Chapter 10

Avoiding Fire in the Operating Suite: An Intersection of Prevention and Common Sense

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Additional information is available at the end of the chapter

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Abstract

The operating room (OR) is a complex environment that involves large teams and multiple competing priorities, dynamically interacting throughout the entire course of a surgical procedure. The simultaneous presence of flammable substances, volatile gases, and the frequent use of electrical current results in a potentially dangerous combination. Operating room fire (ORF) is a rare but potentially devastating occurrence. To prevent this "never event", it is critical for institutions to establish and follow proper fire safety protocols. Adherence to proven prevention strategies and awareness of associated risk factors will help reduce the incidence of this dreaded safety event. When ORF does occur despite strict adherence to established safety protocols, the entire OR team should know the steps required to contain and extinguish the fire as well as essential measures to minimize or avoid thermal injury. If injury does occur, it is important to recognize and treat it promptly. Appropriate and honest disclosure to all injured persons and their families should be made without delay. As with all serious patient safety events, regulatory reporting and root cause determinations must take place in accordance with applicable laws and regulations. The goal of patient safety champions at each institution should be the attainment of zero incidence of ORF.

Keywords: operating room fire, patient safety, prevention, surgical fire, surgical safety, intraoperative fire, operating room, patient safety, prevention

1. Introduction

Although rare, ORFs continue to occur despite staff education and preventive efforts [1, 2]. The scope of patient harm spans an entire spectrum, from aborted surgery to fatal injuries [3].

Although all ORFs should be potentially preventable, their rarity combined with relatively more focus on other OR complications contribute to knowledge gaps and inconsistent approaches to stop these "never events" [4, 5]. Institutions must overcome common misunderstandings about risk factors associated with ORFs including the misconceptions that fires are largely nonpreventable, staff is appropriately trained in fire safety and aware of critical actions required in an ignition event, and fires do not happen at institutions with well-developed cultures of safety [2].

The abovementioned fallacies must be actively countered at all levels of the establishment from the executive suite to the equipment maintenance staff. Continuous education, including didactic sessions, web-based self-assessment activities, multimedia materials, and readiness drills, form the foundation of organizational excellence that is based on the combination of high performing teams, well-designed safety protocols, and zero tolerance for complacency [6, 7]. When implementing and disseminating information about operating room fire safety, all stakeholders must be actively engaged, including nursing staff, surgical technologists, anesthesia professionals and surgeons. As with other forms of patient safety events, effective communication is essential in both prevention and management of ORFs [8]. It is also important to note that the healthcare environment is inherently more prone to fires than other nonindustrial workplace environments, primarily due to the coexisting use of flammable materials and surgical energy sources [8]. As such, other locations within hospitals may be at elevated risk of procedure-related fires, including the emergency department, labor and delivery, and endoscopy suites [9]. In this chapter, we present two realistic clinical vignettes describing ORFs. Detailed discussion of risk factors, preventive strategies, fire preparedness, and post-event management then follows.

2. Clinical vignette #1

Mr. "A" is a 65-year-old male admitted to a local Ambulatory Surgery Center for a minor surgical procedure. He has cervical lymphadenopathy and is scheduled for excisional biopsy of a palpably enlarged right-sided cervical lymph node. After all preoperative medical and safety checks are completed, Mr. "A" is escorted into the OR and positioned supine. General anesthesia is induced after an uneventful endotracheal intubation. The surgical resident assisting with the procedure preps the patient's neck, shoulder and chest using alcohol-containing chlorhexidine solution. Soon after, the surgical site is draped with sterile surgical cotton drapes. An incision is made over the enlarged lymph node, and subcutaneous tissue is exposed. Electrocautery is then introduced into the field for hemostasis and surgical dissection around the enlarged lymph node. Immediately following electrode activation, a flame ignites and rapidly spreads over the surgical field prepped with chlorhexidine. The surgeon in charge immediately removes the drapes, the electrocautery is switched off, the fire is extinguished within seconds, and the lymph node biopsy procedure is aborted. The patient suffers from first degree burns over his neck and chest. His recovery is complete, although he requires another trip to the OR for completion of his lymph node biopsy.

3. Clinical vignette #2

Mrs. "W" is a 75-year-old female, admitted to the intensive care unit (ICU) for severe pneumonia. She subsequently developed respiratory failure and was unable to successfully wean from mechanical ventilatory support. Consequently, she was scheduled for a tracheostomy due to anticipated prolonged need for mechanical ventilation. On the morning of surgery, the patient was transferred directly from the ICU to the OR, with required preoperative safety checks performed at her bedside in the ICU. After the anesthesiologist administered total intravenous anesthesia, the surgical intern prepped and draped the patient's neck in the usual sterile fashion. The surgeon proceeded to perform a transverse incision above the suprasternal notch and dissected down to the trachea using a combination of sharp (scissors) and blunt techniques. The trachea was subsequently exposed and, with appropriate anesthesia (lowering of inspired oxygen concentration) and surgical team (abstinence from electrocautery) precautions, incised sharply. Without consulting the attending surgeon, the surgical intern suddenly noticed significant amount of bleeding in the area of the retracted strap muscles and proceeded to use coagulating diathermy to secure hemostasis. Immediately following the use of diathermy, a loud noise was heard and a large flame burst from the tracheal stoma. Ventilation was immediately stopped, the anesthesia circuit was disconnected from the tracheal tube, and the fire rapidly extinguished using normal saline administered through the endotracheal tube. Without delay, the surgeon gained access into the trachea with a tracheostomy cannula and once the positioning of the tracheostomy device was confirmed, the endotracheal tube was removed. The endotracheal tube was notably burned, with carbonized plastic material visible in the distal portion. The patient suffered superficial thickness burns around the stoma site. Fiberoptic bronchoscopy demonstrated minimal burn injury around the tracheostomy site and the proximal airway. Fortunately, the patient recovered without other major complications and was discharged from the hospital to rehabilitation facility after successful tracheostomy decannulation 2 weeks later.

4. Risk factors for fire in the operating room

Key risk factors for ORF should be well known to all OR team members, should be included as standard parts of staff educational curriculum, and should be readily identified whenever present (alone or in combination) [10, 11]. According to Apfelbaum *et al*., prevention of ORFs begins with minimizing patient exposure to the presence, alone or in combination, of "oxidizer-enriched atmosphere," potential ignition source(s)/surgical energy device(s), flammable liquids (e.g., alcohol-based surgical prep), and other potentially flammable materials (e.g., paper or plastic drapes) [12]. Mandych and his group reported an intraoperative fire that occurred during tracheostomy placement for a patient who had an unresectable lingual carcinoma [13]. When attempting to recreate the circumstances of the fire under laboratory conditions, they found that electrocautery did not ignite any towels, sponges, or other materials without the presence of oxygen. The authors concluded that an "ignition source," a "combustible agent," and oxygen were necessary for a fire to occur. Interestingly, they also cited the organic gases which emanated from the necrotic tumor to be a potential source of combustible

Risk factors for operating room fires
Ignition sources
• Electrosurgical and electrocautery units
• Electrical hemostatic devices
• Lasers
• Fiberoptic light sources and cables
• Defibrillators
• Flexible endoscopes
• Sparks from surgical drills
Fuel sources
• Flammable prepping agents including tinctures (chlorhexidine, thiomersal, iodophor)
• Drapes, towels, surgical sponges, dressings
• Gowns, hoods, masks
• Mattresses, pillows, blankets
• Patient hair (face, scalp, body)
Oxygen sources
• Oxygen (O_2)
• Nitrous Oxide
Risks are grouped by their primary category of "ignition source," "fuel source," and "oxygen source."

Table 1. Listing of major risk factors for operating room fire.

material [13]. Ladas and colleagues have also cited the potential for colonic gas explosion, though arguably this is a very rare scenario and preventive measures seem limited. In their review, they found 11 cases of colonic gas explosion during surgery and nine cases during colonoscopy. Looking back to the 1980s when mannitol was used as the most common bowel prep agent, colonic aspiration evaluation revealed a high concentration of hydrogen in the colon secondary to the mannitol's fermentation by *E. coli*. Though mannitol has largely gone by the wayside, there are still polyethylene glycol solutions with sorbitol, which, if the sorbitol is malabsorbed, can result in formation of combustible gases due to the same fermentation process [14]. Not only is this the case, but sorbitol is present in one's daily diet and malabsorption of sorbitol has been found in up to 60% of normal, healthy patients [15].

A rather thorough set of experiments were performed by Barker and Polson after a 73-year-old man's case of bilateral burr holes for evacuation of subdural hematomas ended up in an OR fire. Having experienced this, the group decided to embark on laboratory simulations using a nonflammable plastic manikin and concluded the following: (1) even without oxygen, paper drapes could be ignited by the electrocautery knife, but that fire was slow-burning and self-resolving; (2) when 5-min drying time was implemented, or if no alcohol based solution

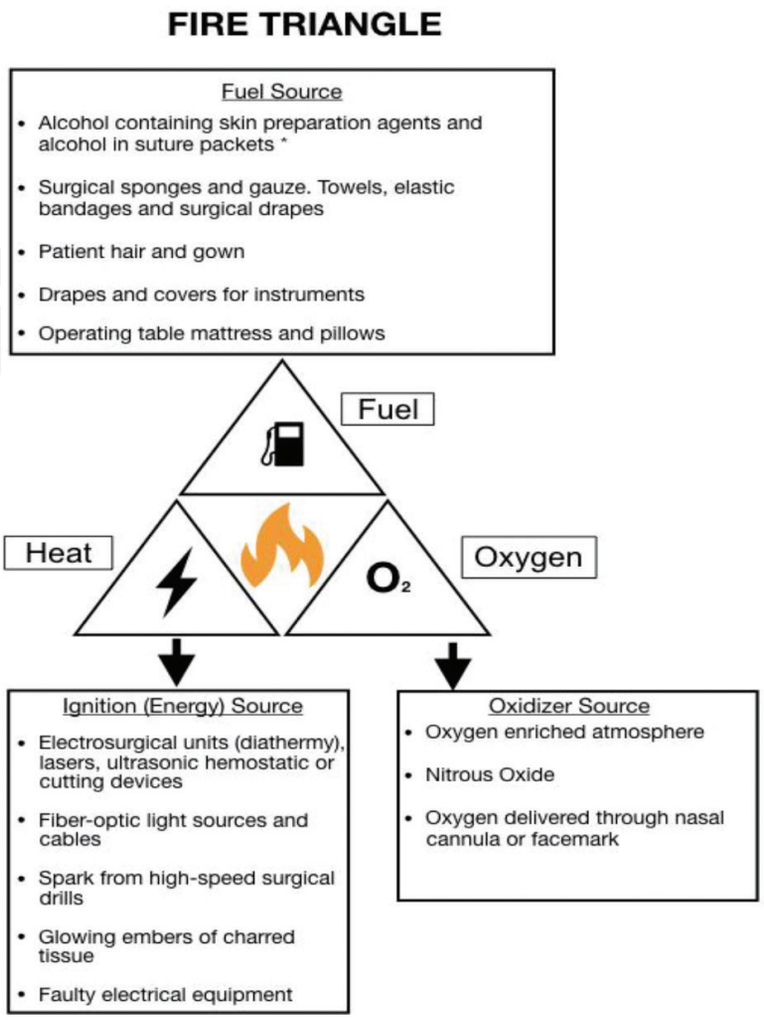

Figure 1. Components of the "fire triangle" that interact to create conditions ultimately responsible for various degrees of risk for operating room fire.

was used, there was no resultant fire; (3) in the absence of closed spaces where oxygen or vapor from the prep solution could gather, there was no fire. In this context, the authors found that the concentrations of oxygen under drapes could be as high as 50% [16].

Overview of major risk factors for ORF, grouped according to specific risk contribution, is provided in **Table 1** and **Figure 1**. Additionally, when considering and conducting the assessment, consideration of the delivery method of oxygen is a critical component. The use of a laryngeal mask airway or an endotracheal tube reduces the risk of fire by decreasing the oxygen concentration under the drapes and in the patient's upper airway [17].

From procedure-based standpoint, operations can be categorized as "general risk" or "high-risk" for ORF [12, 18]. For "general risk" procedures, such as abdominal hernia repairs, any flammable skin-prepping solutions should not be allowed to pool and must be dry before the placement of surgical drapes [19]. Assurance of the same is required before using any surgical energy devices (e.g., electrocautery or laser) [19, 20]. In addition, surgical drapes should be applied in a manner that prevents oxygen from flowing into the surgical site or pooling near

the operative field [12, 21]. Finally, surgical gauzes and sponges should be moistened when used in proximity to any potential source of ignition [22].

Examples of "high-risk" procedures include tracheostomy creation (e.g., direct exposure of surgical field to highly concentrated oxygen) or maxillofacial/head and neck surgery (e.g., close proximity between the endotracheal airway and surgical energy source) [23–25]. For such "high-risk" procedures, where proximity exists between an oxidizer and an ignition source, special caution is required by the entire OR team, including close communication and coordination between the surgeon and the anesthesiologist, as well as the use of operating field suctioning to scavenge any excess oxygen [12]. This is demonstrated well in our Clinical Vignette #2, where both the surgeon and the anesthesiologist took immediate and appropriate course of action. In addition to avoiding/limiting the use of nitrous oxide, the concentration of oxygen being delivered to the patient should be minimized, preferably based on close monitoring of patient oxygenation (e.g., pulse oximetry, and if possible tracking of inspired/expired/delivered oxygen concentration) [12].

The use of surgical laser equipment in a high-risk area (e.g., head and neck, trachea) should be done in the presence of laser "resistant" tracheal tubes, intended specifically for a given procedure and type of laser [12, 26, 27]. For any operative work requiring surgical energy application within the airway, reduction in oxygen or nitrous oxide concentration is thought to be safe for anywhere between 1 and 5 min at a time [12]. The same applies to procedures involving immediate proximity of the oxidizer and surgical energy source in the setting of nasal cannula or face mask [12]. Surgical suction should be utilized to scavenge oxygen or nitrous oxide from the oropharynx during cases involving this anatomic area [26].

5. Operating room fire: true magnitude of the problem

According to the Emergency Care Research Institute (ECRI), approximately 200–240 surgical fires occur each year in the United States [28]. Other sources provide a much wider range of occurrences, ranging between 100 and 2260 annually [2, 24, 29, 30]. Generally speaking, the incidence of ORF appears to be similar to that of wrong-site surgery or retained surgical items [28], some of the most prominent categories of surgical "never events" [31–33]. As outlined in previous sections, the simultaneous presence of key components required for the ignition of a fire is the single biggest risk determinant (**Table 1** & **Figure 1**). Therefore, it is not surprising that surgical fires involve electrosurgical equipment in approximately 67–90% of all cases, and that supplemental oxygen administration was nearly universally present [2, 34]. Of importance, the operative environment is defined as being "oxygen-enriched" when the oxygen concentration is greater than 21% [17]. Most commonly and not surprisingly, given the previously outlined risk factors, ORFs result in burns to the head, face, neck, and upper chest [22]. Thankfully not all ORFs involve patients, operating room staff, or result in significant injury [2].

6. The fire triangle: focus on education and knowledge

As discussed earlier in the chapter, the initiation (and propagation) of ORF is dependent on the simultaneous presence of an ignition source (e.g., surgical energy device), fuel (e.g., paper drapes, alcohol-based skin prep), and an oxidizer (e.g., oxygen, nitrous oxide) [22]. **Figure 1** lists

common types of items and categories within the "fire triangle" paradigm. Although beyond the scope of the current discussion, it is also important to mention that non-anesthetic causes of ORFs have been reported, including flammable gastrointestinal gases (mentioned earlier in the chapter) [35, 36] and surgical lights [37].

The final component is an oxidizer [38]. Although most people realize that oxygen greatly enhances the rate of combustion, many do not know that nitrous oxide supports combustion in roughly similar manner. Oxidizers reduce the fuel ignition temperature, thus elevating the risk of a fire and its continued propagation [39].

7. Fire containment: strategies and procedures

In an event of a fire, healthcare facilities commonly employ the "rescue-alarm-confine-extinguish" or RACE protocol [40, 41]. All team members, regardless of assigned function or seniority, should be aware of the location of pertinent emergency equipment, including the "fire alarm" trigger, fire extinguisher, and phone/extension to be used for notification [42]. Within the OR environment, additional considerations may need to be taken into account, depending on specific circumstances, such as whether the fire involves the patient. Scenarios involving the patient (both cutaneous and within the airway) and those without patient involvement will now be discussed.

If the fire directly involves the patient, the initial steps should involve extinguishing the flames and removing any burning material from the patient [2, 43]. Simultaneously, other team members should be tasked with initiating the established "fire response" protocol, including alarm notification, personnel evacuation, removal of flammable materials from the vicinity of the fire, as well as using fire extinguisher to contain and put out the fire [44, 45]. Alarm notification should clearly indicate the precise location of the fire and any critical information regarding the circumstances of the occurrence [42, 45]. Due to the risk of thermal injury, timing of actions and team coordination are critical. The administration of exogenous gases (oxygen and nitrous oxide) should be discontinued immediately. Once fire control is achieved, care for the patient should resume, with specific management based on the degree of danger from smoke in the area.

If the fire is not able to be immediately contained, then evacuation from the room, notification using established facility infrastructure (e.g., facility alarms, the emergency operator, and the OR operational leadership), and immediate notification of the fire department should take place. The surgeon typically recognizes the fire first and thus is involved in extinguishing and removing the fire, primarily by dousing the area with saline. Equipment immediately available in the event of an ORF includes ample supply of sterile saline or water; a "carbon dioxide" or a "water mist" fire extinguisher; replacement tracheal tubes, guides, and facemasks; rigid laryngoscope equipment; sponge and drape sets ready for rapid re-deployment; replacement ventilator circuits, tubes, and lines [2]. Because many drapes are waterproof, it is important for saline to cover all burning areas. If saline is not available, moist surgical towels draped across the operator's forearms may be used to smother the flames, with a sweeping motion away from the patient's airway. Of note, patting a fire may cause the flames to worsen [46].

During tracheostomy placement and other tracheal procedures, the fire may directly involve the patient's airway [47]. Although rare, this type of event can be fatal [48]. Due to its anatomic location, fire in the tracheobronchial tree is approached differently compared to other

circumstances. As soon as the airway fire is recognized, the administration of all gases by anesthesia must be stopped and the tracheal tube removed (to prevent plastic melting within the airway and the oropharynx) [2, 48]. Any items at risk of ignition should also be immediately removed, followed by the administration of saline or water into the airway [2]. After the fire is extinguished, the patient can be reintubated and ventilated, provided that no smoldering materials remain [2, 48]. Concentration of administered oxygen can be increased after the risk of re-ignition is no longer present. It is important for OR teams to remember that a tracheostomy procedural setup should include a readily available source of saline, preferably in a large syringe suitable for direct and immediate intra-tracheal administration.

One important, and thankfully exceedingly rare consideration is the secondary ignition of the operating room team's gowns, gloves, possibly resulting in thermal injuries among operating team members [49]. Electrical injury causing harm to hospital staff has also been described [50]. Although generally underreported, these and other similar scenarios may put at risk both the patient and his or her caretakers, especially when the fire is intense, when an explosion occurs, or when heavy smoke causes inhalation injury [49, 51, 52]. Also of importance is the need for the OR staff to be aware of the potential for patient thermal injuries from improperly placed electrocautery grounding pads [53].

In fires that occur in the operating suite or its immediate proximity, not involving the patient, the source is usually related to faulty electrical equipment or wires [2, 53]. In case of such occurrence, the initial step is to turn off (if possible, of course) and then safely unplug the affected equipment and remove it physically to reduce any potential future threat of fire [53]. However, if this is not feasible, the device may need to be extinguished in its stationary location [2].

Fire extinguishers using carbon dioxide should be readily available, easily accessible, and regularly checked for operational readiness [25]. Consequently, extinguishers must be clearly identified by an appropriate sign, and each employee should be familiar with operational characteristics of these life-saving tools. It has also been recommended that extinguishers should be located near pull stations, stairwells, and fire exits [2]. All fire extinguishers used in the OR are of the *ABC* variety, meaning that they are effective across all major fire types (A, ordinary combustibles; B, flammable liquids; C, electricity) [41]. The dry chemical fire retardant used is ammonium phosphate and is mildly corrosive in moist environments. If the patient becomes the fuel source, a CO_2 extinguisher (effective on electrical fires and flammable liquids) would be preferable because of its lack of ammonium phosphate and thus less potential for contamination and tissue damage. Proper extinguisher use can be described using the PASS (pull pin, aim, squeeze, and sweep) acronym [54].

Strategically located, centrally monitored fire, smoke, and heat sensors must be present and fully functional at each healthcare facility, including all procedure/operating rooms [55]. Additionally, fire alarm pull stations should be located near evacuation stairwells and other predesignated locations. When any fire is present, both visual (strobe lights) and audible alarms should activate [2]. The hospital fire response plan should immediately go into effect, notifying designated fire response team about where to respond. The response team includes but is not limited to security and facility management personnel. Determinations regarding resource mobilization and whether to initiate additional evacuation procedures should also be made.

In addition to the primary location of the ORF, the alarms should also sound on the floor above and below the fire. Although this may seem obvious in larger hospitals, where fire alarm notifications are usually announced throughout the entire building, some smaller facilities may require specific modifications to ensure this important safety feature. In the case of hospital fire alarm activation, the on-site safety team must determine whether an evacuation is necessary [2, 56]. This is especially important when one considers the risks associated with moving patients who are critically ill or actively undergoing surgery. Thus, in the event of an actual fire, personnel would be notified of detailed plan(s) to have the fire contained and controlled to facilitate safe and orderly evacuation of the involved building or structure [57–60]. Operating room personnel should conduct an assessment of specific patient needs such as monitoring equipment, ventilator availability and appropriate transport platform to safely perform evacuation procedures. Central to the ability to quickly and safely evacuate large number of patients and personnel is the need for specialized infrastructure, including critical components such as "fire-safe" elevators [56].

Gas shut-off valves are used to stop the flow of anesthetic gases into the ORs and are designed for easy access. The front of these gas supply consoles should be clear of medical equipment and clutter at all times [61]. The gas shut-off procedure should be managed using preexisting plans and/or protocols, again emphasizing staff education and periodic team drills. All pertinent equipment should be clearly labeled, including the relationship between valve position and its functional state [61, 62]. As with other emergencies that may involve limited visibility and/or lack of power, emergency lighting, battery-operated safety equipment, and any smoke management devices should be available and operational [63–65].

8. Consequences of fire in the OR: thermal injury

It has been noted that approximately two-thirds of surgical fires occur on the patient while approximately one-third occur in a cavitary location (e.g., airway) [17]. In terms of decreasing frequency of anatomic locations, approximately 40–45% ORFs involve the head, neck, and upper chest; about 25% involve other "external" body areas; and finally about 20% occur in the airway, with the remainder occurring in other "cavitary" locations [17].

In addition to traditional electrocautery equipment, various forms of devices utilizing different types of nonionizing radiant energy have been introduced into medical applications, including ultraviolet, visible light, microwaves, and radio-frequency waves [66, 67]. Starting with overall exposure and risk reduction, providers must be aware of the potential dangers—as well as the full spectrum of possible injury—associated with these devices [66, 68]. Prompt recognition and timely management of injuries from both direct thermal exposure and other forms of "surgical energy" misapplication cannot be overstressed. This includes immediate attention to any injuries sustained by the patient and/or staff [29, 69, 70]. Thermal burns are associated with coagulation necrosis of the involved tissues, with the degree of severity depending on the temperature and the duration of the exposure. The initial tissue response primarily results from the direct transfer of energy in the localized area of injury, resulting in protein denaturation and coagulation [68, 71–73].

In case of cutaneous burn, skin is an effective thermal barrier, causing most of the immediate damage to be confined to epidermis and dermis. At the same time, various humoral mediators (cytokines, prostaglandins, oxygen free radicals, histamine, complement) are released that may result in vasoactive response, increased capillary permeability, and the appearance of local as well as distal tissue edema. Beyond the general pathophysiology of the burn wound, additional factors contributing to the overall physiologic response include resuscitation fluid administration, effects of various therapeutic agents, impaired host defense leading to elevated risk of infection, endocrine system changes, and the associated hypermetabolic state that affects metabolism across a broad range of tissues (e.g., muscle, liver, kidneys, gastrointestinal tract) [73].

If airway or intracavitary fire is present, the abovementioned considerations may become amplified, potentially worsening the clinical prognosis [35, 74, 75]. Injuries involving the airway may become life threatening if not promptly and properly managed [48]. More specifically, what may appear to be a minor injury can result in severe tissue edema that severely restricts or obstructs an airway over the course of a few hours [74, 76, 77]. Long-term follow-up is required in cases of severe airway injury [78].

9. Medico-legal, reputational, and regulatory implications of ORF

Additional consequences of ORFs, above and beyond direct patient harm, include serious medico-legal repercussions, financial costs, and severe reputational damage to both involved providers and their institutions [79, 80]. Moreover, such events inculcate mistrust toward the healthcare system among the public [80]. Although the majority of patients who sustain medical injury do not file lawsuits, the medical system is riddled with an abundance of frivolous claims, the cost of which is not trivial [81–84]. It has also been noted that lack of provider awareness, combined with inadequate levels of communication, may result in elevated malpractice risk [85]. The development of appropriate internal reporting mechanisms and educational programs may help mitigate the overall legal risk associated with adverse events, including ORFs [85, 86]. Factors known to prevent litigation by patients who suffered complications include excellent surgeon-patient relationship, full and honest disclosure, and effective communication between patients, providers, and teams [87, 88].

Consequences of unusual or elevated incidence of ORFs can be significant, up to and including mandatory closure of operative suites at an institution [2]. Consequently, thorough assessment of risks, institutional protocols, and employee competency in this critical area is mandatory [2]. Regular (e.g., quarterly) fire drills may help reinforce the knowledge of essential patient safety protocols and serve to refresh key information among the OR staff [89].

10. Checklists, communication, education, safety protocols, and teamwork

It has been noted that in the presence of all three components necessary for intraoperative fire ignition, the risk of ORF may be further elevated by poor team communication and coordination [90]. From patient safety perspective, virtually all surgical fires should be preventable. Standardized

OR safety checklist aimed at reducing the risk of ORF, either alone or in combination with other existing checklists, has been proposed as one potential solution to the problem [91–93]. Another area where iatrogenic fires can occur, yet the issue appears to be relatively neglected despite some procedural similarities to the OR, is the clinical setting of the emergency department [94].

One important focus of existing guidelines (with some exceptions) is that the traditional practice of using highly concentrated oxygen should be discontinued during head, face, neck, and upper chest surgery [28, 46]. The recommended practice is to use medical air whenever possible in such cases, and if the patient's condition warrants supplemental oxygen, additional precautions should be taken to protect the surgical field from oxygen "contamination" [2]. The exception to this rule would be a case in which a patient must remain responsive but requires supplemental oxygen while undergoing a procedure involving the head, face, neck, or upper chest. Under such circumstances, the lowest concentration of oxygen should be employed (e.g., 30%), and if concentrations exceed 30% prior to using any surgical energy source, one should stop oxygen and deliver medical air at 5–10 L/min for at least 1 min to dissipate any trapped oxygen [95, 96]. As previously outlined, tracheal incision should only be performed using "cold" devices such as scalpels or scissors. Finally, communication among the team members is essential, including universal patient safety education and utilization of patient safety checklists [97].

Because ORF requires the simultaneous presence of an oxidizer, an ignition source, and a fuel, the key to prevention is intentionally minimizing (or eliminating, if applicable) one or more of these components so combustion is not possible [98]. Thus, the overall framework for ORF prevention must incorporate specific steps to identify risk level for each surgical case, ensure proper use of surgical energy devices, safe and appropriate use of supplemental oxygen, excellent communication and coordination, as well as meticulous attention to detail when using any potentially flammable materials to prep and/or drape the surgical field [99]. The assessment of fire risk potential should take place during the universal surgical time-out for every single patient and for each individual procedure [99, 100]. The fire risk is calculated/estimated by considering all possible risk factors associated with a particular surgical procedure [101, 102]. The resulting "risk score" (with "1" representing "low risk," "2" representing "intermediate risk," and "3" representing "high risk") should then be communicated to the surgical team during the "time out" or "pre-op briefing" [102].

In the OR, each healthcare worker takes the "ownership" of a part of the fire triangle. For example, alcohol-based skin preparations have become more common as a source of fuel since the Centers for Disease Control and Prevention identified them as the preferred skin disinfection method. Thus, the team member who applies the prep (e.g., circulating nurse) must work closely with the surgeon who controls the surgical energy device, and these stakeholders must ensure that the potentially flammable prep agent is completely dry, without any identifiable pooling, before proceeding with the use of electrocautery [99].

One never knows who will be present when the fire occurs; thus, the role of each team member may change in any given scenario. A simplified guideline for all three broad types of ORF (e.g., involvement of airway, cutaneous/non-airway, and environment) is presented in **Figure 2**. High degree of flexibility on the part of all team members is required, and this can only be accomplished in the presence of meticulous preparation, optimized use of resources, readiness drills, simulation, and other forms of team practice [103, 104]. For

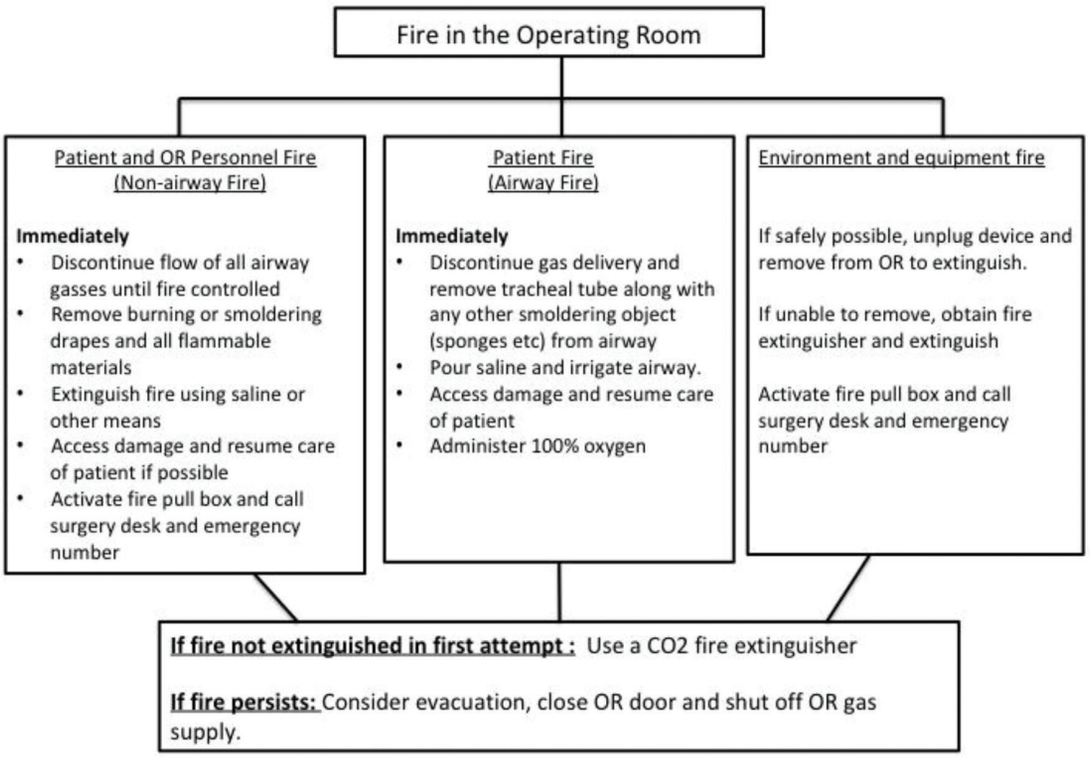

Figure 2. Schematic summary of guidelines for optimal approach to operating room fire. Note: Both carbon dioxide and "water mist" extinguishers can be utilized. Legend: CO_2 = carbon dioxide; OR = operating room.

example, the American Society of Anesthesiologists (ASA) strongly recommends fire safety simulation as a team preparedness tool [12, 89]. It is important that such simulations are as realistic as possible, and that "lessons learned" are discussed during a post-simulation debrief in a constructive, team-oriented fashion, and disseminated afterwards to all stakeholders. Sharing of experiences between different institutions and teams is also very valuable. Helpful information regarding ORF prevention and management is available on the Internet, including the Association of periOperative Registered Nurses (AORN), Anesthesia Patient Safety Foundation (APSF), ASA, and Emergency Care Research Institute (ECRI) websites [105–107]. Finally, in an event of a major unforeseen event in the OR, a crisis checklist has been proposed to help streamline decision-making and team processes required during an orderly response [108].

11. The importance of honest disclosure and risk management

Although uncommon, adverse events and clinical errors do occur, and physicians have an ethical and professional responsibility to honestly disclose such occurrences to patients [109]. Open discussion regarding unfavorable events is an indispensible component of effective clinical risk management in health-care. Failure to do so undermines the public's confidence in the medical profession and has the potential to create legal liability [110]. Moreover, patients need to be informed about medical errors so that additional harm can be avoided, and well-informed decisions about their care can be made [111].

Honest disclosure can be challenging for practitioners as it may be difficult to recognize errors openly before both patients and colleagues [112, 113]. In addition, physicians' fear of litigation can also pose as a major barrier to frank disclosure [114]. However, when handled appropriately, immediate and genuine disclosure of errors frequently leads to improved patient rapport and fewer malpractice claims [115, 116]. Practitioners are encouraged to follow hospital-specific guidelines for the disclosure of errors, patient safety events, and other risk management issues [117–119]. Disclosure needs to take place in an appropriate setting and at the right time, when the patient and/or their family is/are able to understand and sufficiently process the information provided. The surgeon should always take the lead and approach the patient/family with empathy and concern [120]. Behavior that translates into acts of evasiveness or lack of understanding inculcates mistrust and anger in the patient, which may ultimately lead to a legal action against the physician and/or the hospital [121]. Manner and tone are extremely important aspects of disclosure and often more impactful than the actual content of the discussion. A simple "I am sorry" is often appreciated by the patients and results in a stronger patient-physician relationship. In addition, it is important for the physician to articulate clearly what has been done to overcome consequences of the error and to reassure the patient and their family that every effort has been taken to prevent similar events from happening in the future [122].

Open physician-to-patient and physician-to-physician communication is a fundamental aspect of effective clinical risk management and cannot be overemphasized [110]. As outlined throughout the ***Vignettes in Patient Safety*** book cycle, every health-care organization should encourage the internal development of patient safety champions and strictly enforce policies and procedures that prevent occurrence of adverse events [32]. At the same time, when these incidents do occur, all team members (physicians and non-physicians) should be trained to report them without fearing backlash or facing undue blame [32, 33, 123].

12. Conclusions

Although rare, ORFs occur more often than most people realize. Fire safety in the OR is every team member's responsibility, with attention to established safety protocols and focus on prevention constituting the overarching priorities of intraoperative patient care. All stakeholders should be well aware of the "fire triangle" concept, and how the combination of an "ignition source," "fuel source," and "oxygen source" can create a potentially dangerous environment. When ORFs do occur, optimal outcomes depend on immediate recognition, appropriate response, and a coordinated team effort. The focus on team education/training and fire preparedness (through regular exercises and simulations), along with a comprehensive fire safety program, constitute an integral part of preventing adverse occurrences. Patients entrust health-care provider teams with their lives. With this trust comes the expectation that all team members have excellent knowledge (and control) of risk factors potentially responsible for ORF occurrences. In order to further improve our collective understanding of ORFs, including quantitative risk-factor determination, future efforts should include the development of a national registry that will help facilitate prospective tracking of all ORF occurrences, including their relationship to known risk factors and documented risk-reduction strategies. Only when working together can we effectively achieve the "zero incidence" of major patient safety "never events."

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