Comparison of Oropharyngeal Oxygen Pooling and Suctioning During Intubated and Nonintubated Dental Office-Based Anesthesia

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Objective: The risk of a spontaneous surgical fire increases as oxygen concentrations surrounding the surgical site rise above the normal atmospheric level of 21%. Previously published in vitro findings imply this phenomenon (termed *oxygen pooling*) occurs during dental procedures under sedation and general anesthesia; however, it has not been clinically documented.

Methods: Thirty-one children classified as American Society of Anesthesiologists I and II between 2 and 6 years of age undergoing office-based general anesthesia for complete dental rehabilitation were monitored for intraoral ambient oxygen concentration, end-tidal CO_2, and respiratory rate changes immediately following nasotracheal intubation or insertion of nasopharyngeal airways, followed by high-speed suctioning of the oral cavity during simulated dental treatment.

Results: Mean ambient intraoral oxygen concentrations ranging from 46.9% to 72.1%, levels consistent with oxygen pooling, occurred in the nasopharyngeal airway group prior to the introduction of high-speed oral suctioning. However, 1 minute of suctioning reversed the oxygen pooling to 31.2%. Oropharyngeal ambient oxygen concentrations in patients with uncuffed endotracheal tubes ranged from 24.1% to 26.6% prior to high-speed suctioning, which reversed the pooling to 21.1% after 1 minute.

Conclusion: This study demonstrated significant oxygen pooling with nasopharyngeal airway use before and after high-speed suctioning. Uncuffed endotracheal intubation showed minimal pooling, which was reversed to room air ambient oxygen concentrations after 1 minute of suctioning.

Key Words: Pediatric dentistry; Office-based general anesthesia; Oxygen pooling; Surgical fires; Operative dentistry.

Sudden, unanticipated fire continues to be an uncommon but devastating, potentially fatal complication of surgery.[1] Sources estimate 50 to 600 fires occur each year in operating rooms (ORs) across the United States, with up to 20% involving serious injury or death.[2–4] A surgical fire is most likely to occur when surgery is performed in the presence of supplemental oxygen along with instrumentation that serves as an ignition source.[5] In the dental context, the concurrence of oxygen from a nasal cannula or nitrous oxide system, a flammable dental object, and a spark from an electrosurgical unit or diamond burr compromise the fire or combustion triangle. This educational model summarizes the 3 elements needed for fire: an oxidizer, fuel, and an ignition source.[5–9] While a substantial number of published reports have documented OR surgical fires, very few describe surgical fires in dental offices. Since the necessary conditions for fire are common during dental surgery, many more reports of fires would be expected to be found in the dental literature.

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VanCleave and colleagues[6] proposed that the use of perioperative high-speed intraoral suction may act as a unique, mitigating factor during dental surgery and potentially explain the low number of reported dental office fires. Using an in vitro model of the oral cavity, they demonstrated that accumulation of oxygen (termed *oxygen pooling*) occurred in the mouth when supplemental oxygen was used. Spontaneous fire was easily induced under these conditions when an electrosurgical unit was activated with a cotton gauze pad present in the surgical field. Equally important was the demonstration that oxygen pooling was reversed when high-speed suction was added, diminishing the capacity to induce spontaneous fire. In a subsequent study, Cox et al[10] demonstrated oxygen pooling in human volunteers using a simulated, in situ dental setting in which oxygen was supplied through a nasal cannula.[10]

Although the data strongly support the belief that oxygen pooling occurs during actual dental treatment when supplemental oxygen is used, no published studies have confirmed this phenomenon during general anesthesia in a dental office when a nasopharyngeal airway (NPA) or uncuffed endotracheal tube (ETT) was in use. The first aim of our study was to determine if oxygen concentrations in the oral cavity rise during general anesthesia. We investigated children undergoing office-based general anesthesia for complete rehabilitation of early childhood caries. Airway management involved 1 of 2 modes commonly used by dentist anesthesiologists to facilitate oxygen delivery and maintain airway patency: (1) endotracheal intubation or (2) the use of NPAs.[11,12] Modifying the method by Cox et al[10] to measure intraoral oxygen concentrations, this study used continuous, real-time gas analysis to detect intraoral oxygen pooling, defined as oxygen concentrations >21%, as is normally found in room air. A second aim of the study was to determine if the introduction of high-speed intraoral suction during dental procedures affected oxygen pooling in the oropharynx.

METHODS AND MATERIALS

After receiving approval from the Indiana University Institutional Review Board, children between the ages of 24 and 72 months scheduled for comprehensive dental rehabilitation under office-based general anesthesia were identified as potential study participants. They were sequentially selected in the order of their appearance on the schedule of 2 pediatric dental practices. In addition to age, an American Society of Anesthesiologists (ASA) physical status classification of I or II was used as a criterion for study inclusion. Exclusion criteria included a history of breathing disorders, current signs or symptoms of acute respiratory infection, and a known history of nasal obstruction. Informed consent was obtained from the participant's parent or legal guardian. All participants received anesthesia care from a single, experienced dentist anesthesiologist who performed each preoperative evaluation, selected an appropriate mode of airway management, and performed all other aspects of total intravenous general anesthesia.

Perioperative monitoring for all participants included pulse oximetry, electrocardiography, noninvasive blood pressure, capnography, respiratory rate, and pretracheal stethoscopy (Sedation Stethoscope, Sedation Resources). Supplemental oxygen was administered using a modified nitrous oxide delivery system (Porter MXR3000, Parker/Porter). In addition, a portable oxygen analyzer (Viasensor G210 Medical Gas Analyzer, QED Environmental Systems) was used to collect real-time in situ oropharyngeal oxygen concentrations during general anesthesia.

Preoperative evaluation including a review of the patient's medical history, limited physical examination, and airway assessment and baseline data were recorded for all patients, including sex, age, height, and weight. To facilitate cooperation and parenteral separation, initial dissociative deep sedation was induced in all patients with an initial intramuscular injection of ketamine 2 mg/kg combined with midazolam 0.2 mg. After peripheral venous access was obtained, general anesthesia was induced using total intravenous anesthesia with bolus doses of propofol 3 mg/kg and remifentanil 1 μg/kg delivered over a 40-second period. After the airway was secured, general anesthesia was maintained with simultaneous continuous infusions of propofol 100 μg/kg/min and remifentanil 0.05 μg/kg/min. The airway was secured with either an uncuffed nasal Ring-Adair-Elwyn (RAE) ETT[13] (Ventiseal, Flex-iCare) or bilateral ringed soft rubber NPAs[14] (Hull Anesthesia, Hull Medical Systems). Direct visualization was used to confirm placement of the ETT through the vocal cords and placement of the tip of the NPAs within ~5 mm of the arytenoid cartilages.

The remaining open oropharyngeal space was obtunded with 1 to 2 methylcellulose sponges (C sponge, Xemax Surgical Products) as a throat pack. Nasal ETTs were attached to a Modified Jackson Rees circuit (Medline), which was supplied with oxygen from the modified nitrous oxide unit at a rate of 3 L/min. Patients receiving NPAs were administered supplemental oxygen at 3 L/min by inserting the feed line from a nasal cannula into one of the NPAs until resistance was met (~1/3-1/2 the NPA depth). The capnography sampling line from the anesthesia monitor was inserted in the contralateral NPA at roughly the same depth. The

Figure 1. Participants Under General Anesthesia with Bilateral Nasopharygeal Airways (NPAs) in Place

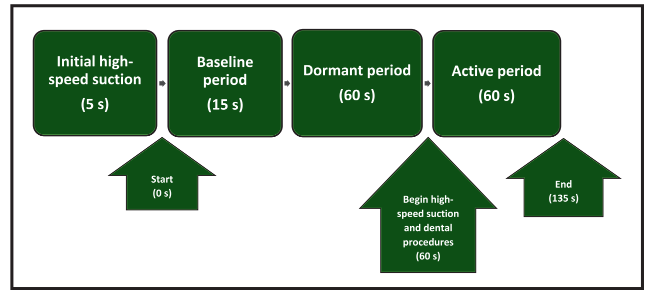
Supplemental oxygen is supplied through the left NPA (red arrow), while the capnography sample line is inserted in the right NPA (yellow arrow). The oxygen analyzer probe (pink) is fixed within the silicon intraoral bite block on the left side of the mouth.

patient's head was wrapped and stabilized, and local anesthesia was administered via infiltration by the dentist anesthesiologist. Return of spontaneous ventilation was achieved within 5 minutes for all subjects. The experimental protocol did not begin until spontaneous ventilation had returned to a rate and depth that did not require positive-pressure assistance.

A pediatric dental silicon mouth prop was modified to hold the tip of the oxygen sensor apparatus, allowing the tip to detect oxygen concentrations in the oropharynx distal to the dentition and anterior to the throat pack (Figure 1). Using a modification of the method described by Cox et al,[10] oxygen concentrations were continuously assessed while the mouth prop was in place.

A 135-second measurement protocol was performed in all subjects after local anesthetic administration but prior to the start of the restorative dental procedures (Figure 2). Before any measurements, high-speed suction was applied to the oral cavity for 5 seconds. Oropharyngeal oxygen concentrations were then measured and recorded at 15-second intervals for a total of 135 seconds using a stopwatch. For purposes of analysis, the following 3 time periods were noted within the 135 seconds of oropharyngeal oxygen concentration monitoring:

Figure 2. Study Protocol Schematic



The 135-second study protocol performed in all subjects after local anesthetic administration before starting any restorative dental procedures. Oxygen concentration measurements were taken every 15 seconds, and means were calculated for each of the 3 periods.

- Baseline period: The first 15 seconds following the initial high-speed suctioning of the oral cavity.
- Dormant period: Immediately following baseline measurement, a 60-second dormant period was allowed to simulate time in which no high-speed suction was present, and no dental handpiece was in use.
- Active period: Immediately following the dormant period, high-speed intraoral suction was applied to the oral cavity and tooth preparation was simulated by the pediatric dentist by activating a high-speed handpiece in front of the high-speed suction tip near the dentition for 60 seconds.

Following the end of the active period, the mouth prop and saliva ejector were withdrawn, and oropharyngeal oxygen concentration assessment was ended.

Statistical Analysis

An a priori power analysis was performed using an α of .05, a β of .8, a group number of 2, and an effect size of a 5% change in oxygen concentration. A total of at least 30 patients were determined to be required for a statistically significant difference between the 2 groups.

Statistical analysis was performed using SPSS 28 (IBM Corporation) by summarizing data by time point, group, and airway type (ETT vs NPAs). Data were also summarized for patient age, sex, weight, height, ASA class, and airway management. Oxygen levels were summarized and categorized as >21% or >25%. The mean oxygen concentrations for each of the 3 periods (baseline, dormant, and active) were calculated.

Repeated-measures with 1-way analysis of variance (ANOVA) with fixed effects for time point was used to assess the differences between the time points. The independent variable was airway type, and the depen-

Demographics of Study Participants

Variable	*Mean (SD)*
Age, mo	47.5 (10)
Weight, kg	17.7 (2.5
Height, in.	38.9 (3.0)
Gender	n (%)
Male	16 (51.2)
Female	15 (48.8)
ASA class	n (%)
I	30 (96.8)
II	1 (3.2)
Airway management	n (%)
Endotracheal intubation	14 (45.2)
Nasotracheal airway	17 (54.8)

dent variable was the oxygen level. A repeated effect was included. One-way ANOVA to determine differences between the time points in each group was performed. A 5% significance level was used for all tests.

RESULTS

A total of 34 children were identified for potential inclusion in this study, and 3 children were disqualified (due to active upper respiratory infection, violation of fasting protocols, or exceeding the age parameters for the study), leaving 31 participants (16 male and 15 female) for the study. Participant demographics are summarized (Table). There were no significant differences between the 2 groups (ETT vs NPAs) with respect to age, weight, and height, and all participants with one exception were classified as ASA I.

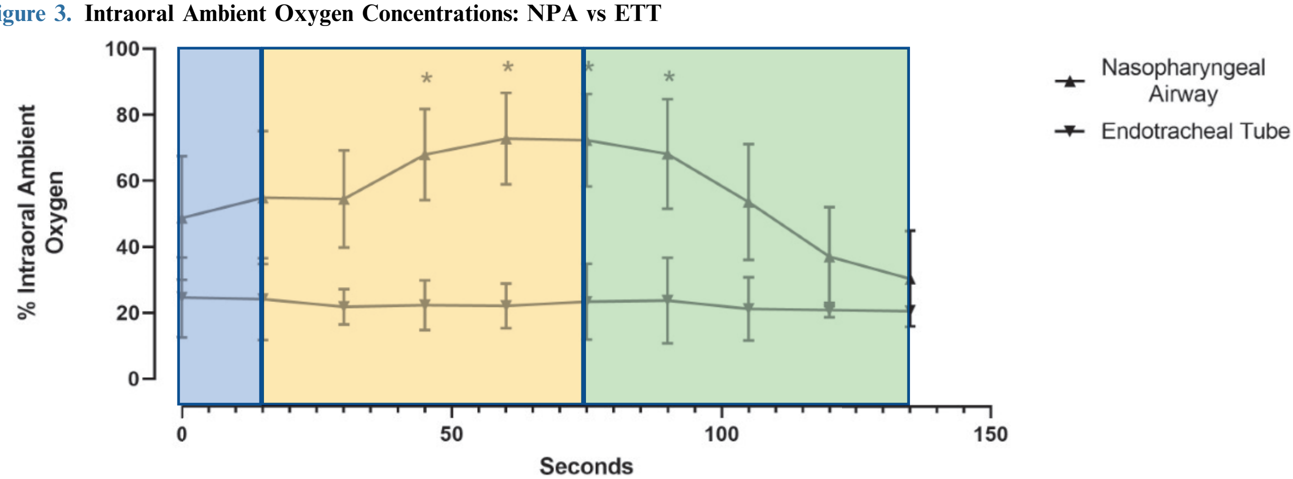
Oropharyngeal oxygen concentrations were significantly higher at all 3 time points in the NPA group compared with the ETT group (Figure 3). The mean oropharyngeal airway oxygen concentration for the NPA group was 46.9% at baseline, which increased to 72.1% by the end of the dormant period and dropped to 31.2% at the end of the active period. These data suggest oropharyngeal pooling occurred immediately in the NPAs group, continued to increase during the dormant period, and dropped sharply once high-speed suction was introduced. In contrast, the mean oropharyngeal oxygen concentration in the ETT group was 24.1% at baseline, increased to 26.6% by the end of the dormant period, and dropped to 21.1% at the end of the active period.

Throughout the testing period, both end-tidal carbon dioxide levels (Figure 4) and respiratory rate (Figure 5) were observed for evidence of a change in trends (as opposed to absolute values) due to inherent differences between intubated and nonintubated patients that could affect absolute value measurements. Both trends remained essentially constant with no significant differences seen in either the ETT or NPAs groups. These data suggest the rate and depth of ventilation in both groups was unaffected by the type of airway management used in this study and affirms the consistency of the induction technique across both groups.

DISCUSSION

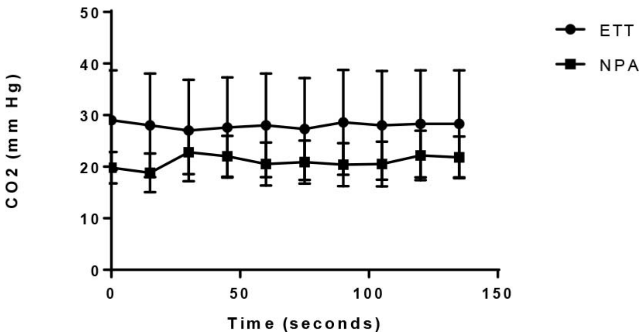
To minimize surgical fire risk, the Anesthesia Patient Safety Foundation (APSF) suggests the use of endotracheal intubation or a laryngeal mask airway in any procedure above the xiphoid process or if oxygen supplementation >30% is required. The APSF also recommends the use of air or a fraction of inspired

Figure 3. Intraoral Ambient Oxygen Concentrations: NPA vs ETT



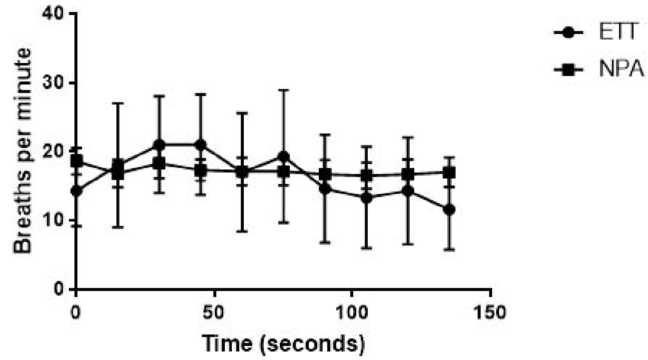
Oropharyngeal oxygen concentrations for patients managed with NPAs vs nasal intubation with ETT. Study periods denoted by color (baseline, blue; dormant, yellow; active, green). *Difference between groups is statistically significant, $P < .05$. ETT, endotracheal tube; NPA, nasopharyngeal airway.

Figure 4. **End-Tidal CO_2: NPA vs ETT**



Comparison of end-tidal CO_2 measurements obtained throughout the study. ETT, endotracheal tube; NPA, nasopharyngeal airway.

Figure 5. **Respiratory Rate: NPA vs ETT**



Comparison of respiratory rate measurements obtained throughout the study. ETT, endotracheal tube; NPA, nasopharyngeal airway.

oxygen (FiO_2) ≤30% for open delivery airway management systems.[15] Prior to this study, we were unaware of any published data describing ambient intraoral oxygen concentrations during pediatric dental rehabilitation under general anesthesia, a procedure commonly performed with supplemental oxygen with and without endotracheal intubation. To our knowledge, this article provides the first quantitative analysis of oxygen concentrations in that setting.

The data from our study suggest 2 conclusions. First, the use of the NPA technique was associated with significant oxygen pooling at levels above the recommended maximum safe limit of 30% beginning with the period immediately after airway placement and continuing until high-speed suction had been applied for several seconds. By comparison, endotracheal intubation with an uncuffed nasal tube produced only minimal oxygen pooling, which remained below 30% within the conditions of this study.

Second, high-speed intraoral suction appears to be remarkably effective in reducing oxygen pooling and impeding conditions for a fire regardless of whether intubation or NPAs were used for airway management. Although sponges were used to obtund the oropharynx above the tip of the NPAs, oxygen was still delivered at the level of the epiglottis, outside of the trachea and near the oral cavity. In contrast, the tip of the ETT remains within the confines of the trachea, below the vocal cords and beneath oropharyngeal sponge. Our trial set an arbitrary limit of 60 seconds for high-speed suctioning, which was sufficient for drastically reducing the mean oxygen concentration to levels approximating 30% within the NPA group. It is unknown whether continued suctioning for longer than 60 seconds would further reduce ambient intraoral oxygen concentrations to levels that approximate room air (as seen in the intubated group) or whether the NPA technique is associated with some persistent level of oxygen pooling. Additional studies with longer suctioning times would help to clarify this question.

The delivery of supplemental oxygen to children under procedural sedation and general anesthesia is a long-standing practice intended to produce a temporary hyperoxic state, thereby preventing rapid oxygen desaturation if apnea or airway obstruction should occur.[16] Following this line of reasoning, one might conclude that a residual level of oxygen pooling between 21% and 30% is tolerable and perhaps even desirable. In that case, the data from this study suggest that uncuffed ETTs could provide a low level of oxygen pooling within this range. In contrast, the high levels of ambient intraoral oxygen produced by the NPA technique underscore the need for frequent, careful use of high-speed dental suction and perhaps a reduction in the commonly used but arbitrary flow rate of 3 L/min of oxygen used in this study. Further studies are needed to determine both the optimal oxygen flow rate and the duration of high-speed suctioning in the intraoperative period.

This study was limited by its relatively small sample size and the limited number of airway management modalities used. Further studies using cuffed ETTs and nasal cannula oxygen delivery would provide a broader understanding of the relative risk of intraoperative oral fires during pediatric dental rehabilitation.

CONCLUSION

This study demonstrated that significant oxygen pooling occurred with NPA use for airway management before and after the application of high-speed suctioning, in contrast to uncuffed ETT use, which showed minimal oxygen pooling. In addition, the application of high-speed suction for 1 minute successfully lowered intraoral oxygen concentrations to ~30% in the NPA group and ~21% in the ETT group.

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