The Effects of Different Levels of Ambient Oxygen in an Oxygen-Enriched Surgical Environment and Production of Surgical Fires

Leah B. Davis, DMD,* Mark A. Saxen, DDS, PhD,† James E. Jones, DMD, MSD, EdD, PhD,‡ James D. McGlothlin, MPH, PhD, CPE,§ Juan F. Yepes, DDS, MD, MPH, MS, DrPH,|| and Brian J. Sanders, DDS, MS¶

*Pediatric Dental Resident, Department of Pediatric Dentistry, Riley Hospital for Children/Indiana University School of Dentistry, Indianapolis, Indiana, †Adjunct Clinical Associate Professor, Department of Oral Pathology, Medicine and Radiology, Indiana University School of Dentistry, Indianapolis, Indiana, ‡Starkey Research Professor and Chair, Department of Pediatric Dentistry, Riley Hospital for Children/Indiana University School of Dentistry, and Adjunct Clinical Professor of Pediatrics, Indiana University School of Medicine, Indianapolis, Indiana, §Professor Emeritus, Purdue University, Grand Rapids, Michigan, ||Associate Professor of Pediatric Dentistry, Riley Hospital for Children/Indiana University School of Dentistry, Indianapolis, Indiana, and ¶Program Director and Professor, Department of Pediatric Dentistry, Riley Hospital for Children/Indiana University School of Dentistry, Indianapolis, Indiana

Surgical fires require an oxygen-enriched environment, a flammable substrate, and an ignition source. We hypothesized ambient oxygen concentration is proportional to the latency time to combustion and the incidence of surgical fires that are detected. We examined latency time and number of events, utilizing the VanCleave et al model of intraoral fire ignition under 60, 80, and 100% oxygen concentration and flow rates of 4 and 10 L/min. Results demonstrated that ambient oxygen concentration and flow rate correlated positively to the initiation of combustion. The number of combustion events with 60% oxygen was significantly lower than with both 80% ($p = .0168$) and 100% ($p = .002$). Likewise, the number of events with 80% oxygen was significantly lower than with 100% oxygen ($p = .0019$). Flow rate has a significant effect on the time to the first event ($p = .0002$), time to first audible pop ($p = .0039$), and time to first flash or fire ($p < .0001$). No combustion occurred at oxygen concentrations less than 60% or flows less than 4 L/min. We conclude that latency time to combustion is directly proportional to ambient oxygen concentration and flow rate. Minimum oxygen concentration and flow rate were identified in our model. Further research is indicated to determine the minimal clinical oxygen concentration and flow rate needed to support combustion of an intraoral fire in a patient.

Key Words: Surgical fires; Levels of oxygen-enriched environments; Latency time to combustion.

In February 2013, the American Society of Anesthesiologists Task Force on Operating Room Fires updated their "Practice Advisory for the Prevention and Management of Operating Room Fires."[1] The advisory is a systematically-designed summation of scientific evidence and expert opinion intended to assist anesthesia providers in decisions regarding patient care but does not set a standard of care.[1] Several statements within the advisory clearly relate to anesthesia provided for dental procedures, including the following:

1. A high-risk procedure is defined as one in which an ignition source (eg, electrosurgery) can come in close proximity to an oxidizer-enriched atmosphere (eg, oxygen and/or nitrous oxide);
2. When administered in an open system, supplemental oxygen in the operating room is defined as a high-risk situation;
3. The literature is insufficient to evaluate whether avoidance of nitrous oxide for high-risk procedures, insufflating with room air, or scavenging with suction in and around the airway affects the risk of operating room fires;

Received June 20, 2016; accepted for publication November 21, 2016.

Address correspondence to Dr Leah Davis, 210 E Main Street, Mahomet, IL 61853; leahbethrippy88@gmail.com.

Anesth Prog 65:3–8 2018 | DOI 10.2344/anpr-64-04-12

4. For cases involving an ignition source and surgery inside the airway, cuffed endotracheal tubes should be used when clinically appropriate.

Supplemental oxygen, delivered through an open system, to a nonintubated airway is very common in dentistry,[2] yet the dental literature is lacking with regard to intraoral fires during dental office–based anesthesia. In a 2014 review of the dental literature dating back 50 years, only 4 published reports of dentistry-related intraoral fires were recorded.[3] This compares to an estimated rate of up to 200–600 operating room fires that occur each year in hospitals.[3,4,5] It was unclear whether this disparity represented the effect of nearly universal use of high-volume intraoral suction during dental procedures or other causes, such as the lack of a formal outcomes reporting system in dentistry. Dental anesthesia and sedation providers are left with no current information to help them determine if their open-airway, oxygen-enriched surgical environment was a high-risk situation that required modifications in clinical protocols. Additionally, the disparity raised the question as to whether dental operating practices, such as high-volume suction, should be examined and whether other forms of anesthesia, such as mandatory intubation, should be routinely used as a way to reduce the risk of intraoperative fire.

In 2014, VanCleave et al[6] examined the effect of intraoral suction on fire ignition in a simulated intraoral cavity. They were able to demonstrate that the use of intraoral high-volume suction significantly inhibited the onset of combustion, and also lowered the amount of fire that was recorded.[6]

Based upon these initial results, there was a need to determine the lowest level of ambient oxygen needed to support combustion in an oxygen-enriched field to help improve safety protocols and help prevent accidental fires during oral and dental surgeries. It was hypothesized that the amount of ambient oxygen would have an effect on the latency time to combustion and the number of incidents that are detected.

MATERIALS AND METHODS

In the study we used the VanCleave et al[6] model, derivative of the model of Roy and Smith,[7] to capture simulated conditions required to produce an oropharyngeal fire in an environment enriched with oxygen.[7] These 2 models use the eviscerated body cavity of a raw chicken ("preparation") to simulate the dimensions, volume, and gross anatomical characteristics of the human oral cavity. Sixteen gutted, raw chickens, chosen for consistent body size, were obtained from a local butcher and stored in a temperature- and climate-controlled environment prior to the initiation of the study. An oxygen supply tube was secured through the cervical opening to the body cavity. Prior to each experiment, the preparation was infused with oxygen-enriched air (60 or 80% oxygen) or 100% oxygen supplied from premixed E cylinders (Indiana Oxygen). The level of ambient oxygen was verified prior to the start of each trial with a Mini-Ox Oxygen Monitor (Apogee MO-200 O sensor) using a standard sensor, using the highest ambient oxygen reading recorded after infusion of the oxygen-enriched gas.

A standard electrosurgical tip (MACAN, RadioSurg) was used for the ignition source. The thermometer, dew point hygrometer sensor, and oxygen sensor were placed inside of the preparation but far enough away from the electrosurgical tip to ensure the measurements were not distorted by the initial ignition of the fire. Two dry gauze dental sponges were placed in close proximity to the electrosurgical tip. A second gauze sponge was opened at dimensions to simulate the pharyngeal drape that is used during most dental surgeries under deep sedation or general anesthesia with an open airway.

The thermometer, dew point hygrometer, and oxygen sensor were connected to a computer with software that recorded continuous real-time data throughout each trial. The time of ignition of combustion for each trial was recorded by a single dedicated observer using a digital stopwatch.

A total of 30 trials were run at each ambient concentration of 60, 80, and 100% oxygen at flow rates of 4 L/min and 6 trials with each concentration at 10 L/min. All trials were conducted under a vented chemical hood (34.3 m/min air flow velocity) to control the trial environment. Baseline levels of ambient oxygen, temperature, and humidity were standardized for all trials. A new test spot of electrocautery was chosen within the preparation for each trial. If a new suitable environment was not found or if the simulated environment had been altered from the previous trials, a new preparation was obtained and standardized.

The effect of oxygen concentrations (60, 80, and 100%) on the proportion of trials with events (flash, pop, and fire) was evaluated using logistic regression, while accounting for multiple trials on the same preparation. Time to ignition was evaluated using Cox proportional hazard survival analysis, again accounting for multiple trials on the same preparation. Temperature and humidity were summarized and examined using Microsoft Excel tables.

RESULTS

Specimen characteristics are provided in Table 1, showing mean values with standard deviation of

Table 1. Specimen Characteristics

Characteristic	*Mean (SD)*
Height, cm	8.3 (1.1)
Width, cm	8.7 (0.9)
Depth, cm	8.7 (1.1)
Volume, cm^3	624.0 (129.5)
Weight, kg	1.8 (0.5)
Starting temperature, °C	15.6 (2.9)
Ending temperature, °C	20.9 (4.0)
Starting humidity, %	58.4 (12.5)
Ending humidity, %	58.8 (14.6)

* The VanCleave et al[6] model uses a gutted chicken to simulate the dimensions of the oral cavity. Chicken specimens in these trials were selected and prepared to maximize consistency.

Table 2. Time to Event*

Outcome	*Effect*	*p*
Time to first event	Oxygen	.1025
	Flow rate	*.0002*
	Oxygen × flow rate	.1372
Time to first pop	Oxygen	.4713
	Flow rate	*.0039*
	Oxygen × flow rate	.7964
Time to first flash or fire	Oxygen	*.0215*
	Flow rate	*<.0001*
	Oxygen × flow rate	*.0362*

* Flow rate has a significant effect on the time to the first event, time to first pop, and time to the first flash or fire. Oxygen and the interaction of oxygen and flow rate have a significant effect on the time to first flash and fire. Italics indicate statistically significant data.

preparation measurements. These data, along with temperature and humidity measurements of the specimen taken before and after each trial, confirmed consistent conditions for all trials.

The total number of fire events as a function of ambient oxygen concentration is displayed in Figure 1. The number of events increased significantly with increasing oxygen concentration.

A positive correlation is also observed between flow rate, time to first event ($p = .0002$), time to first flash or fire ($p < .0001$), and time to first pop ($p = .0039$). Both oxygen concentration and the interaction of oxygen and flow rate had a significant effect on the time to first flash or fire ($p = .0215$ and $p = .0362$) (Table 2).

Statistical analysis of events within a trial is represented for 4 and 10 L/min in Figures 2 and 3. Overall, there was a significant effect of oxygen on the total number of events ($p = .0001$) and the total number of flashes and fires ($p = .0010$), but flow rate did not have such an effect (Table 3). For the total number of fire events, 60% oxygen resulted in a significantly lower number of events than both 80% ($p = .0168$) and 100% oxygen ($p = .0002$); 80% oxygen resulted in a significantly lower number of events than 100% oxygen ($p = .0019$). For total numbers of flashes and fires, 60% oxygen resulted in a significantly lower number of events than both 80% ($p = .0338$) and 100% oxygen ($p = .0011$); 80% oxygen resulted in a significantly lower number of events than 100% oxygen ($p = .0123$). Note that because each trial was for a set period of time, more than 1 flash or pop may have been recorded.

For occurrence of any event within a trial, there was a significant effect of oxygen and flow rate separately on the occurrence of any events, any flashes and fires, and any ignitions. There was also a significant effect of the interaction of oxygen and flow rate on ignition (Table 4). The proportion of trials with any events was substantially lower for 60% oxygen than for 80% ($p = .0096$) and 100% oxygen ($p = .0016$), but 80 and 100% oxygen were not significantly different. The proportion of trials with any events was significantly lower for flow rate of 4 L/min than for 10 L/min ($p = .0447$).

The proportion of trials with any flash or fire was significantly lower for 60% oxygen than for 80% ($p = .0101$) and 100% oxygen ($p = .0005$), but 80 and 100% oxygen were not significantly different. The proportion

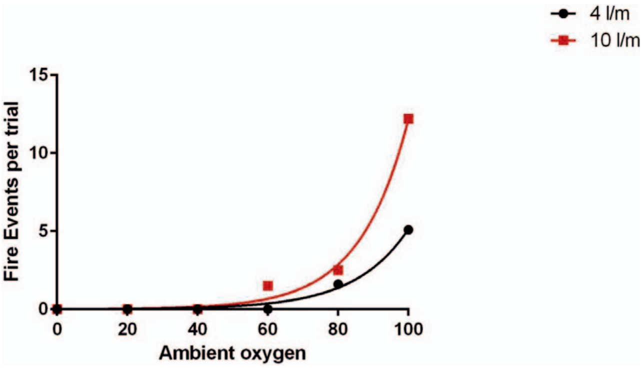


Figure 1. The number of fire events per trial is positively correlated to ambient oxygen concentration.

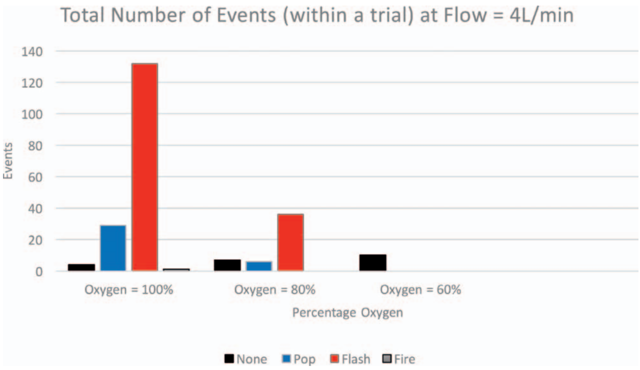


Figure 2. Total number of events (within a trial) at flow = 4 L/min.

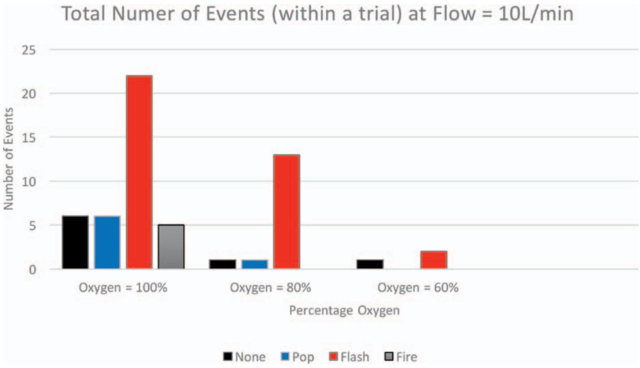


Figure 3. Total number of events (within a trial) at flow 10 L/min.

of trials with any flash or fire was significantly lower for 4 L/min than for 10 L/min ($p = .0335$).

The proportion of trials with any ignitions was significantly higher for 100% oxygen than for 60% ($p < .0001$) and 80% oxygen ($p < .0001$), but 60 and 80% oxygen were not significantly different. The proportion of trials with any ignitions was significantly lower for the 4 L/min than for the 10 L/min flow rate ($p < .0001$) at 100%. At a flow rate of 4 L/min, the proportion of trials with any ignitions was not significantly different for 100% oxygen than for 60 and 80% oxygen. At 10 L/min, the proportion of trials with any ignitions was significantly higher for 100% oxygen than for 60% ($p < .0001$) and 80% oxygen ($p < .0001$).

Table 3. Total Number of Events (Within a Trial)

Oxygen Level (%)	*Event*	*Flow = 4 L/min*	*Flow = 10 L/min*
100	None	4	6
	Pop	29	6
	Flash	132	22
	Fire	1	5
80	None	7	1
	Pop	6	1
	Flash	36	13
	Fire	0	0
60	None	10	1
	Pop	0	0
	Flash	0	2
	Fire	0	0

Outcome	*Effect*	*p*
Events (total number)	Oxygen	.0001
	Flow rate	.3408
Flashes and fires (total number)	Oxygen	.0010
	Flow rate	.2771

* Overall, there is a significant effect of oxygen, but not flow rate, on the total number of events and the total number of flashes and fires.

Table 4. Occurrence of Any Events (Within a Trial)*

Outcome	*Effect*	*p*
Any events	Oxygen	*.0066*
	Flow rate	*.0447*
	Oxygen × flow rate	.2989
Any flash or fire	Oxygen	*.0023*
	Flow rate	*.0335*
	Oxygen × flow rate	.6272
Any ignition	Oxygen	*<.0001*
	Flow rate	*<.0001*
	Oxygen × flow rate	*<.0001*

* Italics indicate statistically significant data.

DISCUSSION

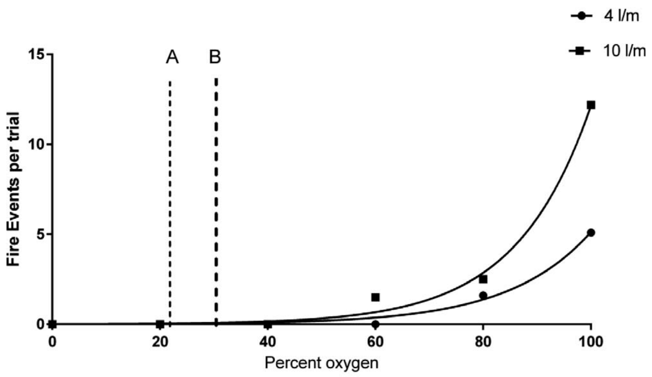
The interpretation of results from an in vitro model and the application of that interpretation to clinical practice are always more difficult and guarded when compared to human investigations performed. However, the study of life-threatening clinical events, such as intraoral fires, precludes the use of in vivo experimental models. The results of this study reproduced the results obtained by VanCleave et al,[6] which lends credibility to this model that was developed. That research showed that ignition of a fire readily occurred in the presence of 100% oxygen, and this ignition was readily inhibited by the introduction of high-speed suction into the surgical field.

The results of this study were consistent with the study by VanCleave et al[3] in that we also found a positive relationship between the amount of oxygen used and fire ignition. The relationship between oxygen and fire events was not found to be linear, in that no fire occurred with ambient oxygen levels at 60%. Trials were not conducted at concentrations below 60%; however, a clear trend is noted in these data that suggests no fire events would occur at these lower concentrations in this model. It appears that 60% represents an approximate threshold for the initiation of fire in this model of intraoral surgical conditions in the presence of high-speed suction.

The flow rate at which oxygen was introduced into the preparation was also correlated to the latency time to ignition. Reduced latency time occurred at 10 L/min as opposed to 4 L/min, and the number of fire events occurring at 10 L/min was much higher than the number that occurred at 4 L/min. This finding may be interpreted as evidence that the higher flow rate helped to maintain a high concentration of oxygen in this enclosed space in the presence of high-speed suction, making it available for fire ignition once the electrosurgery tip created a sufficient amount of heat in the gauze pad fuel source. One may speculate that high flow rates may also contribute to oxygen pooling within the preparation, although for the purpose of the experiment we were unable to determine if this in fact occurred.

One remaining critical question is whether the 60% ambient oxygen threshold seen in this model is applicable to surgical conditions in humans. As noted in the introduction, the medical literature contains reports of operating room fires occurring with supplemental oxygen being supplied at relatively low concentrations and flow rates, but high-speed suction in the area of pooling is not noted in these papers. Oxygen readily accumulates below surgical drapes, in an area much larger than the enclosed oral cavity.[8] If significant oxygen pooling occurs in the oral cavity during surgery with supplemental oxygen, it appears to be contained and evacuated by the high-speed dental suction tip. This question can be answered by further research to measure ambient oxygen concentrations in humans during oral surgical procedures, without the presence of an electrosurgery tip or other ignition source.

Directly related to the question of whether oxygen pooling occurs during oral surgical conditions is the determination of the recommended safe maximum delivered oxygen concentration and flow rate to observe during dental and oral surgical procedures when the potential for fire exists. Figure 4 displays the current maximum delivered supplemental oxygen concentration recommended by the American Society of Anesthesiologists superimposed on the graph of the results from this study. If the VanCleave et al[6] model closely simulates intraoral conditions, it appears that administration of supplemental oxygen at the current recommended maximum delivered concentration of 30%,[9] delivered at 4 L/min, provides a reasonable margin of safety. This supports the clinical decision to use supplemental oxygen, up to the maximum recommended dosage, during oral surgical procedures with cautery in patients, in which the risk of intraoperative oxygen desaturation is more likely than the risk of intraoral fire. Looking at our model, it may be that higher delivered oxygen concentrations may also be acceptable during routine dental procedures without cautery, and provide increased safety from oxygen desaturation due to airway emergencies, in a dental/oral surgical procedure. Further studies would need to be completed to determine the actual highest safe delivered oxygen concentration for use in routine dental practice.



A = amount of oxygen in room air
B = recommended maximum amount of oxygen enhancement

Figure 4. Comparison of the minimum amount of oxygen required to support combustion in the VanCleave et al[3] intraoral model to the amount of oxygen in room air (A) and the maximum amount of supplemental oxygen recommended for sedation in the clinical environment.

Procedural limitations were also encountered during the experiments with the VanCleave et al[3] model. Although the initial temperature and humidity were readily recorded, real-time oxygen, temperature, and humidity readings could not be recorded throughout the entire time for each trial. It is reasonable to suggest the variability seen in our results could have occurred secondarily to fluctuations in oxygen concentration, temperature, and humidity. During these experiments, researchers could also not account for amounts of oxygen entrapment throughout fatty tissue inside the specimen.

Despite the limitations of our in vitro model, and the fact that the level of ambient oxygen during intraoral surgeries with supplemental oxygen is not described in current medical or dental literature, the results of this study support the use of oxygen during intraoral electrocautery procedures up to the previously published maximum recommended safe levels.

REFERENCES

1. Practice advisory for the prevention and management of operating room fires: an updated report by the American Society of Anesthesiologists Task Force on Operating Room Fires. *Anesthesiology*. 2013;118:271–290.

2. Kerins C, Casamassimo PS, Ciesla D, et al. A preliminary analysis of the US dental health care system's capacity to treat children with special health care needs. *Pediatr Dent* 2011;33: 107–112.

3. VanCleave AM, Jones JE, McGlothlin JD, Saxen MA, Sanders BJ, Walker LA. Factors involved in dental surgery fires: a review of the literature. *Anesth Prog*. 2014;61:21–25.

4. Emergency Care Research Institute. Surgical fires: chronological bibliography 1949–2009. Supplement to: Emergency Care Research Institute. A clinician's guide to surgical fires: how they occur, how to prevent them, how to put them out. *Health Devices*. 2009;32:5–24.

5. Clark JR. Bruley ME. Surgical fires: trends associated with prevention efforts. *Pa Patient Saf Advis*. 2012;9:130–135.

6. VanCleave AM, Jones JE, McGlothlin JD, Saxen MA, Sanders BJ, Vinson LA. The effect of intraoral suction on oxygen-enriched surgical environments: a mechanism for reducing the risk of surgical fires. *Anesth Prog*. 2014;61:155–161.

7. Roy S, Smith LP. What does it take to start an oropharyngeal fire? Oxygen requirements to start fires in the operating room. *Int J Pediatr Otorhinolaryngol*. 2011;75:227–230.

8. Greco RJ, Gonzalez R, Johnson P, Scolieri M, Rekhopf PG, Heckler F. Potential dangers of oxygen supplementation during facial surgery. *Plast Reconstr Surg*. 1995;95:978–984.

9. Menta SP. Cautery fires in the operating room. *Am Soc Anesthesiol Newsl*. 2012;76:16–18.