead>
<tr>
<th>Cuff pressure changes with time</th>
<th>Minutes</th>
<th>HiLo (mmHg)</th>
<th>Brandt (mmHg)</th>
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<tr>
<td></td>
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<tr>
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<td>0</td>
<td>15.00 ± 0</td>
<td>15.00 ± 0</td>
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<tr>
<td></td>
<td>10</td>
<td>18.73 ± 1.9</td>
<td>15.49 ± 1.2</td>
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<tr>
<td></td>
<td>20</td>
<td>22.15 ± 2.3</td>
<td>16.55 ± 1.5</td>
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<tr>
<td></td>
<td>30</td>
<td>25.06 ± 3.1</td>
<td>17.15 ± 2.0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>27.42 ± 3.5</td>
<td>17.89 ± 2.2</td>
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<tr>
<td></td>
<td>50</td>
<td>29.50 ± 3.8</td>
<td>18.54 ± 2.2</td>
</tr>
</tbody>
</table>

Results

Thirty-two American Society of Anesthesiologists' physical status I, II, and III patients who required general anesthesia with endotracheal intubation participated. Measurements of nitrous oxide concentration from two patients in each group had to be discarded because of malfunctions in an anesthesia gas machine and a scavenger system.

The rediffusion tube group had more males (P < .04), more smokers (P < .03), and weighed more (P < .02) than the control group (Table I). The groups did not differ in age, height, or physical status.

Intracuff pressure was higher in the control group than in the rediffusion group (P < .01) at all times after the initial measurement. The changes in cuff pressure are shown in Table II and represented graphically in Figure 2.

The mean nitrous oxide concentration in the anesthetist's breathing area was less than 10 ppm in both groups (Table I, Figure 3). Mean concentrations at the pilot balloon were higher than in the provider's breathing area (P < .01; see Table I and Figures 4 and 5) but still less than 20 ppm. The small difference observed in mean nitrous oxide concentration between groups at either site did not reach statistical significance.
Discussion

The conventional type of endotracheal tube had a higher intracuff pressure than the rediffusion type at 10 minutes after initial inflation, a difference that persisted for each subsequent pressure reading. These data support the findings of Stanley, Revenas and Lindholm, and Brandt and associates. Because the groups differed in some of the demographic variables (number of males, number of smokers, and weight), caution is appropriate in interpreting these findings. The manner in which these differences might bias the findings is unclear, but it seems negligible.

The National Institute for Occupational Safety and Health (NIOSH) has published recommendations for worker exposure to nitrous oxide of less than 25 ppm. This study suggests that neither type of endotracheal tube produced mean nitrous oxide concentrations in excess of this guideline, even when sampling was performed in close proximity to the pilot balloon.

Higher mean nitrous oxide concentration at the pilot balloon could be the result of either percutaneous loss of nitrous oxide or the characteristics of the operating room ventilation system. The percutaneous loss of nitrous oxide is 3.6 mL/min/m² at an average alveolar concentration of 70%, which, converted to an hourly loss, amounts to 214 mL/m². Hourly loss for patient of average body surface area (1.73 m²) would be approximately 372 mL/hr; this nitrous oxide might

Figure 3
Nitrous oxide in breathing area

Figure 4
Nitrous oxide at pilot balloon

Figure 5
Ambient nitrous oxide similar for endotracheal tubes (ETTs)

*P<.01 for the sites; no difference between groups at each site

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collect under the drapes. It would not collect near the anesthetist's breathing area, because operating room ventilation provides as many as 15-25 air exchanges per hour, an amount sufficient to produce near uniformity of anesthetic concentrations in all locations except those close to the source of the leakage (patient). In operating rooms, the background concentration of nitrous oxide should be essentially nil.

Several incidental observations were made. If the anesthetist placed a heat-and-moisture exchanger in the circuit after the nitrous oxide was flowing, it took as long as 20 minutes for the nitrous oxide concentration in the area of the patient's head to decrease from 40-10 ppm. Assuring the tightness of fit of the circle system components (PETCO₂ connector, Y-connector, tubing, carbon dioxide absorber, and ventilator) could reduce nitrous oxide concentration by as much as 30 ppm. These observations are congruent with previous suggestions that alterations in work practices, in combination with scavenging, can help to limit healthcare worker exposure to waste anesthetic gases.

Several characteristics of the rediffusion-type tube deserve comment. It was observed that the rediffusion-type tube has a rather fragile pilot balloon because of the thinness required. One of the pilot balloons received a pinhole leak during the process of turning the patient prone for a laminectomy. If compressed, the pilot balloon also transfers the pressure to the cuff. This could occur unintentionally in intubated patients during postoperative position changes. The large volume required to inflate the rediffusion-type cuff (approximately 40 cc) is awkward. In view of these disadvantages, perhaps the best application of rediffusion-type endotracheal tubes might be when the anesthetist's access to the airway is restricted. In a sitting case, for example, it is more difficult to measure or adjust intratracheal cuff pressure.

In conclusion, this study demonstrated that a significant rise in endotracheal tube cuff pressure occurs in a conventional-type intratracheal cuff within 10 minutes of initial inflation, as compared to a rediffusion-type endotracheal tube cuff. The amount of nitrous oxide that is diffused into the anesthetist's breathing area and at the pilot balloon is well below the NIOSH standard of less than 25 ppm.

REFERENCES


AUTHORS

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