

ANESTHESIOLOGY

Operating Room Fires

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Operating room fires are devastating events that occur at least 650 times annually.¹ These “never events” result in at least two to three patient deaths per year and not only affect the patient but impact the entire operating room team and hospital system.^{2,3} Surgical fires have recently garnered significant media attention and are a source of an increasing number of surgical liability claims: from less than 1% in the late 1980s to almost 5% between 2000 and 2009.^{4,5} This change is echoed by an increasing number of voluntarily reported surgical device–related fires in the Food and Drug Administration’s (Silver Spring, Maryland) Manufacturer and User Device Experience database.⁶ (fig. 1)

Written and video–based guidelines on fire prevention are available from the American Society of Anesthesiologists (Schaumburg, Illinois), the Anesthesia Patient Safety Foundation (Rochester, Minnesota), the Emergency Care Research Institute (Plymouth Meeting, Pennsylvania), and the Society of American Gastrointestinal and Endoscopic Surgeons (Los Angeles, California).^{7–10} These guidelines, in general, are based upon expert opinion and cases series due to the overall rarity of the event and lack of evidence. Regardless, as a result of these guidelines, many institutions have begun to assign a “fire risk assessment” score as part of a surgical “time-out”^{11,12} (fig. 2). This checklist ensures all members of the team consider what part they play in protecting patients from a fire. Calculating this score increases awareness of the risk of fire but lacks actionable items beyond what should be considered the standard of care in all surgical cases. To develop a more robust preventative strategy, our group has sought to define high-risk situations as well as modifiable anesthetic, surgical, and nursing techniques.

This review of operating room fires is intended to provide practicing clinicians with the tools and evidence to effectively prevent and/or manage an operating room fire. It is organized around the three components essential for fire creation: an oxidizer, an ignition source, and a fuel. This creates the “fire triangle” (fig. 3). The majority of fires occur “on the patient” during monitored anesthesia care; thus, special attention will

ABSTRACT

Operating room fires are rare but devastating events. Guidelines are available for the prevention and management of surgical fires; however, these recommendations are based on expert opinion and case series. The three components of an operating room fire are present in virtually all surgical procedures: an oxidizer (oxygen, nitrous oxide), an ignition source (*i.e.*, laser, “Bovie”), and a fuel. This review analyzes each fire ingredient to determine the optimal clinical strategy to reduce the risk of fire. Surgical checklists, team training, and the specific management of an operating room fire are also reviewed.

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be paid to the oxidizing component of the fire triangle.⁴ The complete elimination of fire risk is impossible as these components are key to a successful surgery; however, the risk can be minimized by careful separation of the components of the fire triangle. We will break down each component and examine the modifiable factors and available evidence as well identify high-risk scenarios that should be avoided if possible.

Oxidizer

When ignited, oxygen combines with a fuel source to produce heat, gas, and light. At sea level, air is composed of 21% oxygen and is the most common “oxidizer.” Nitrous oxide is the other major oxidizer in operating and procedure rooms. The importance of oxygen content cannot be overemphasized as studies have revealed that nearly all objects can become fuel for a fire once the oxygen content increases to greater than 30%.^{13,14}

Emphasis on oxygen delivery is critical not only because of increasing flammability but also because of increased rates of injury when operating close to an oxygen source and/or airway. A review of operating room fire claims found that 85% of fires occurred in the head, neck, or upper chest, and 81% of cases occurred with monitored anesthesia care.⁴ These fires are typically attributed to increases in oxygen content at the surgical site.

The local oxygen concentration is significantly affected by anesthetic care providing supplementation *via* “open” or “closed” sources. Open systems include nasal cannula or mask oxygen delivery and will increase surrounding oxygen content in relation to oxygen delivered (fraction of inspired oxygen [FiO_2]). When monitored anesthesia care is employed, the onus is on the anesthesiologist to titrate oxygen delivery to the minimal acceptable saturation.¹⁵

Given the increased fire risk related to oxygen, the Joint Commission (Oakbrook Terrace, Illinois) and the Emergency Care Research Institute recommend use of air or FiO_2 less than or equal to 30% for open delivery.¹⁶ Per the Emergency

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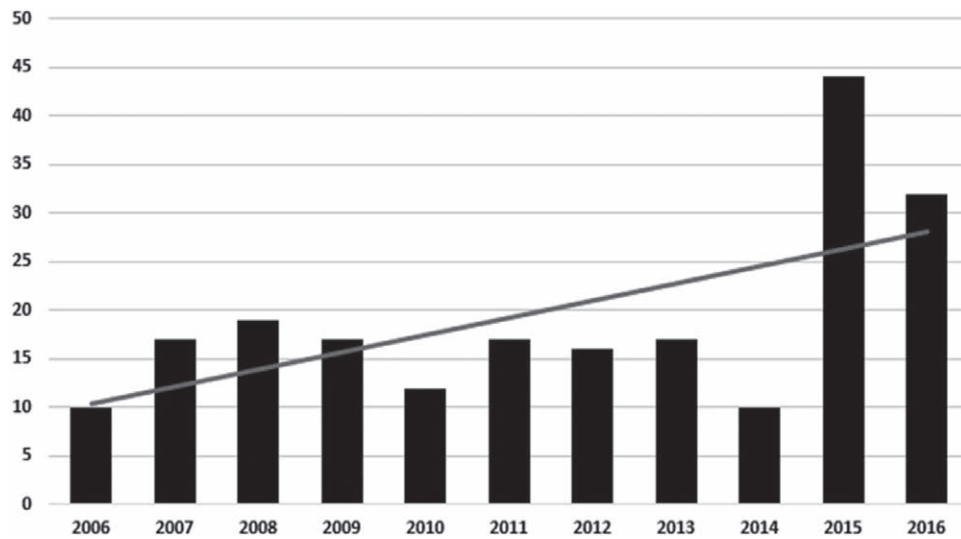
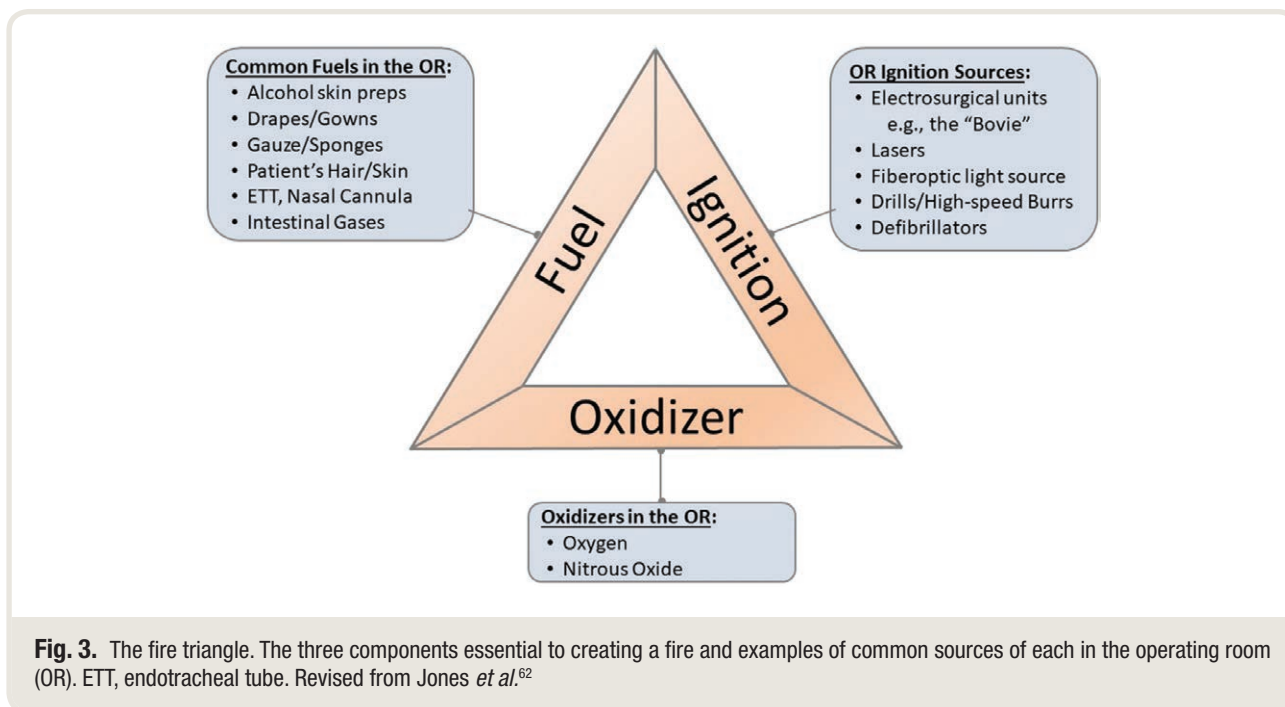


Fig. 1. Annual incidence of surgical device-related operating room fires. Annual incidence of surgical fires caused by surgical devices as voluntarily reported to the U.S. Food and Drug Administration Manufacturer And User Device Experience database. Overlying trend line demonstrates linear growth. Data extrapolated from Overbey *et al.*⁶

Discipline	Potential Risk	Intervention	Score
Circulator/ Tech	Fuel <ul style="list-style-type: none"> Surgical site ABOVE xiphoid Drapes/Blankets Gowns Sponges/Gauze Alcohol-based skin preps Patient's hair/skin ETT, SGAs, masks, nasal cannulas, tents, tags Intestinal gases 	<ul style="list-style-type: none"> Communication of risks in Time-out Confirm no tunneling of drapes between oxygen rich environment and surgical field Bovie in holster when not in use Laser on stand-by when not in use Fiberoptic source "off" when not in use Fiberoptic source never in contact with fuel Saline soaked sponges/gauze/towels Saline/sterile water on field Preps allowed to dry 3 minutes No pooling of preps 	1
Anesthesia	Oxidizer <ul style="list-style-type: none"> Surgical site ABOVE xiphoid Oxygen rich environment (> 30%) Nitrous Oxide in the presence of Oxygen 	<ul style="list-style-type: none"> Communication of risks in Time-out Confirm no tunneling of drapes between oxygen rich environment and surgical field Minimize or discontinue (when appropriate) oxygen 1 min prior to energy device use Titrate oxygen to lowest safe concentration Avoid oxygen trapping with tenting of drapes or use "open" draping Consider ETT if patient likely to require >30% FIO₂ Utilize cuffed ETT for airway surgery (when appropriate) Utilize laser-reinforced ETT with methylene blue in cuff (when appropriate) 	1
TOTAL			(1-3)

Fig. 2. Example of a fire risk assessment tool. A robust fire risk assessment tool that includes recommended interventions within each component of the fire triangle updated from the fire risk assessment utilized at Memorial Medical Center (Springfield, Illinois) made in conjunction with the Emergency Care Research Institute. ETT, endotracheal tube; FIO₂, fraction of inspired oxygen; SGA, supraglottic airway. Original available from SurgicalFire.org.¹²

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Care Research Institute, this recommended oxygen concentration has not been verified, but should be used as a marker to “establish guidelines for minimizing oxygen concentration under surgical drapes.” These recommendations are echoed by the Anesthesia Patient Safety Foundation, which suggests the use of endotracheal intubation or laryngeal mask airway in any procedure above the xiphoid or if oxygen supplementation greater than 30% is required.⁹

Determining the relationship between oxygen supplementation and room oxygen content is not a simple task. Operating rooms have a federal requirement of at least 20 air exchanges per hour, which creates enough circulation to disperse oxygen delivery by nasal cannula for the entire room.¹⁷ What is more important, however, is the oxygen content at the site of the procedure. With respect to nasal cannula delivery, local oxygen concentrations can increase by more than 5% at low flow rates (less than 4 L/min) and can become disastrous with levels up to 60 to 70% at higher flow rates.^{18,19}

Further complicating matters is that measurement of inhaled gas composition (*i.e.*, oxygen content) at delivery is not standard on all anesthesia machines. Reducing oxygen concentration by blending 100% oxygen with room air and delivery *via* a common gas outlet can be done in some cases, but may also require an add-on gas blender.¹⁶ In addition, there is often a lag between reductions in oxygen delivery and exhaled oxygen content. In a closed circuit model, it took up to 5 min to reduce inspired and expired oxygen from 60% to 30%.²⁰ If one is lacking the capability to measure oxygen content as it is delivered and returns from the patient, the current recommendation is to discontinue 100% oxygen supplementation for at least 60 s and up to 3 min before (and during) energy use.⁷

The interruption of air exchange by surgical drapes also significantly affects oxygen concentration. For example, the draping for a neurosurgical procedure and use of an oxygen mask with 6 L/min of oxygen resulted in oxygen concentrations of 35 to 50% in the operative field.²¹ Redraping so that no “tent” covered the field resulted in normal oxygen content. A similar study recreating operating room conditions during a facial surgery that resulted in a fire found that supplemental oxygen increased oxygen concentration under the drapes to over 50%.²² These findings highlight the dangers of open oxygen sources and surgical draping and have led to the recommendations for an open draping technique whenever surgery is required close to the oxygen source.²³

Closed systems can maintain atmospheric oxygen levels near, or at, normal room air concentration while still providing increased levels of supplemental oxygen to the patient.^{18,19} Endotracheal tubes (ETTs) are the most common delivery method; however, laryngeal mask airways are also considered a closed system. Inflating the cuff of the ETT can decrease oxygen leakage but is not always feasible.²⁴ With a closed system, the utilization of elevated oxygen content remains risky as the ETT cuff itself can be damaged or even ignited by heat sources (energy devices) when operating on or near the airway.²⁵ In “closed” sources, a recent review in otolaryngology procedures identified inspired oxygen delivered was greater than 30% in 97% of surgical fires in general anesthesia cases.²⁶ Even reinforced, “laser resistant” ETTs are not recommended to be used with oxygen content greater than 30% because of the risk of fire if damaged or leaking.²⁷

Unique methods have been developed to decrease oxygen concentration around the operative field due to its massive impact on the risk of fire. A suction system for excess oxygen under drapes significantly reduces ambient oxygen concentrations, and our most recent testing demonstrated that utilization of combined energy/suction devices significantly reduced the incidence of fires.^{28,29} “Flooding” the surgical field with carbon dioxide has been shown to prevent fires during tracheostomy in an animal model.³⁰ A carbon dioxide projecting sleeve has been developed for utilization around the monopolar, “Bovie” unit and eliminated the fire risk when tested with 100% oxygen.³¹ Utilization of these devices may become more common as the most effective technique to minimize fire risk in a cost-effective manner is refined.

Another novel solution may be the use of closed-loop oxygen titration to adjust the delivered FIO_2 to the lowest possible amount. There has been considerable research in closed-loop oxygen delivery in order to reduce oxygen consumption in austere environments, reduce hyperoxia, reduce hypoxia, and offer earlier intervention in acute lung injury. This technology may also be applicable in preventing operating room fires, but implementation remains far in the future.^{32,33}

In sum: clinicians can reduce the risk of surgical fires by maintaining the local oxygen concentration at less than 30%. Even minor elevations in oxygen concentration as a result of supplemental oxygen and/or surgical drapes result in an astronomically increased risk for fire.

Ignition Source

Surgical energy is the ignition source in 90% of operating room claims.^{6,34} The most common form of surgical energy is monopolar radiofrequency energy, also known as the “Bovie,” after William T. Bovie, Ph.D., who developed the first electrosurgical generator in 1926.³⁵ The Bovie converts electromagnetic energy into thermal energy.³⁶ Slow heating of tissue results in melting of intracellular proteins and the creation of a coagulum. Rapid heating can cause “boiling” of the cells with vaporization of the contents. No matter the technique, it is the heating of tissue or the energy device itself that serves as the ignition source for the fire.

No specific studies have been done to compare the fire risk of common types of surgical energy (monopolar, bipolar, or ultrasonic); however, clinical experience dictates that monopolar energy is the most susceptible to the creation of an ignition spark.³⁶ Bipolar energy forces cellular heating only between the jaws of the instrument with minimal space for spark creation; however, bipolar energy has also been reported as a source of fire in oropharyngeal surgery.³⁷ Ultrasonic energy creates a direct heating effect due to rapid vibration of the tips of the device without the transfer of electromagnetic energy to the tissue but can cause elevation in tissue temperatures to more than 200°C.^{36,38}

It is important to note that monopolar energy takes many forms, including the handheld “Bovie,” radiofrequency ablation catheters, and the argon plasma coagulator. In particular, forced spark gaps can be easily created with monopolar devices, especially the handheld Bovie and the argon plasma coagulator device. Education in the appropriate techniques of use, including fire prevention, is available from the Society of American Gastrointestinal and Endoscopic Surgeons through their Fundamental Use of Surgical Energy program.

The second most common ignition source is the “light amplification by stimulated emission of radiation,” commonly known as the laser.³⁹ Lasers are used in cosmetic, eye, and oral surgeries—all areas above the xiphoid that are considered high-risk. The high risk of fire with lasers in these locations is known to physicians who indicated on a recent survey that the most common major complication of endoscopic laser surgery was a fire.⁴⁰ Even with an ETT in place, a surgical laser can penetrate an unprotected tube and cause a fire in less than 2 s when 100% FIO_2 is being used.^{30,41,42} Protected ETTs are no guarantee against fire, and instead surgeons must be vigilant about avoiding direct contact with the laser no matter the type of ETT.^{41,43} In addition, current American Society of Anesthesiologists guidelines recommend instillation of saline and methylene blue within the cuff in order to rapidly demonstrate inadvertent cuff balloon perforation.⁷

One additional ignition source warrants specific mention due to its increasing use: the fiberoptic light cord. This cord is utilized during laparoscopic and robotic procedures and, when not in standby mode, can rapidly burn through drapes and cause thermal injury to patients.⁴⁴ In the appropriate setting, it is feasible these cords could ignite an operating room fire, and care must be taken to ensure that they are in standby mode when not in use.

In sum: surgical and nursing vigilance is essential to identify potential ignition sources and is a central part of the fire risk assessment. Avoidance of all energy devices is not viable; however, selection of low-risk devices (ultrasonic devices) and/or adopting techniques that avoid the creation of a spark-gap can decrease the risk of fire.

Fuel

All things flammable are potential fuel sources for a surgical fire (table 1).¹⁷ We have categorized these fuel sources into two groups: patient-dependent and non-patient-dependent factors.

Patient-dependent Factors

Common patient-dependent “fuels” include hair, soft tissue, and even luminal contents (*e.g.*, methane gas).^{6,34,45,46} There are limited ways to modify patient-dependent factors.

Hair clipping can be easily performed immediately prior to procedures and has been promoted as a technique to

Table 1. Fuel Sources in the Operating Room Fires

Patient-dependent	Hair Tissue Gastrointestinal content (methane, hydrogen)
Patient-independent Solutions	Alcohol-based sterile skin preparations Wound closure (benzoin, mastazol) Degreasers (acetone, ether) Petrolatum-based dressings/ointments Paraffin, wax
Materials	Drapes (paper, cloth, plastic) Protective equipment (gowns, gloves, caps, and others) Dressings (gauze, bandages, tape) Gauze, sponges Airway devices (endotracheal tubes)
Equipment	Anesthesia (endotracheal tubes, masks, tubing, and others) Surgical (fiberoptic cables/wires, cuffs, tubing, drains, endoscopes, and others)

Common fuels in the operating room. Of note, nearly all materials, even those marked "nonflammable," become flammable when the oxygen content is elevated.

decrease infection risk as well as the risk of operating room fires. While hair clipping does decrease the risk of surgical site infection when compared to preoperative *shaving*, there is minimal evidence to suggest that hair removal itself decreases the risk of surgical site infection or operating room fires.^{47,48} As an alternative, the Association of periOperative Registered Nurses recommends the use of a non-flammable gel to isolate hair that is not clipped in order to decrease the risk of fire.²³

Combustible gas in the gastrointestinal tract has been the fuel source for a fire or explosion in at least 20 reported cases, including during open surgery.^{49,50} The presence of methane and hydrogen in the colon is a result of fermentation of non-absorbable or incompletely absorbed carbohydrates by colonic flora. Mannitol-based bowel preparations had been associated with increases in combustible gas production and are no longer widely used. Mechanical bowel preparation (polyethylene glycol [GoLytely; Braintree Laboratories, USA] and oral sodium sulfate [Suprep; Braintree Laboratories], among others) is now commonly used to remove bowel contents and explosive gases preoperatively. A non-mannitol-based prep can be combined with an antibiotic prep to reduce intracolonic bacteria, has demonstrated to decrease wound infection rates, and should also decrease fire risk.^{51,52}

Non-Patient-dependent Factors

Factors independent of the patient include the drapes, sponges, and linens associated with creating a sterile operating field as well as the antiseptic skin prep. Airway devices, including ETT and supraglottic airways, are all composed of combustible materials.²³ Anesthetic gases used prior to the 1960s (cyclopropane, ethylene chloride, among others)

Table 2. Comparison of Alcohol vs. Non-Alcohol-based Preps

Drying Time	Non-Alcohol-based Fires	Alcohol-based Fires	P value
None	0% (0/40)	22% (13/60)	<0.001
3 min	0% (0/40)	10% (6/60)	0.08

All fires with the alcohol-based prep were ignited after the "drying time" with a 2-s activation of a standard monopolar "Bovie" pencil. No fires were ignited with a non-alcohol-based prep. Reproduced from Jones *et al.*⁶²

were combustible, but nonflammable agents have been used primarily since the 1970s.⁵³

Dry surgical sponges, gauze, and drapes can be easily ignited. The flammability of these fuels can be reduced when the materials are moistened.⁷ While not clinically useful in all surgical scenarios, the use of saturated gauze may still be effective in removing blood and debris from the operative field during procedure in high (fire) risk locations (head and neck, oropharynx, and trachea/bronchus).^{54,55} The use of saline-soaked gauze when utilizing an ignition source near the airway is recommended by the American Society of Anesthesiology in the 2012 Practice Advisory on the Prevention and Management of Operating Room Fires.⁷

Paper drapes and gowns are also frequently implicated in surgical fires. While these items are often rated as "flame resistant" and/or "nonflammable," they can still ignite in normal operating conditions.¹³ In fact, benchtop testing revealed common surgical materials (surgical gowns, gauze laparotomy pads, among others) that met non-flammability criteria set by the Consumer Product Safety Commission (Bethesda, Maryland) *all* become flammable with small elevations in room oxygen content.⁵⁶

Alcohol-based skin preps are frequently blamed for fueling surgical fires, and multiple published reports confirm this accusation.⁵⁷⁻⁵⁹ The flammability of alcohol-based surgical skin preps is acknowledged by their manufacturers, who recommend waiting at least 3 min and up to 1 h after application to allow complete drying with the goal of eliminating fire risk.^{60,61} This delay is to allow evaporation of the immediate bactericidal agent (isopropyl alcohol) so that it cannot be ignited by a nearby heat source. It is important to remember that skin preps that include the word "tincture" contain isopropyl alcohol.

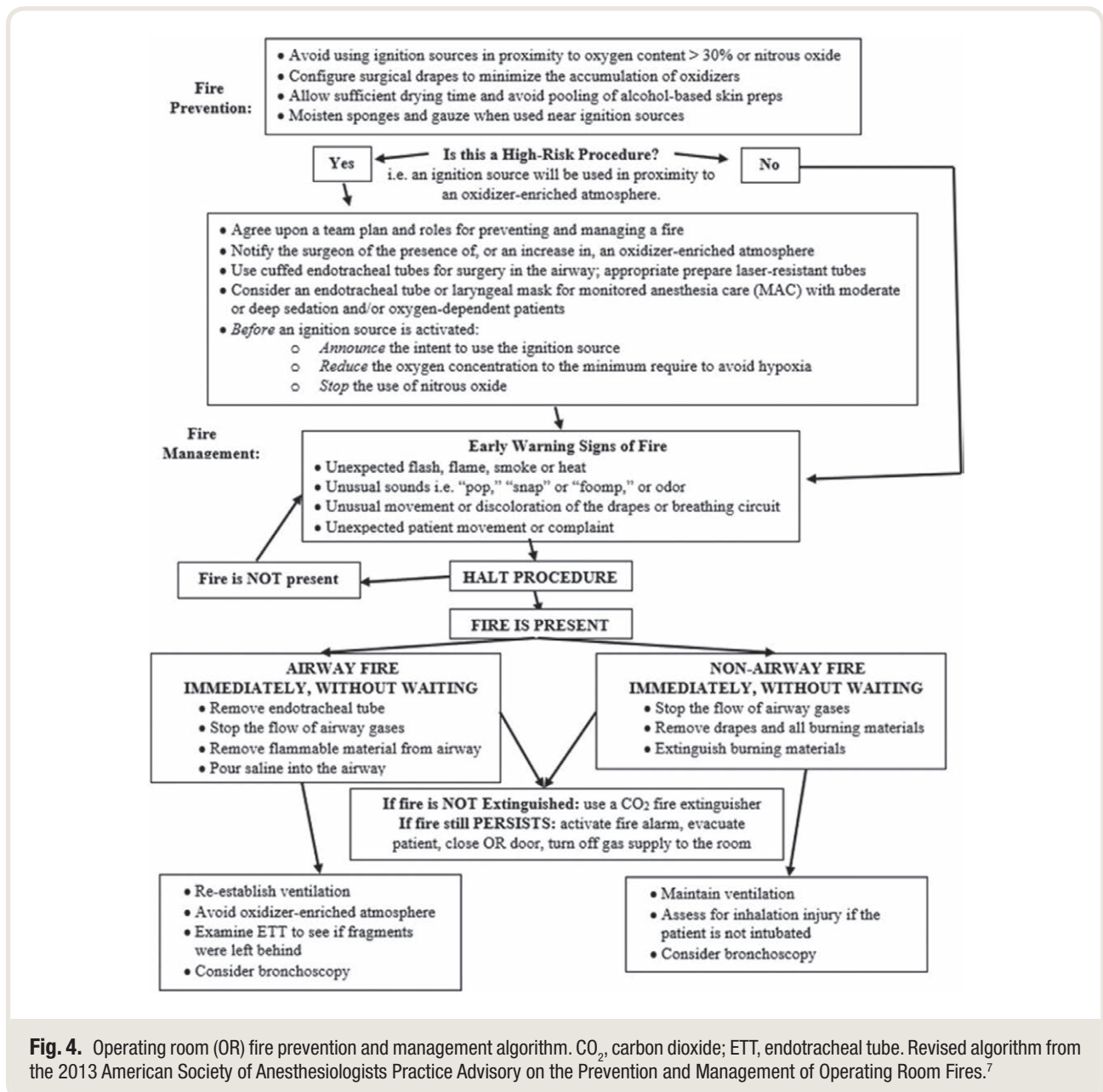
To test the efficacy of these recommendations and the flammability of all skin preps, our group recently published our findings utilizing an *ex vivo* porcine model for testing.⁶² Alcohol-based preps (2% chlorhexidine with 70% isopropyl alcohol and 0.7% iodine povacrylex with 74% isopropyl alcohol) could be ignited in almost one quarter of cases immediately after application, and this did not significantly decrease after waiting 3 min for drying time. Allowing the alcohol-based prep to pool created the highest risk scenario, with fires occurring in 38% of cases (table 1). No fires were created with non-alcohol-based preps (table 2).

In light of these findings, the use of a non-alcohol-based prep (2% chlorhexidine or 0.7 to 1% iodine) may seem like an attractive alternative in order to reduce fire risk. Unfortunately, this runs counter to recent 2017 recommendation for the use of alcohol-based antiseptic agents (for intraoperative skin preparation to decrease superficial and deep surgical site infections) by the Centers for Disease Control and Prevention (Atlanta, Georgia).^{57,63-66} As more data emerge regarding alcohol-based preps, clinicians will need to compare the risk of fire to the risk of surgical infections to appropriately protect their patients from fire and/or infection.

Airway devices themselves have been the source of fuel in upper airway fires. A recent review found the ETT

was the fuel source in 49% of fires in the operating room during surgery on the airway.²⁶ Similarly, nasal cannulas and supraglottic airways are also composed of polyvinylchloride, a combustible material, as defined by the American Society of Testing Materials.²³ In high risk situations, particularly laser surgery of the larynx, metal reinforced “laser-safe” tubes are recommended. Unfortunately, these tubes are not foolproof, and fires were easily started in models with laser-safe tubes when the cuff is damaged or the laser is directed at the tip of the tube (which lacks metal reinforcement).⁶⁷

In sum, clinicians can reduce the risk of surgical fires by altering or eliminating fuel sources as follows: (1) utilize non-alcohol-based skin preps or, at the very least, (2)



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strictly avoid allowing alcohol-based skin preps to pool; (3) utilize moistened surgical gauze when appropriate; (4) utilize a non-mannitol-based mechanical bowel prep with or without concomitant antibiotics when bowel surgery is indicated; and (5) utilize laser-safe tubes in upper airway surgery with careful attention to cuff integrity.

Management of a Surgical Fire

A fire in the operating room is a terrifying event, but it can be stopped quickly with early identification and management. In addition to a fire risk assessment and checklist before surgery, cognitive aids such as emergency manuals have been successfully used during both training and emergencies to improve team performance in times of duress.^{68,69} In contrast to many emergencies (*e.g.*, cardiac arrest), immediate action is required when a fire is identified; thus, cognitive aids may be of benefit in training alone in this regard.

Free cognitive aids are available from the Anesthesia Patient Safety Foundation and the Emergency Care Research Institute for training, as well as handouts and signage for rapid review in the operating room.^{8,70} The American Society of Anesthesia published a Practice Advisory in 2013 regarding operating room fires that includes an algorithm from basic risk assessment through management of the fire itself.⁷ These algorithms distill the key points into a single piece of paper that should be reviewed at least annually by the operating room team in order to adequately prepare for a surgical fire (fig. 4).

When there is suspicion of a fire by any member of the team, the surgery should be stopped immediately. Rapid identification is key and can be problematic with alcohol-based prep fires as they exhibit a light blue flame that is difficult to visualize alongside blue surgical drapes. Besides the obvious heat and smoke, fires may also be preceded by unusual sounds, odors, or patient complaints. Once a fire is identified, the following tasks should be performed almost simultaneously by all members of the operating room team⁷¹:

1. Stop the flow of all airway gases and disconnect the breathing circuit.
 - a. For airway fires, remove the ETT and pour saline in the airway.
2. Remove all burning and burned materials from the patient.
3. Extinguish the fire on the burning material.
4. Care for the patient.
 - a. Restore breathing with room air.

The operating room has many unique circumstances that make elimination of the fire triad difficult.⁵³ Many surgical drapes are water-resistant and repel water and must be submerged after their removal to completely extinguish flames.⁷² Fires that occur within a body cavity require dousing with saline or sterile water and should not be

extinguished with fire extinguishers.⁵³ Of importance, fire blankets should not be used in the operating room since they can concentrate both heat and oxygen on the patient, potentially worsening the fire.⁷³

Use of a fire extinguisher is exceedingly rare, but all operating suites are required to maintain them for use. Should one be required, please remember the “PASS” method of use: **P**ull the safety pin from the handle; **A**im at the base of the fire; **S**queeze slowly to discharge the extinguishing agent; **S**weep side-to-side, keeping a safe distance from the fire.⁷⁴

Surgical fires also present a unique microcosm of modern medicine. They are rare events that need a systemic approach to prevent and study, yet because of their rarity, interventions are difficult to assess. New safety solutions may have unintended effects. For example, regulations to protect against fire in hospitals in France have been revised five times in the past 8 yr, despite few data on whether these regulations have improved fire safety as opposed to simply making the system more unwieldy.⁷⁵ The system needs to abandon some professional autonomy, have system-level arbitration to optimize safety strategies, and simplify the system; however, these barriers need to be addressed in a successive manner. Prevention of operating room fires will also require these barriers to be overcome in order to truly decrease risk for all involved in patient care.

Conclusions

Surgical fires are a rare but devastating complication that can occur in surgical or endoscopic procedures. Knowledge of the three ingredients for a fire (oxygen, heat, and fuel) and their sources in the operating room are key to decreasing the fire risk. Constant preparation with freely available training aids and routine team training are needed to ensure the rapid extinguishment of a fire so that patient, personnel, and hospital injury is minimized.

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Competing Interests

The authors declare no competing interests.

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