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Laser Ignition of Surgical Drape Materials in Air, 50% Oxygen, and 95% Oxygen

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Background: **Operating room fires fueled by surgical drapes and ignited by high-energy surgical tools in air and oxygen-enriched atmospheres continue to occur.**

Methods: **The authors examined the time to ignition of huck towels and three commonly used surgical drape materials in air, 50% oxygen, and 95% oxygen using a carbon dioxide surgical laser as an ignition source. In addition, a phenol-polymer fabric was tested.**

Results: **In air, polypropylene and phenol polymer do not ignite. For polypropylene, the laser instantly vaporized a hole, and therefore, interaction between the laser and material ceased. When tested in combination with another material, the polypropylene time to ignition assumed the behavior of the material with which it was combined. For phenol polymer, the laser did not penetrate the material. Huck towels, cotton–polyester, and nonwoven cellulose–polyester ignited in air with decreasing times to ignition. All tested materials ignited in 50% and 95% oxygen.**

Conclusion: **The results of this study reveal that with increasing oxygen concentration, the time to ignition becomes shorter, and the consequences become more severe. The possibility exists for manufacturers to develop drape materials that are safer than existing materials.**

IT is estimated that 50–100 operating room fires occur in the United States each year.[1] Assuming a tendency for such mishaps to be underreported, the true number of fires may be substantially higher. Even if relatively rare, each case is potentially lethal to the patient and dangerous to the operating room team. The most common operating room fire occurs when an electrosurgical unit ignites a surgical drape in an oxygen-enriched atmosphere.[1] However, little information is available about the ignitability of various surgical drapes under various levels of oxygen concentration,[2–4] and no information is available about the effect of burning underlying materials on surgical drape ignition.

The purpose of this study was to determine the time to ignition (TTI) of currently used surgical drape materials using our experimental protocol. In addition, an experimental fabric (a phenol polymer) was tested to evaluate the feasibility for manufacturers to develop drapes that can reduce operating room fire risk. Materials were tested in air and in 50% and 95% oxygen in nitrogen.

Materials that did not exhibit primary ignition in air were further tested for secondary ignition in air by an underlying ignitable material. The rationale is to emphasize that a material tested for fire safety in isolation may provide incomplete information regarding risk assessment.

Materials and Methods

The three major classifications for surgical drapes are nonwoven cellulose, polymer, and reusable drapes. Nonwoven cellulose drapes are usually combined with polyester, polymer drapes are usually polypropylene, and reusable drapes are usually woven cotton combined with polyester. Huckaback weave cotton towels (huck towels) are commonly used as a drape adjunct. Although drape materials serve their primary function well, they were not designed with fire safety as a priority. There exists a wide range of materials in service and under development that may offer improved fire safety and still perform primary drape functions. Therefore, a phenol-polymer fabric not currently used as a surgical drape was tested.

The materials tested were

1. nonwoven cellulose/polyester blend surgical drape (Allegiance Healthcare, Edison, NJ)
2. polypropylene surgical drape (Kimberly-Clark, Roswell, GA)
3. reusable woven cotton/polyester blend surgical drape (tested in double layer as supplied and used)
4. huck cotton towel drape adjunct
5. phenol polymer, an experimental potential surgical drape material of woven phenol polymer (Ronald Holmberg, Consultant, Fairfield, CT)

The TTI after laser impact of these five materials was determined in air and in an oxygen-enriched atmosphere. *Primary ignition* is defined as the TTI of a single sample of material. *Secondary ignition* is defined as the TTI of a sample of material combined with a promoter (filter paper placed behind or in front of the sample material).

A reference sample of qualitative cellulose filter paper of 11-μm retention size (No. 1 filter paper; Whatman International, Ltd., Maidstone, England), served as the promoter and was similarly tested for TTI in air.

The size of the tested sample was 50 × 150 mm. Because water content can affect ignition, all samples,

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Table 1. Time to Primary Ignition

	21% O_2		50% O_2		95% O_2	
Material Tested	No. Ignited/ No. Tested	TTI, s (mean ± SD)	No. Ignited/ No. Tested	TTI, s (mean ± SD)	No. Ignited/ No. Tested	TTI, s (mean ± SD)
Phenol polymer	0/10	Does not ignite	10/10	4.9 ± 0.88	10/10	0.68 ± 1.3
Polypropylene	0/10	Does not ignite	9/10	0.14 ± 0.13	10/10	0.18 ± 0.17
Huck towel	8/10	11.9 ± 5.0	10/10	2.3 ± 1.0	10/10	< 0.1 ± 0.0
Cotton–polyester	10/10	4.0 ± 0.94	10/10	1.1 ± 0.32	10/10	0.65 ± 0.24
Nonwoven cellulose–polyester	10/10	2.7 ± 2.2	10/10	< 0.1 ± 0.0	10/10	< 0.1 ± 0.0

except for polypropylene, were dried before testing by preconditioning for 30 min in an oven set at 105°C and then placed in a desiccator for at least 10 min.[5] Because polypropylene absorbs practically no water and because it is degraded by heat, polypropylene was not placed in the oven but placed in a desiccator overnight before testing.

The test samples were removed from the desiccator, immediately placed on a sample holder,[5] and placed in a nonflammable metal test box with nonflammable components,[6] previously placed in a fume hood. The sample holder supported the sample to be tested at 45° to horizontal. The laser beam impinged the sample at 90°. Experiments were conducted in air, 50% oxygen, and 95% oxygen. The test box was open to air for air test determinations. For 50% and 95% oxygen determination, the test box was semiclosed and flooded with oxygen–nitrogen adjusted concentration flowing at 9–12 l/min. A galvanic oxygen analyzer (MiniOX; Mine Safety Appliance Co., Pittsburgh, PA) sensor, placed 3 cm above the laser-impact point on the sample, determined the concentration of oxygen in the test box. The oxygen sensor was removed immediately before laser strike. Ignition tests were performed at zero flow of both the test gases and the fume hood.

A carbon dioxide surgical laser (Sharplan Surgical Laser; Lumenis, Inc., Yokneam, Israel) was used as an ignition source. The laser emitted 15 W of power using a 400-mm lens to achieve a 2-mm spot size on the sample. Laser power was determined using an Ophir Nova Laser Power/Energy Monitor (RS232, thermal head 30Amp SH-Head; Ophir Optronics, Ltd., Wilmington, MA). A laser strike of 15 W, 0.01-s pulse, onto photosensitive paper produced a circular, donut-shaped imprint. The spot size of the laser strike was determined by measuring the diameter of the imprint using a 12-power magnifier with line reticle divided into 0.1-mm divisions.

To simulate the random motion and the reduced time/temperature exposure to a drape that would be expected to occur during an inadvertent laser strike, an elliptical sweep of the laser spot was used. The elliptical sweep was achieved using a 9-V–powered electric motor with an offset drive shaft cam attached to the joystick control of the laser. The ellipse, measured at the sample, was 2.5 × 3.5 cm and rotated at 70–100 rpm. The lower edge of the ellipse impinged the sample approximately 0.5 cm from its lower margin. The laser mode was continuous and was maintained until ignition of the test sample. If ignition did not occur, laser impact was continued for a total of 30 s, or discontinued when an ellipse of drape material was incised by the laser and dropped from the sample.

Ignition was determined by visual observation. TTI, defined as the time from the actuation of the laser to the ignition of the sample as determined by observation of a self-sustaining flame, was measured by stopwatch. For analytic purposes, instantaneous TTI was reported as less than 0.1 s and was used as 0.1 s for statistical analysis.

Some materials do not ignite in air. All materials ignited in oxygen-enriched atmospheres. Those materials that did not ignite in air were further tested for secondary ignition. For materials that were penetrated by the laser, a coupon of readily ignitable qualitative filter paper was stapled behind the drape sample, and the combination was tested for laser ignition. For materials that were not penetrated by the laser, the same test was conducted and, in addition, a coupon of filter paper was stapled in front of the drape sample and tested for laser ignition.

Results

Primary Ignition

The results for ignition are reported in table 1. Phenol-polymer samples did not show primary ignition in air. For these samples, laser contact was maintained for 30 s and then discontinued. Polypropylene showed rapid gasification and shrinkage on exposure to the laser heat source, resulting in perforation of the sample and release of the laser-scribed elliptical button. The laser beam, no longer in contact with the sample, was then discontinued.

Secondary Ignition in Air

Because neither polypropylene nor phenol polymer primarily ignited in air, they were tested for secondary ignition by placing filter paper behind the sample and striking the combination with laser energy (table 2). In the case of polypropylene, this resulted in penetration of the sample, ignition of the filter paper, and flaming consumption of the combination. The mean TTI of the polypropylene–filter paper combination (4.7 ± 1.3 s)

Table 2. Time to Secondary Ignition in Air

Material Tested	No. Ignited/ No. Tested	TTI, s (mean ± SD)
Polypropylene–filter paper	10/10	4.7 ± 1.3
Filter paper	10/10	5.2 ± 0.2.8

was not significantly different from the mean TTI for filter paper alone (5.2 ± 2.8 s; $P = 0.054$). For phenol polymer, secondary ignition resulted in charring of the laser-scribed ellipse, no ignition or penetration, and elliptical charring of the filter paper behind without ignition. When phenol polymer was tested for ignition in air with filter paper placed in front of the sample, the laser strike resulted in ignition of the filter paper and charring of the phenol polymer behind with no ignition during the total 30 s of laser strike.

Discussion

The introduction of nonflammable anesthetics into clinical practice half a century ago was expected to eliminate the danger of operating room fires. The frequency of operating room fires was diminished, but not eliminated, most likely because of several factors: (1) the introduction of new potential fuels, *i.e.*, paper drapes, polyvinyl endotracheal tubes, and others; (2) new potential ignition sources, *i.e.*, lasers, fiberoptic light sources, and other sources; and (3) the increased use of oxygen, subtly encouraged by the required use of pulse oximetry and the clinical expectation of near 100% oxygen saturation in almost all patients.

Operating room fires are currently reported in the United States 50–100 times/yr.[1] The actual number of operating room fires may be substantially higher.[7–11] Examination of the data reported to the Federal Drug Administration (Medical Device Reporting database) and incidents investigated by Emergency Care Research Institute reveal that 60% of those reports involve the surgical drape as fuel and 40% occur in an oxygen-enriched atmosphere.

This article reports the ignition characteristics of common classes of surgical drapes. The study was performed in air, 50% oxygen, and 95% oxygen.

The direct transfer of combustion data from the laboratory to the clinical situation should be tempered by sound judgment. Combustion characteristics vary depending on fuel characteristics (dry kindling wood *vs.* green logs), ignition source characteristics (spark plug *vs.* blowtorch ignition), oxidant concentration (air *vs.* 100% nitrous oxide), and many other characteristics such as fuel orientation (horizontal *vs.* vertical), degree of ventilation, and many other examples related to the geometry and physics of the combustion experiment.

A conservative approach to transfer of this data to the clinical situation is warranted. Use of the data to rank the materials according to TTI is valid, with the realization that the actual TTI may vary from laboratory to clinical conditions.

Clinical Significance of TTI

The clinical import of TTI is dual. First, an aberrant laser beam, inadvertently in contact with a surgical drape, could be unintentionally directed from a position where it could cause drape ignition. If the material were classified as no ignition, that period of time might be infinite (or at least 30 s). As TTI shortens from no ignition to instantaneous ignition, the clinical significance of short ignition times increases. Second, considering intentional redirection of an aberrant beam, the TTI brackets the time from laser beam contact with material to completion of corrective action.

Examining TTI data for studies in air, the phenol-polymer fabric and polypropylene did not ignite within 30 s. Huck towel, a surgical drape adjunct (TTI, 11.9 s), offers advantage over cotton polyester (TTI, 4.0 s), followed by nonwoven cellulose polyester (TTI, 2.7 s).

In 50% oxygen, phenol polymer, with a TTI of 4.9 s, has a clinical advantage when compared with available surgical drapes. This is reinforced in the light of studies that reveal 50% oxygen under drapes during nasal insufflation of oxygen.[12,13]

There is no surgical drape material, either currently available, or proposed, that exhibits a clinically acceptable TTI in 95% oxygen. All materials ignite within 0.68 s of laser strike. Ninety-five percent oxygen has not been reported in the atmosphere of the surgical field, but it is possible that it exists in local pockets.

Clinical Significance of No-ignition Scenarios

In air, two no-ignition scenarios were observed. In the first, phenol polymer was shown to be a laser barrier with no penetration and no ignition when laser emission was continued for 30 s. In the second, polypropylene demonstrated laser penetration, resulting in an excised circumscribed ellipse with no ignition of either the ellipse or the test material no longer in contact with the laser beam.

Presuming clinical safety based on no ignition of polypropylene drapes could be misleading. Certain polymeric materials with low melting points shrink away from heat. In this study, the heat of the laser beam caused the polypropylene to shrink away from heat, creating a perforation through which the laser beam passed. The laser beam, then no longer in contact with the material, resulted in no ignition of the polypropylene. However, polypropylene presents no barrier protection to the laser beam, and materials beneath are exposed to the laser heat. If patient skin is behind the polypropylene, it will predictably be burned. If the beam impacts a readily ignitable material, *e.g.*, a patient gown, another drape, or an alcohol-based preparation solution, a fire may result.

Clinical Significance of Secondary Ignition

Secondary ignition is used to simulate a fire in the operating room in which a primary fuel, once ignited, ignites another fuel less readily ignitable. For example, a readily ignitable surgical drape, a patient garment, or an alcohol-based preparation solution ignites, and that flame ignites the less readily ignitable surgical drape. Therefore, materials that did not ignite were examined for secondary ignition.

To determine whether polypropylene would secondarily ignite, a coupon of filter paper was placed behind the polypropylene, and then the combination was exposed to the laser beam. The polypropylene was perforated by the laser beam, the filter paper ignited, and the resultant filter paper flame incorporated the polypropylene in the flame process. This result shows the necessity for secondary ignition testing. In the clinical situation of an operating room fire, polypropylene can be expected to secondarily ignite and contribute to the operating room fuel load.

The TTI of polypropylene–filter paper combination is not significantly different from the TTI of filter paper alone (table 2). We extrapolate (but did not examine) that the TTI of polypropylene, when used in combination with another drape material, would not be significantly different from the TTI of that other drape material.

In air, the only other material that did not ignite, either by primary or by secondary ignition, was the phenol polymer. On examining phenol polymer for secondary ignition in air, it was shown to be a laser barrier, with insufficient heat transfer to cause ignition of filter paper placed behind it. When a sample of filter paper was placed in front of phenol polymer, the laser ignited the filter paper, and no ignition of the phenol polymer occurred.

Clinical Significance of Patterns of Ignition

In air, at the site of the elliptically scribed laser contact point for the huck towel and phenol polymer samples, a 2-mm flame developed soon after initiation of the laser. The source of the flame was the limited amount of gaseous fuel volatilized by the laser. This flame continued until ignition of the huck towel and until cessation of the laser for phenol polymer. In 50% oxygen, at the site of the elliptically scribed laser contact point, for phenol polymer, the 2-mm flame occurred and continued until ignition.

In 50% and 95% oxygen, when polypropylene ignited, melting of the specimen occurred with release of molten, flaming droplets.[14,15] Such droplets have the potential to ignite materials they contact and to burn patient skin.

In 95% oxygen, surface flash (ignition of nap fibers with rapid surface flame spread, initially sparing base material[16]) was observed for the huck towel and phenol polymer.

In 95% oxygen, for the huck towel, surface flash occurred instantaneously on laser contact and rapidly spread centrifugally, leaving residual islands of fire and ignition at the upper edge of the sample where there was no contact with the sample holder. Flaming combustion of the base fiber immediately followed the surface flash, and is reported in table 1 as instantaneous ignition.

In 95% oxygen, for the phenol polymer, surface flash immediately occurred and spread centrifugally toward the sample edges. On reaching the upper edge of the sample where there was no contact with the sample holder, the surface flash immediately continued in a downward direction on the back surface of the sample. Glowing combustion of the base fiber occurred rapidly after the surface flash with continued laser contact and is reported as TTI in table 1.

In the clinical situation, surface flash can ignite fuels remote from the original ignition source, thereby creating confusion as to the ignition mechanism of the remote fuel. Patterns of ignition may change with washing if residual surface contamination or manufacturing lubrication oils or finish is washed away. In addition, after repeated washing of reusables, fire retardants may erode away.

Implication of Various Oxygen Concentrations

It has been shown that, during nasal insufflation of oxygen for procedures involving the head and neck, an atmosphere of more than 50% oxygen has been observed in the surgical field.[9] When increasing the oxygen concentration from air to 50%, comparison of individual materials reveals clinically important differences for all materials.

When the oxygen concentration in the surgical field is increased to 95%, the danger of ignition for all materials is high but does not increase dramatically from 50% oxygen, except for phenol polymer material. When increasing the oxygen concentration from 50% to 95% for phenol polymer, the mean TTI shows the only clinically important difference.

Conclusions

Our results reveal that with increasing oxygen concentration, the TTI becomes shorter and the consequences become more severe. It is the responsibility of the anesthesiologist to consider the risk:benefit ratio attendant to nasal oxygen insufflation during monitored anesthesia care, particularly during a surgical procedure involving the head and neck. Supplemental oxygen should be delivered as determined by clinical judgment considering the preoperative oxygen saturation of the patient as determined by pulse oximetry in room air. Avoidance of "luxury oxygen" should be considered. The secondary ignition test is a necessary component to flammability testing of surgical drapes to reveal those materials that are resistant to ignition but flammable in a clinical operating room fire event.

Before this study, no surgical drape material had been proposed to offer a fire safety advantage in the oxygen-enriched atmosphere of the operating room. Hopefully, market forces will stimulate further initiative on the part of manufacturers to fill this patient safety need.

Knowledge of the relative flammability characteristics of surgical drapes should be a part of the algorithm of risk:benefit ratio and cost accountability. Choice of drape material should involve consideration of proximate oxygen concentration and proximate use of potential ignition sources. The data on phenol polymer demonstrated in this study reveals the feasibility of the application of that option.

We believe that flammability specifications of surgical drapes are necessary for informed choice. The oxygen-enriched atmosphere of the operating room in which potential ignition devices are routinely used is a hostile environment for fire safety. It requires that surgical drape manufacturers supply relevant flammability data on primary ignition and secondary ignition in air and in oxygen-enriched atmospheres to limit and possibly control that hazard. Market forces can surely drive industry to produce according to patient safety needs as determined, in large measure, by operating room personnel.

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