The Effect of Intraoral Suction on Oxygen-Enriched Surgical Environments: A Mechanism for Reducing the Risk of Surgical Fires

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In this study, a mechanical model was applied in order to replicate potential surgical fire conditions in an oxygen-enriched environment with and without high-volume suction typical for dental surgical applications. During 41 trials, 3 combustion events were measured: an audible pop, a visible flash of light, and full ignition. In at least 11 of 21 trials without suction, all 3 conditions were observed, sometimes with an extent of fire that required early termination of the experimental trial. By contrast, in 18 of 20 with-suction trials, ignition did not occur at all, and in the 2 cases where ignition did occur, the fire was qualitatively a much smaller, candle-like flame. Statistically comparing these 3 combustion events in the no-suction versus with-suction trials, ignition ($P = .0005$), audible pop ($P = .0211$), and flash ($P = .0092$) were all significantly more likely in the no-suction condition. These results suggest a possible significant and new element to be added to existing surgical fire safety protocols toward making surgical fires the “never-events” they should be.

Key Words: Surgical fires; Oxygen-enriched environments; High-volume suction.

Surgical fires are well-characterized,^{1,2} readily preventable,³ and potentially devastating⁴ operating room catastrophes that continue to occur as often as 600 times per year in US operating rooms, sometimes with fatal results.⁵ A review of the literature by VanCleave et al⁶ on dental surgical fires specifically, and surgical fires more generally, however, yielded few conclusive answers with respect to the characterization

of conditions that can result in actual in situ dental surgical fires. This research seeks to add to the overall understanding of this unfortunate and rare, but potentially lethal, event.

Since the decline in the use of flammable anesthetics in operating rooms, fire safety research has identified the presence of a pooled or trapped oxygen-enriched environment, eg, in or around a patient's tissue,^{1,5} under surgical drapes,^{7,8} or in the environment generally,⁵ as a major exacerbating factor in the onset of surgical fires. Factors increasing the risk for oxygen-enriched environments include equipment leaks⁹

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Table 1. Chicken Parameters and Variability Between Chickens

<i>Chicken Parameters</i>	<i>Mean (SD)</i>	<i>Minimum</i>	<i>Maximum</i>
Height, cm	6.80 (0.84)	5.4	8
Width, cm	7.08 (0.53)	6.5	7.9
Depth, cm	9.19 (1.07)	7.5	10.8
Volume, cm ³	443 (89)	343	590
Gross weight (from package label), lb	3.91 (0.43)	3.24	4.46
Start chicken temperature, F	56.4 (5.4)	47.7	65.1
Start chicken temperature, C	13.5 (3.0)	8.7	18.4
Start chicken humidity, %	73.3 (7.2)	57.1	79.5
Stop chicken temperature, F	66.2 (4.4)	59.1	72.1
Stop chicken temperature, C	19.0 (2.5)	15.1	22.3
Stop chicken humidity, %	58.7 (6.8)	52.5	67.1

through uncuffed as opposed to cuffed endotracheal tube during general anesthesia,¹⁰ or most commonly through the administration of supplemental oxygen, typically with a nasal cannula.⁵ Moreover, for all types of surgery, the majority of fires have affected the upper torso, head, and neck region,^{5,9} while lasers and electrocautery equipment most frequently provide the source of ignition.^{5,11}

The Anesthesia Patient Safety Foundation along with accepted industry safety protocols cite the use of ignition sources such as laser or electrocautery equipment in oxygen-enriched environments as the most risk-intensive surgical situation for fires.^{3,12,13} This is particularly true for procedures performed in the head, neck, and upper torso, with oxygen delivered via nasal cannula.⁵ However, precisely these conditions occur regularly in the course of procedural sedation for pediatric dentistry,¹⁴ sometimes even in nonsurgical procedures for children with special health care needs.¹⁵ Given the apparent paucity of surgical fires reported in pediatric dental literature, factors that may decrease the risk for such fires include potentially greater fire safety awareness on the part of dental practitioners,^{16–19} ventilation of oxygen-enriched environments in patient oral cavities due to breathing, or evacuation of the oxidizer by high-volume suction, used by dental practitioners as an integral part of the greater portion of dental procedures.²⁰

In surgical circumstances where an oxidizer must accumulate to provide the right conditions for ignition to occur,¹ natural or mechanical ventilation of the space could delay or inhibit ignition. During dental procedures, the patient's breathing may provide such spontaneous ventilation during minimal, moderate, and some types of deep sedation and general anesthesia. Alternatively, or in addition to this, intraoral high-volume dental suction might also serve to draw off sufficient oxygen in an oxygen-enriched environment to delay or inhibit the onset of combustion.

Of these possible mechanisms, intraoral high-volume suction more readily permits simulation in a research model. It was hypothesized that high-volume suction

typical for surgical dental applications used in an oxygen-enriched environment would increase the length of time prior to the onset of combustion if not inhibit it entirely. The null hypothesis states that suction would have no effect on the length of time prior to the onset of combustion.

MATERIALS AND METHODS

Roy and Smith¹ modeled conditions necessary to start an oropharyngeal fire in an oxygen-enriched, partially enclosed environment using an electrosurgical unit as an ignition source. They found, consistent with other studies,^{7,8} that decreased concentrations of oxygen and decreased flow rates of oxygen at each concentration resulted in longer durations prior to the onset of combustion. This approach was adapted to test the hypothesis that suction can sufficiently deplete the oxygen-enriched environment of a partially enclosed space to delay if not inhibit combustion entirely.

Eight raw, degutted chickens of a consistent size and weight were obtained from a single local butcher. Chickens with any internal body cavity anomalies visible on inspection were not selected. Body cavity volume ranged from 343–590 mL (mean = 443 mL, SD = 89 mL); weight varied from 3.26–4.46 pounds (mean = 3.91 lb, SD = 0.43) (Table 1). Chickens were stored in an environmentally controlled refrigeration unit prior to the experimental trials to ensure, as much as possible, a consistency of storage, maintenance, and moisture content for all samples.

For each trial, the chicken was placed in a chemical hood. External temperature and humidity were controlled in the chemical hood and measured using an EL-USB-2-LCD RH temperature data logger (Table 2). Hood face velocity (air flow velocity) was 31.394 m/min. Internal temperature and humidity were measured before and after each trial by inserting a probe (TSI Model 8762

Table 2. Trial Parameters and Variables Between Trials

<i>Trial Parameters</i>	<i>Mean (SD)</i>	<i>Minimum</i>	<i>Maximum</i>
Start ambient temperature, C	20.8 (0.3)	20.5	21.5
Start ambient temperature, F	69.4 (0.6)	68.9	70.7
Start ambient humidity, %	26.7 (4.2)	20.0	31.5
Stop ambient temperature, C	20.8 (0.3)	20.5	21.5
Stop ambient temperature, F	69.4 (0.6)	68.9	70.7
Stop ambient humidity, %	26.8 (4.3)	20.0	31.5
Duration, min	3.45 (0.97)	0.6	4

IAQ-Calc meter) 6 cm into the body cavity of the chicken (Table 1).

For all trials, 2 dry gauze dental sponges (Venture cotton-filled sponges 2 × 2-inch, lot no. 202546-2013-03) were placed in the chicken prior to initiating trials and replaced if ignition scorched the gauze. One gauze was opened to 2 inches × 4 inches and placed approximately 1.0 cm from the oxygen input to simulate a pharyngeal drape. The other was positioned on the internal side of the chicken, opposite to the test site, to represent gauze on the buccal mucosa during dental procedures. A clip and support cord hanging from a cast-iron stand was used to hold the body cavity open and prevent collapse of the skin over the opening (Figure 1).

Oxygen was delivered directly into the neck portion of the chicken through nasal hood tubing inserted 4.5 cm into the neck portion of the chicken forming a seal (Figure 2). For each trial, 100% oxygen at 6 L/min entered continuously into the body cavity of the chicken. An oxygen sensor (Apogee MO-200 O₂ sensor) was inserted into the body cavity of the chicken and monitored the environment until the reading was stable near 100%. The oxygen sensor was removed and electrocautery (MACAN, RadioSurg) was initiated with the unit set to its highest level.

Figure 1. Internal set-up of chicken body cavity with gauze placed as a simulated pharyngeal drape and on simulated buccal mucosa.

For all trials, the electrocautery hand piece was held in place by a single operator. The operator moved the electrocautery tip within approximately a 2-cm radius to maintain contact with unburnt chicken. As the chicken tissue moved away from the tip, the tip was directed deeper into the tissue to maintain contact.

For trials with suction, a suction tip with a 10-mm beveled opening was positioned 3.5 mm (tip of bevel) to the electrocautery tip and secured in place so that it moved with the electrocautery device. Suction draw was regulated to 10 inches mercury (Dwyer Series 477 digital manometer) in order to meet or exceed clinically recommended levels of suction.²⁰ Typical oral evacuation systems create a vacuum of 8–10 inches of mercury that draws through a 10-mm internal diameter suction tip.²⁰

Five trials were performed on the interior of each chicken: 4 were equally spaced around the circumference of the interior without touching the gauze and 1 occurred while touching the pharyngeal drape gauze. Each trial was run for 4 minutes (or until fire forced early termination) with constant oxygen infusion and electrocautery. Following each trial, the electrocautery tip was cleaned using steel wool and an alcohol swab. The gauze was replaced when it appeared scorched after a fire occurred. At the conclusion of the 5 trials, new internal

Figure 2. Chicken model with oxygen delivered through neck opening.

Table 3. Results for Ignition, Audible Pop, and Flash Events in the No-Suction and Suction Conditions

Location	Outcome	Response	No-Suction	Suction	P Value
Overall	Ignition	N	8 (38%)	18 (90%)	.0005
		Y	13 (62%)	2 (10%)	
	Audible pop	N	10 (48%)	18 (90%)	.0211
		Y	11 (52%)	2 (10%)	
	Flash	N	8 (38%)	16 (80%)	.0092
		Y	13 (62%)	4 (20%)	
Gauze	Ignition	N	1 (20%)	4 (100%)	.0164
		Y	4 (80%)	0 (0%)	
	Audible pop	N	4 (80%)	4 (100%)	.3428
		Y	1 (20%)	0 (0%)	
	Flash	N	2 (40%)	4 (100%)	.0578
		Y	3 (60%)	0 (0%)	
12 o'clock	Ignition	N	2 (50%)	4 (100%)	.1025
		Y	2 (50%)	0 (0%)	
	Audible pop	N	2 (50%)	4 (100%)	.1025
		Y	2 (50%)	0 (0%)	
	Flash	N	1 (25%)	4 (100%)	.0285
		Y	3 (75%)	0 (0%)	
3 o'clock	Ignition	N	0 (0%)	3 (75%)	.0285
		Y	4 (100%)	1 (25%)	
	Audible pop	N	1 (25%)	4 (100%)	.0285
		Y	3 (75%)	0 (0%)	
	Flash	N	3 (75%)	2 (50%)	.4652
		Y	1 (25%)	2 (50%)	
6 o'clock	Ignition	N	2 (67%)	3 (75%)	.8091
		Y	1 (33%)	1 (25%)	
	Audible pop	N	2 (67%)	3 (75%)	.8091
		Y	1 (33%)	1 (25%)	
	Flash	N	1 (33%)	3 (75%)	.2703
		Y	2 (67%)	1 (25%)	
9 o'clock	Ignition	N	2 (50%)	4 (100%)	.1025
		Y	2 (50%)	0 (0%)	
	Audible pop	N	0 (0%)	3 (75%)	.0285
		Y	4 (100%)	1 (25%)	
	Flash	N	1 (25%)	3 (75%)	.1573
		Y	3 (75%)	1 (25%)	

temperature and humidity readings were taken. The used chicken was disposed of and a new electrocautery tip was placed. In trials where suction was used, the suction and the electrocautery were initiated at the same time. Suction, oxygen, and electrocautery were all allowed to run for the duration of the trial.

RESULTS

Comparisons between the trials with and without suction for differences in the percentages with ignition, flash, and audible popping were made using generalized estimating equation methodology for binary data. This method was necessary to account for multiple observations of each chicken. Analyses by location were made using chi-square tests.

Overall, ignition ($P = .0005$), audible pop ($P = .0211$), and flash ($P = .0092$) were all significantly more likely

without suction than with suction. Of the 20 with-suction trials, 18 had no ignition (Table 3). In the 2 trials where ignition did occur, the flames were much smaller in size and shorter in duration (less than approximately 2 seconds) than fires that occurred in the no-suction condition (Figure 3).

Statistical analysis comparing trials was completed at the 4 different positions around the interior of the body cavity of the chicken as well as 1 additional trial conducted touching the pharyngeal drape gauze. These trial locations were described in terms of a position on a clock face; 12 o'clock (position 1) points to the breastbone of the chicken; 3 o'clock indicates position 2; 6 o'clock (toward the backbone of the chicken) indicates position 3; and 9 o'clock indicates position 4. Comparing trials by location did not generally yield statistically significant results to support the hypothesis, except as follows: *ignition* at the gauze ($P = .0164$) and position 2 ($P = .0285$); *audible pop* at position 2 ($P =$

Figure 3. Ignition during no-suction condition with large, persistent flames.

.0285) and position 4 ($P = .0285$); and *visible flash* at position 1 ($P = .0285$) (Table 3).

DISCUSSION

High-volume suction either clearly inhibited the onset of combustion or greatly affected the qualitative extent of the fires that occurred. Nonetheless, in 2 trials for the with-suction condition, ignition still occurred, while for 8 trials in the no-suction condition ignition did not occur. Moreover, while it may seem reasonable to assume that an audible pop or flash of light would precede any onset of combustion, in the 13 no-suction condition trials where ignition occurred, an audible pop occurred in only 11 trials, while a flash was observed in all 13 trials. Similarly, in the 2 with-suction condition trials where ignition occurred, an audible pop occurred in both trials, while a flash was observed in 4 trials. Thus, trials were observed where a flash or an audible pop could occur without also cooccurring with ignition. To attempt any sort of similar analysis of the trials where events *did not happen* can only be speculative. It can only be stated that in 8 no-suction cases where ignition did not occur, no flash also occurred, while in an additional 3 trials (11 total) no audible pop occurred. This suggests that the 3 phenomena observed—flash, audible pop, and ignition—may be dissociated in some way from one another. Future research might better characterize any relationship that prevails between these 3 conditions.

In these trials, an initial interior oxygen concentration was maintained at 100% as closely as could be established. Once the trial began, however, various

factors likely would have influenced the actual oxygen concentration within the model. While oxygen ran continuously into the interior, any cumulative effect due to differential flow rates between the input flow, 6 L/min, and the suction output, 10 mm Hg, remained undetermined, as real-time oxygen concentration readings in the interior of the chicken could not be obtained. In this experiment, researchers were also unable to collect internal real-time data for any temperature or humidity fluctuation during the electrocautery procedure. This possible variability of oxygen concentration, temperature, and humidity as factors in the onset of combustion within the body cavity may explain both why 2 fires, admittedly small and of short duration, occurred during the with-suction condition and why 8 trials in the no-suction condition saw no onset of combustion.

This research is limited by the fact that published case reports describe the occurrence of surgical fires associated with an FIO_2 less than 40%. This study was designed in light of the fact that Roy and Smith¹ were unable to produce fire below an oxygen concentration of 50%, at either a 15 L/min or 10 L/min flow rate. They also investigated oxygen concentrations of 100, 80, 60, and 40%. Although in this study 18 of 20 trials with suction at an oxygen concentration of 100% at a 6 L/min flow rate resulted in no ignition, that 2 smaller fires did occur suggests further experimentation at additional oxygen concentrations is needed. The study is also limited in that it does not address the potential combustibility of dental lasers and sparks from high-speed dental cutting burs and diamonds. The data from this study on the use of suction, which almost invariably accompanies the use of these instruments, may inform us on the desirability of designing further research to study these other potential ignition sources.

It also was not an aim of this research to characterize what specific conditions lead to the onset of combustion. Despite being deemed a completely preventable surgical event^{3,21,22} that should never occur,²³ the exact conditions of oxygen concentration, temperature, humidity, or other factors that might lead to a surgical fire in any given instance remain elusive. Stoelting et al² have called for surgical fire-safety experts to reconsider what constitutes safe levels of oxygen concentration in the surgical area. With respect to the fire triangle model of fire safety, this proposes to identify a safe level of oxygen concentration applicable across all circumstances, but studies indicate that even nonflammable materials may become flammable in the presence of sufficient oxygen^{7,8} and that oxygen concentration levels seemingly at identified safe levels may still result in ignition.⁹ This research suggests that the mechanism

at work here in the observed inhibition or reduction of combustive severity results from an adequate *removal* of the source of oxidation from the surgical site rather than any strict maintenance of a given oxygen concentration level.

This points as well to future research where sensors to detect for oxygen concentration, temperature, humidity, and/or other measurable elements might be collected in real time from the interior of a similar model body cavity in order to identify not only the parameters specifically present at the moment of the onset of combustion but also the duration from the beginning of any given trial to that moment of combustion. Such research might disclose what factors or combinations of factors are in play for given ignition events and would add the dynamic element of time, or duration, to the current fire triad model, which stipulates the necessary conditions to create an environment for combustion to occur but does not describe how long or to what degree those conditions must prevail in a given circumstance before combustion actually occurs.

Such additional factors may underlie the difference between situations where a surgical fire occurs, despite following the best current protocols, and circumstances where a fire does not occur. Repeating this experiment or one similar with sensors to measure known factors affecting combustion in real time seems to offer a strong prospect for making surgical procedures safer not just for pediatric dental patients but for all patients, practitioners, and staff.

CONCLUSIONS

At the time of this study, there appeared to be no other published studies that documented the effects of high-volume intraoral suction as a factor in the inhibition or suppression of the onset of combustion in surgical contexts. Our research strongly suggests that such suction can inhibit entirely or highly reduce the qualitative severity of surgical-like fires.

Future research may better characterize still more exactly the specific conditions under which surgical fire ignition occurs. Our present findings nevertheless suggest that the incorporation of high-volume suction in the area of the ignition source during oxygen-enriched surgical procedures might be added to existing surgical fire-safety protocols in order to further decrease the risk of surgical fires. This might not only enhance fire safety in dental pediatric surgical settings and surgical operatories in general but finally make surgical fires the “never event” surgical fire safety experts declare they should be.²³

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REFERENCES

1. 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.
2. Stoelting RK, Feldman JM, Cowles CE, Bruley ME. Surgical fire injuries continue to occur: prevention may require more cautious use of oxygen. *APSF Newsletter*. 2012;26:41, 43.
3. Menta SP. Cautery fires in the operating room. *American Society of Anesthesiologists Newsletter*. 2012;76:16–18.
4. Bruley ME. Surgical fires: perioperative communication is essential to prevent this rare but devastating complication. *Qual Saf Health Care*. 2004;13:467–471.
5. Anesthesia Patient Safety Foundation. *Prevention and Management of Operating Room Fires*. Available at: <http://www.apsf.org/resources/fire-safety/watch>. Accessed October 10, 2012.
6. 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.
7. Wolf GL, Sidebotham GW, Lazard JL, Charchafli JG. Laser ignition of surgical drape materials in air, 50% oxygen, and 95% oxygen. *Anesthesiology*. 2004;100:1167–1171.
8. Goldberg J. Brief laboratory report: surgical drape flammability. *AANA J*. 2006;74:352–354.
9. Yardley IE, Donaldson LJ. Surgical fires, a clear and present danger. *Surgeon*. 2010;8:87–92.
10. Raman V, Tobias JD, Bryant J, et al. Effect of cuffed and uncuffed endotracheal tubes on the oropharyngeal oxygen and volatile anesthetic agent concentration in children. *Int J Pediatr Otorhinolaryngol*. 2012;76:842–844.
11. Bhananker SM, Posner KL, Cheney FW, Caplan RA, Lee LA, Domino KB. Injury and liability associated with monitored anesthesia care: a closed claims analysis. *Anesthesiology*. 2006;104:228–234.
12. 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*. 2003;32:5–24.
13. Joint Commission on Accreditation of Healthcare Organizations. Sentinel event alert: preventing surgical fires. Available at: http://www.jointcommission.org/sentinel_event_alert_issue_29_preventing_surgical_fires/. Accessed October 10, 2012.

14. American Academy of Pediatric Dentistry. Guidelines on use of anesthesia personnel in the administration of office-based deep sedation/general anesthesia to the pediatric dental patient. *Reference Manual*. 2009–2010;31:169–171.
15. Kerins C, Casamassimo PS, Ciesla D, Lee Y, Seale NS. 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.
16. Weaver JM. Prevention of fire in the dental chair. *Anesth Prog*. 2012;59:105–106.
17. Rinder CS. Fire safety in the operating room. *Curr Opin Anaesthesiol*. 2008;21:790–795.
18. Warren E, McAuliffe M. Fire safety in the dental practice: a literature review. *J Ir Dent Assoc*. 2011;57:311–315.
19. Weaver JM. Fire hazards with ambulatory anesthesia in the dental office. *Anesth Prog*. 2004;51:45.
20. Charlton DG. Determination of minimum suction level necessary for field dental units. *Mil Med*. 2010;175:285–288.
21. US Food and Drug Administration. Preventing surgical fires: collaborating to reduce preventable harm. Available at: <http://www.fda.gov/Drugs/DrugSafety/SafeUseInitiative/PreventingSurgicalFires/default.htm>. Accessed October 11, 2012.
22. Gibbs VC. Thinking in three's: changing surgical patient safety practices in the complex modern operating room. *World J Gastroenterol*. 2012;18:6712–6719.
23. Zahiri HR, Stromberg J, Skupsky H, et al. Prevention of 3 “never events” in the operating room: fires, gossypiboma, and wrong-site surgery. *Surg Innov*. 2011;18:55–60.