

Flammability of Surgical Drapes and Materials in Varying Concentrations of Oxygen

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ABSTRACT

Background: Over 600 operating room fires occur annually although many cases go unreported. Over 81% of operating room fires involve surgical drapes, yet limited data exist on the differing degrees of flammability of drapes and other surgical fuel sources in varying oxygen concentrations. The purpose of this study is to assess the flammability characteristics of fuels in the operating room under varying oxygen concentrations.

Methods: Five fuel sources were analyzed in three levels of oxygen: 21%, 50%, and 100%. Three test samples of each material were burned in a manner similar to that established by the Consumer Product Safety Commission. Time to sample ignition and time to complete burn were measured with video analysis.

Results: The median [minimum, maximum] ignition time in 21% oxygen was 0.9 s [0.3, 1.9], in 50% oxygen 0.4 s [0.1, 1.2], and in 100% oxygen 0.2 s [0.0, 0.4]. The median burn time in 21% oxygen was 20.4 s [7.8, 33.5], in 50% oxygen 3.1 s [1.4, 8.1], and in 100% oxygen 1.7 s [0.6, 2.7]. Time to ignite and total burn times decreased as oxygen concentration increased ($P < 0.001$). Flammability characteristics differed by

What We Already Know about This Topic

- Burn injury from operating room fires often involve sedation cases for superficial surgery on the upper chest, neck, or head when supplemental oxygen is administered beneath a drape covering the head

What This Article Tells Us That Is New

- Test samples of five surgical materials were ignited in three oxygen concentrations
- At 21% oxygen, all materials tested met the Standard for Flammability of Clothing Textiles established by the Consumer Product Safety Commission
- When exposed to 100% oxygen, all surgical materials tested would be categorized as unacceptable for consumer wear

material and oxygen concentration. Utility drapes and surgical gowns did not support combustion in room air, whereas other materials quickly ignited. Flash fires were detected on woven cotton materials in oxygen-enriched environments.

Conclusions: Operating room personnel should be aware that common materials in the operating room support rapid combustion in oxygen-enriched environments. The risk of ignition and speed of fire propagation increase as oxygen exposure increases. Advances in material science may reduce perioperative fire risk.

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OPERATING room fires present a real threat to patients undergoing a variety of surgical procedures. The Emergency Care Research Institute estimates that over 600 operating room fires occur annually in the United States¹ and many more are likely unreported.² It is estimated that operating room fires occur at least as often as wrong-sided surgery.³ Operating room fire risk and safety have become a focus of intense attention, including from The American Society of Anesthesiologists,⁴ the Anesthesia Patient Safety

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Foundation,[‡] the Emergency Care Research Institute,⁵ The Joint Commission,[§] the U.S. Food and Drug Administration,^{||} major healthcare institutions,[#] and surgeons.⁶⁻⁹

For a fire to occur, all three points of the fire triad must be present: an oxygen source, an ignition source, and a fuel source. Oxygen-enriched environments occur frequently around patients receiving supplemental oxygen *via* nasal cannula or face mask. Oxygen-enriched environments serve to increase the likelihood of operating room fires while also increasing the risk of rapid fire spread. In fact, recent American Society of Anesthesiology practice guidelines and the Anesthesia Patient Safety Foundation recommend avoiding open oxygen sources when ignition and fuel sources are present.^{‡4} An electrosurgical unit is used in 85% of surgical procedures,^{10,11} operates at up to 12,000 V,¹² and serves as a common source of ignition. There are also numerous potential fuel sources for fire in the operating room, including surgical drapes, gowns, towels, sponges, alcohol-prep solutions, and patient hair. Surgical drapes have been identified as a potential fuel source, particularly in oxygen-enriched environments,^{12,13} and can be ignited by electrosurgical unit or laser.¹⁴ Among fires in anesthesia malpractice claims from 1990 to 2006, the overwhelming majority (81%) of the fires were fueled by surgical drapes.¹⁵

Currently, there are no regulations in force that require surgical drapes to meet the flammability requirements established by the Consumer Product Safety Commission (CPSC 16 Code of Federal Regulations 1610).^{13,16-19} Surgical gowns are required to meet clothing textile flammability standards, and by common practice, many companies design their surgical drapes to meet these same standards.^{||6} Thus, there are no specific mandatory standards in place that govern many of the common fuels in operating room fires: drapes, towels, and sponges.^{#6-8} In addition, none of the current flammability testing evaluates these products in the oxygen-enriched environments typical in operating room fires.¹⁶

In spite of this recent attention to operating room fire safety, there are minimal data regarding the flammability characteristics of common fuels in the operative environment in both room air and oxygen-enriched atmospheres. We hypothesize that the threat of flammability and rate of fire spread will increase in common operating room materials as ambient oxygen concentrations increase. In this study, we test the flammability of surgical drapes and other fuel

sources in room air, 50% oxygen, and 100% oxygen environments. By determining the flammability characteristics of potential fuel sources, practitioners may be able to better prevent operating room fires.

Materials and Methods

For evaluating the flammability of garments, the CPSC has developed a specific testing protocol known as the Standard for Flammability of Clothing Textiles (SFCT).¹⁶ This standard measures the burn time of samples of materials in a controlled, regulated manner. Plain surface textile fabrics that take 3.5 s or more to burn are labeled Class I Normal Flammability materials, whereas those that burn in less than 3.5 s are considered Class III and are therefore unacceptable for use. Raised surface textile fabrics that burn in more than 7.0 s are graded Class I, 4.0–7.0 s are graded Class II, and less than 4.0 s are graded Class III and are unacceptable for use. The standard also defines fabric ignition as the time at which the fabric has a base material burn with a self-sustaining flame. A surface flash is defined as a rapid burning of raised fibers on a textile that may or may not result in the base of the material burning.¹⁶

Our study generally followed the testing method as established by the SFCT with certain modifications. One key added element to this study, which is not covered by the CPSC, is the testing of materials in varying oxygen concentrations. To test the samples, we used three ranges of oxygen concentrations: 19–23% (room air), 50–60%, and 90–100%. In these oxygen environments, we evaluated the flammability of five surgical materials: a standard blue operating room towel, a utility drape, a surgical gown, a surgical drape, and a laparotomy sponge. The utility drape, surgical gown, and surgical drape were primarily composed of polypropylene, whereas the blue operating room towel and laparotomy sponge were entirely composed of cotton (table 1). Swatches of size 150 mm by 50 mm were precisely measured and cut from each of the surgical materials and used as test samples. A swatch rested in between an aluminum rack and a specimen holder set at a 45 degree angle (fig. 1). Both the rack and specimen holder contained a 152 mm by 38 mm open area to allow the swatch to be exposed to oxygen on either side as specified by the SFCT. A mercerized cotton stop thread was placed 127 mm from the base of the swatch and rested on two stop thread holders. A 15 g weight was attached to each end of the stop thread as specified by the SFCT. A match was used as the ignition source and was placed such that the match head rested near the center of the bottom edge of the swatch. To ignite the match, a remote electronic trigger device was designed. Heat produced from high-resistance wire wrapped around the match head enabled the match to ignite.

The testing apparatus was placed within a 46 cm by 46 cm by 46 cm testing chamber with transparent walls. Oxygen was then piped into the test chamber, and its concentration measured using a multigas analyzer (Apollo Anesthesia Workstation; Dräger Medical, Lübeck, Germany). This standard setup was used in all experiments.

‡ Prevention and Management of Operating Room Fires. Available at: http://www.apsf.org/resources_video.php. Accessed February 25, 2013.

§ Preventing surgical fires. Sentinel Event Alert 29 (June 24, 2003). Available at: http://www.jointcommission.org/sentinel_event_alert_issue_29_preventing_surgical_fires/. Accessed February 25, 2013.

|| FDA Safety Communication: Preventing Surgical Fires; Date Issued Oct. 13, 2011. Available at: <http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/ucm275189.htm>. Accessed February 25, 2013.

Suchetka D. Cleveland Clinic reports six operating room fires in past year, three patients injured. Available at: http://blog.cleveland.com/metro/2010/05/clinic_reports_six_operating_r.html. Accessed February 25, 2013.

Table 1. List of Surgical Materials Tested and Their Composition

Name of Materials	Reference Number	Manufacturer	Percent Composition	Flammability Standard
Laparotomy sponge	MDS251518LF	Medline	100% cotton	None
Utility drape	DYNJP2405	Medline	95% polypropylene, 5% other	Class I Normal Flammability
Surgical gown	DYNJP2003S	Medline	96% polypropylene, 4% other	Class I Normal Flammability
Blue operating room towel	MDT2168284	Medline	100% cotton	None
Surgical drape	DYNJP3003	Medline	80% polypropylene, 8% polyethylene/rayon, 8% polyethylene panel, 4% other	Class I Normal Flammability

List of all surgical materials tested with respective percent composition and stated flammability testing characteristics. Class I flammability is defined as a textile that demonstrates normal flammability qualities, Class II flammability is intermediate (raised surface textiles only), and Class III is characterized by rapid and intense burning, and is not acceptable for wear.¹⁶

Three test samples of each of the five surgical materials were ignited in each of the three oxygen concentrations. Therefore, 45 total tests were conducted and then analyzed. Videography was used in each test to measure ignition time and burn time using frame-by-frame analysis. Ignition time was measured as the time between initial ignition of the match and the time at which a sustainable flame was produced on the surgical material. Burn time was calculated as the time between ignition of the match and the time at which the stop thread burned, as detected by the falling 15 g weights. Times were determined by one investigator (B.A.K.) by manually scrolling through each video recording three times and averaging the results for each value. Random video recordings were checked for

accuracy by the other investigators. The video recording had a temporal resolution of 30 frames per second. Note that shortening ignition and burn times reflect an increase in flammability.

Statistical Analysis

Medians were determined as summary statistics for each surgical material in the following oxygen concentrations: 21, 50, and 100%. Utilizing the rank test by Kruskal–Wallis, we tested the differences in ignition and burn times across the various oxygen concentrations for each surgical material. Statistical tests were two-tailed, with significance determined as *P* value less than 0.05. Analysis was performed with SPSS 18 (IBM, Armonk, NY).

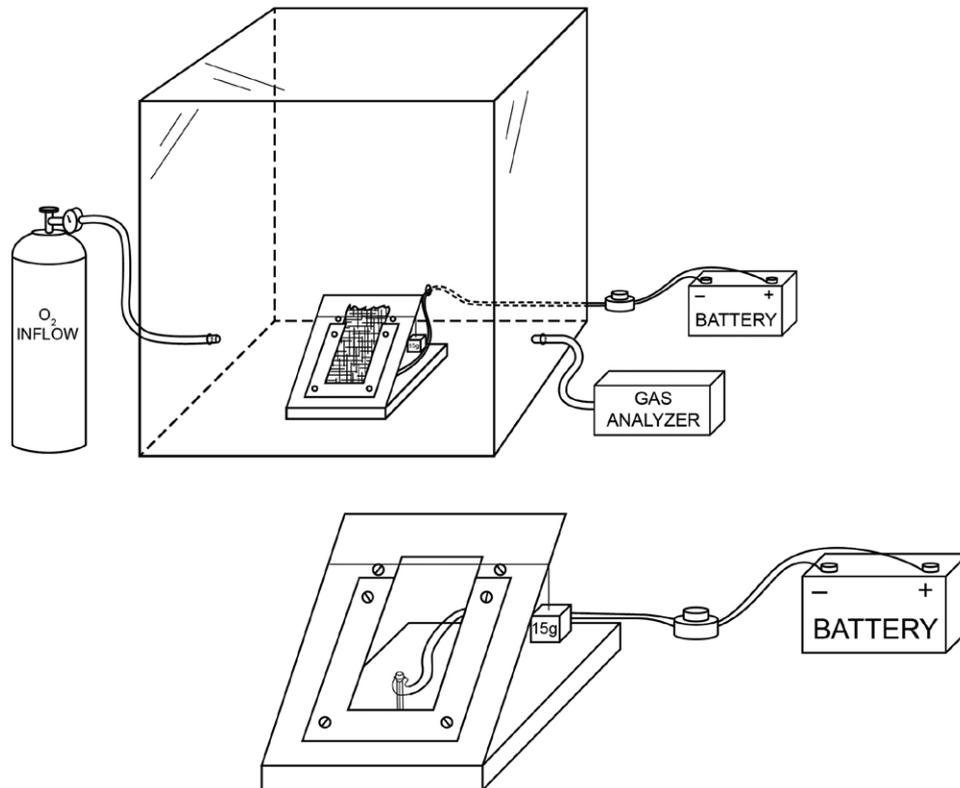


Fig. 1. Testing chamber with specimen rack.

Table 2. Ignition and Burn Times

Materials	Ignition Time in 21% O ₂ (s)	Ignition Time in 50% O ₂ (s)	Ignition Time in 100% O ₂ (s)	Burn Time in 21% O ₂ (s)	Burn Time in 50% O ₂ (s)	Burn Time in 100% O ₂ (s)
Laparotomy sponge	0.9 [0.8, 1.4]	0.3 [0.1, 1.0]	0.1 [0.0, 0.1]	26.6 [7.8, 33.5]	1.9 [1.4, 4.5]	0.8 [0.6, 0.9]
Utility drape	Did not ignite	0.2 [0.1, 0.4]	0.2 [0.1, 0.4]	Did not ignite	3.1 [2.9, 3.1]	1.7 [1.7, 2.0]
Surgical gown	Did not ignite	0.4 [0.3, 0.4]	0.3 [0.2, 0.4]	Did not ignite	2.9 [2.8, 3.1]	2.0 [1.9, 2.0]
Blue operating room towel	1.6 [1.3, 1.9]	0.5 [0.4, 0.5]	0.1 [0.1, 0.2]	21.8 [20.4, 31.9]	7.0 [5.4, 8.1]	0.9 [0.7, 1.0]
Surgical drape	0.7 [0.3, 0.8]	0.8 [0.7, 1.2]	0.3 [0.3, 0.4]	14.9 [10.8, 18.6]	4.9 [4.9, 7.1]	2.4 [2.3, 2.7]

Ignition and burn times for each sample type in room air, 50% oxygen, and 100% oxygen environments, expressed as median [minimum, maximum].

Results

The median [minimum, maximum] ignition time of all the materials in 21% oxygen was 0.9 s [0.3, 1.9], in 50% oxygen 0.4 s [0.1, 1.2], and in 100% oxygen 0.2 s [0.0, 0.4]. These values excluded data from samples that did not ignite. Median [minimum, maximum] ignition times ranged from 0.7 s [0.3, 0.8] (surgical drape) to no ignition (utility drape and surgical gown) in room air; from 0.2 s [0.1, 0.4] (utility drape) to 0.8 s [0.7, 1.2] (surgical drape) in 50% oxygen; and from 0.1 s [0.0, 0.2] (laparotomy sponge, blue operating room towel) to 0.3 s [0.2, 0.4] (surgical gown, surgical drape) in 100% oxygen (table 2). Based on the Kruskal–Wallis test, ignition time decreased as oxygen concentrations increased ($P < 0.001$; near-instantaneous ignition and difficulty assessing the precise start of combustion in high oxygen environments made determination of ignition time challenging).

In addition to ignition time, we also examined burn time results to further determine the flammability characteristics of the surgical materials. The median [minimum, maximum] burn time of all the materials in 21% oxygen was 20.4 s [7.8, 33.5], in 50% oxygen 3.1 s [1.4, 8.1], and in 100% oxygen 1.7 s [0.6, 2.7]. These values excluded data from samples that did not ignite. Median [minimum, maximum] burn times ranged from 14.9 s [10.8, 18.6] (surgical drape) to no ignition (utility drape and surgical gown) in room air; from 1.9 s [1.4, 4.5] (laparotomy sponge) to 7.0 s [5.4, 8.1] (blue operating room towel) in 50% oxygen; and from 0.8 s [0.6, 0.9] (laparotomy sponge) to 2.4 s [2.3, 2.7] (surgical drape) in 100% oxygen (table 2). Of note, neither the utility drape nor the surgical gown supported combustion in 21% oxygen (fig. 2). In addition, the laparotomy sponges burned the quickest among all tested materials in oxygen-enriched environments. Based on the Kruskal–Wallis test, burn time decreased as oxygen concentrations increased ($P < 0.001$).

A rapidly moving flame front was observed in oxygen-enriched environments while testing the standard blue operating room towel and the laparotomy sponge. These surface flash fires were unable to break the stop thread, and therefore were not detected by the burn time measurement but were captured by videography (fig. 3 and see video, Supplemental

Digital Content 1, <http://links.lww.com/ALN/A966>, which is a video of a flash fire).

Discussion

In order to prevent patient injury due to operating room fires, knowledge about the various fuel sources present in the operating room is essential. Flammability classifications of many surgical materials can be found on product labels. As a garment, the surgical gown is required to meet the CPSC Standard as a Class I Normal Flammability fabric.^{13,16} The surgical drape and utility drape in this study stated on the

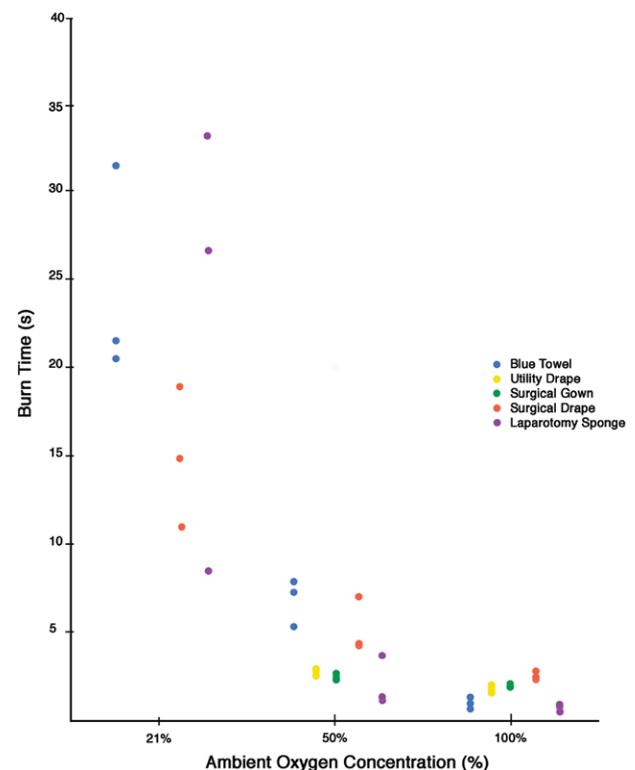


Fig. 2. Burn times of all surgical materials tested in three concentrations of oxygen are depicted in this binned scatter plot. Each circle represents the burn time of one of 45 test samples. The utility drape and surgical gown did not ignite in room air (21% oxygen). Note that a decrease in burn time represents an increase in flammability.

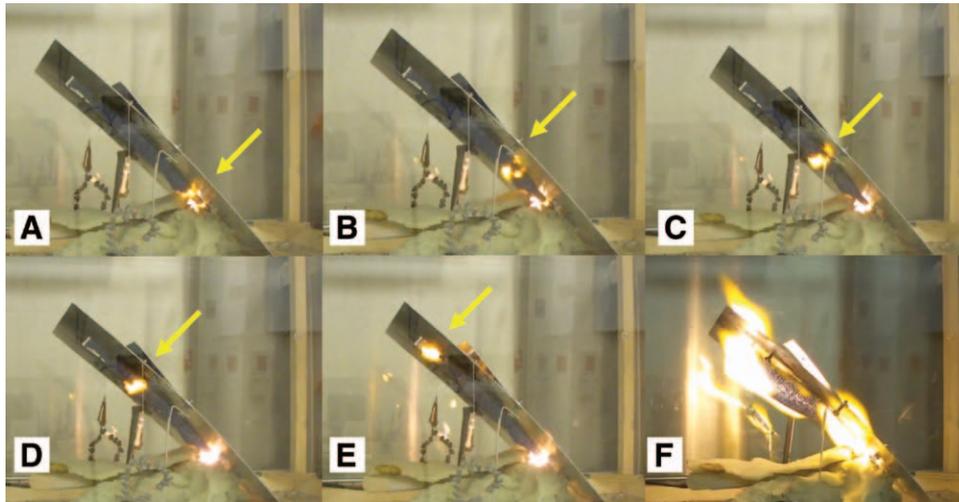


Fig. 3. A flash fire is seen in this series of photographs during flammability testing of a blue operating room towel in a 100% oxygen environment. Times of each picture starting with ignition in frame: A = 0 s, B = 0.10 s, C = 0.17 s, D = 0.27 s, E = 0.40 s, F = 3.00 s.

label that these materials voluntarily also met the SFCT. Importantly, of all these potential fuels, only the surgical gown is required to undergo flammability testing.^{16–18} The laparotomy sponge and blue operating room towel are not required to meet the SFCT and have no flammability testing results displayed on current product packaging.^{13,17–19} Of note, the SFCT does not regulate the testing of any of these products in oxygen-enriched environments.¹⁶

Although not required for the majority of surgical materials, in our study all materials tested met the SFCT established by the CPSC at 21% oxygen. However, when exposed to 100% oxygen, all the surgical materials tested would likely be categorized as Class III fabrics, an unacceptable rating for consumer wear. In addition, in 50% oxygen, the surgical gown, utility drape, and laparotomy sponge would each be classified as a Class III fabric.

We found that the flammability characteristics of various surgical materials were related to the material composition and weaving pattern. The utility drape and surgical gown are very similar materials. Each is nonwoven with nearly identical polypropylene percentages. Both did not support combustion in room air but rapidly burned with similar burn times in oxygen-enriched environments. The surgical drape is also nonwoven but substitutes polyethylene for some of the polypropylene in the gown and utility drape products. As a result, its flammability characteristics differ—it does support combustion in room air, an important fact to note because many operating room fires are fueled by surgical drapes.^{14,15,20} In contrast to the polypropylene drape and gown, the laparotomy sponge and blue operating room towel are both made of 100% cotton and are woven products. The laparotomy sponge has a more open weave than the blue operating room towel which allows for even greater exposure to oxygen. As a likely result, the laparotomy sponge had the shortest median burn time in oxygen-enriched environments.

Burn time decreased as oxygen levels increased in all materials regardless of material composition and weave pattern (note

that a decrease in ignition or burn time reflects an increase in flammability). The median burn time for all materials was 20.4 s in room air. In 100% oxygen, although, the median burn time decreased dramatically to only 1.7 s. As oxygen concentrations increased, the time for ignition decreased. These findings underscore the critical nature that supplemental oxygen has both in increasing likelihood of ignition and in rapidly propagating the spread of fire. In addition, these findings emphasize the need to perform flammability testing of materials in oxygen-enriched environments to ensure patient safety.

As the oxygen concentration increased, another behavior of certain fabrics could be noted: surface flash fires. A flash fire is a rapidly moving flame front that appears to be almost instantaneous and may or may not lead to a base material burn.^{16,21,22} Flash fires were seen on the blue operating room towels and the laparotomy sponges when tested in oxygen-enriched environments (fig. 3 and see video, Supplemental Digital Content 1, <http://links.lww.com/ALN/A966>, which is a video of a flash fire). Flash fires did not reliably burn the stop thread (likely due to their short duration and rapid movement) and therefore were not measured by the burn time parameter. However, high-speed videography clearly demonstrated this phenomenon. None of the other nonwoven materials demonstrated a flash fire suggesting that advances in materials science and improved product selection could decrease the incidence of this event. Flash fires occur too rapidly for operating room personnel to effectively respond and may trigger sustained fires on patients.

Many burn injury accidents from operating room fires involve sedation cases for superficial surgery on the upper chest, neck, or head when supplemental oxygen is administered *via* nasal cannula or face mask underneath a drape covering the head. This potentially creates an oxygen-enriched compartment, and with continued flow of oxygen, may lead to oxygen seeping into the operative field, contacting fuel and ignition sources. Alcohol-based prep solutions,

particularly when not permitted to dry completely, are also associated with fires, with 31% of sedation case fires fueled by these solutions.¹⁵ A landmark case and its simulated re-creation illustrate this phenomenon.²²

One limitation of this study is that rarely is an operating room fire caused by an open flame source. Our model used an open flame source to more closely mirror the testing protocol required by the Code of Federal Regulations.¹⁶ Instead, the most common ignition source in the operating room is the electrosurgical unit. Observed natural gas flame temperatures are approximately 1,800°–1,900°C, match temperatures are approximately 1,100°C, and spark temperatures are roughly 1,300°C.²³ Fire ignition is affected not only by the temperature of the heat source, but also the heat sink characteristics of the material to be burned and the duration of the exposure. Similarly, for an electric current to generate adequate heat to ignite a material, the electrical parameters and material characteristics as governed by Joule's Law should be considered. Joule's Law states that $Q = I^2 \times R \times t$, where Q is heat produced by a current I over a time t as it flows through a material with resistance R .¹¹ Future studies should also examine operating room materials' flammability characteristics when ignited by a monopolar electrosurgical unit pencil. In addition, our 100% oxygen fire model is not likely to exactly replicate an operating room environment. New operating rooms are mandated to have high air current patterns (20 air exchanges per hour) to minimize room atmospheric contaminants including oxygen.²⁴ Our test chamber was designed to artificially create an oxygen-enriched environment. Similar environments may occur, although, during surgery when oxygen becomes trapped underneath surgical drapes or in body cavities, creating pockets of high concentration oxygen.^{13,25–28} It is in this circumstance that the potential for operating room fires is increased. Finally, the precision of our ignition time measurements in 100% oxygen environments was somewhat limited due to near-instantaneous ignitions making it challenging to differentiate the initial match burst from sustained material combustion.

A recent study revealed that most anesthesiologists are unprepared in the event of an operating room fire.²⁹ Due to the rapid ignition and burning of certain surgical materials in the operating room environment along with the flash fire phenomenon, anesthesiologists and other operating room personnel should focus on fire prevention strategies rather than planning to treat after burn injuries have been sustained. Costly legal expenses, tarnished personal and institutional reputations, and most importantly patient injury could then be avoided.^{2,13,15,22,30}

Appreciating differences in commonly used products in the operating room environment may allow more informed material choices to decrease the likelihood of perioperative fire. Awareness of high oxygen concentration environments and the resultant increase in ignition and spread of fire can prompt the surgical team to decrease this oxygen room contamination when possible. Flash fires are nearly instantaneous and occur with some fabrics and may be reduced by proper

product selection. Due to the rapid spread of operating room fires, fire prevention rather than treatment should be stressed. As noted, fire risk is increased during upper body sedation cases using open supplemental oxygen under enclosing drapes. Recent American Society of Anesthesiology guidelines and Anesthesia Patient Safety Foundation recommendations suggest avoiding open-source oxygen if at all possible when fuel and ignition sources are present, including through the use of general anesthesia *via* sealed gas delivery device for oxygen-dependent patients. The FiO_2 should be minimized well in advance of electrosurgical unit use, and alcohol-based prep solutions should be allowed to completely dry. Future study on fabric flammability, advances in materials science, and improved awareness and education of personnel may all help to reduce the threat of fire in the future.

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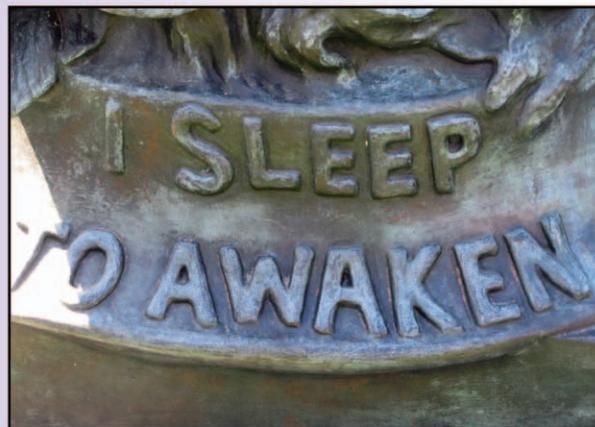
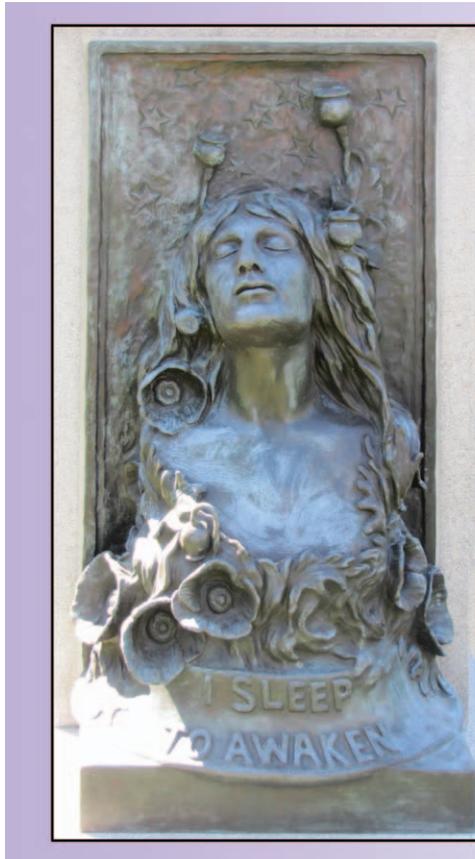
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ANESTHESIOLOGY REFLECTIONS FROM THE WOOD LIBRARY-MUSEUM

"I Sleep to Awaken"



When nitrous oxide pioneer Horace Wells was reburied in 1908 at Hartford's Cedar Hill Cemetery, his son Charles commissioned Louis Potter to create front and side relief sculptures for the memorial monument. After the side sculptures were stolen in the 1980s, the Horace Wells Club and other donors funded replacement bronze castings by Anatoly Mikhailov. Shaded day-long, the north-facing side sculpture (*left*) features a woman with her eyes closed in repose among symbols of sleep (poppies) and night (stars). Cast in bronze beneath the sleeping woman (*right*) are four words: "I Sleep to Awaken." (Copyright © the American Society of Anesthesiologists, Inc.)

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