A Fire in the Operating Room: It Could Happen to You

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In the days when flammable anesthetic agents were frequently used, fire and explosion hazards were of paramount importance to the anesthesiologist. Although most operating room personnel do not consider fires a major safety hazard, in reality many fires occur in the operating room every year. It has been estimated by the ECRI (Emergency Care Research Institute) that there are approximately 100 operating room fires every year in the United States. About 10% of these produce serious injury to patients or operating room personnel. However, the number may be significantly higher due to under reporting. Therefore, it is incumbent upon all those who work in the operating room to be aware of how to prevent fires and what to do if one should occur.

The Fire Triad

In order for a fire to occur, three elements must come together at the same time. These elements are known as the fire triad. They include; (1) heat, or an ignition source; (2) fuel; and (3) an oxidizer. In the operating room, the heat source is commonly the electrosurgical unit (ESU), a laser, or a fiberoptic light cord. There are many elements that can provide fuel for an operating fire. These include paper drapes, plastics, gauze dressings, endotracheal tubes, the patient's hair, linens and gel mattress pads. The common oxidizers in the operating room are oxygen, air and nitrous oxide.

A fire is actually the chemical reaction of fuel rapidly combining with oxygen with the resultant release of heat and light energy. Prevention is clearly better than extinguishing a fire. Fires can be prevented by isolating the various legs of the fire triad. This can be done by minimizing the amount of oxygen or nitrous oxide that is delivered to the patient. It should be remembered that oxygen and nitrous oxide support combustion equally well. Therefore, a mixture of 50% nitrous oxide and 50% oxygen is virtually the same as 100% oxygen. Oxygen and nitrous oxide are not explosive gases. Examples of explosive gases are cyclopropane, hydrogen and methane.

Keeping heat sources away from flammable materials is another important safety precaution. It should be remembered that an ESU tip remains hot for a few seconds after the instrument has been deactivated. Similarly, ends of fiberoptic cables can retain significant amounts of heat after being disconnected from their light source. Therefore, it is important to be careful where one places the end of a fiberoptic cord. Lasers should be immediately placed in standby mode and ESUs placed in a appropriate holder when they are not in use. Finally, volatile liquids must be allowed to dry since the vapors can be quite flammable.

There are many dangers from a fire. Obviously, heat can cause burns to the patient or operating room personnel. Of great importance is that smoke from the fire can necessitate that the room be evacuated. Depending on what is burning, toxic products can be given off by the combustion of various materials. Many of these products such as carbon monoxide, ammonia, cyanide, isocyanates and hydrogen chloride are quite toxic. They can cause chemical and physical irritation to the tracheal-bronchial system but more important, they cause asphyxia.

Being prepared for a fire and knowing what to do if one should occur are key elements of a fire safety program. Knowing the location of fire extinguishers and having fire drills will enable all operating room personnel to become familiar with proper procedures. Operating room personnel should be familiar with the location of alarm boxes, gas shut-offs, and fire extinguishers. People should realize that it is important to immediately call for help, decide who is going to fight the fire, when it will be appropriate to leave the room and how to care for the patient during the fire. If drapes are burning, they must be removed as most OR paper drapes are impervious to water. Therefore, the fire will burn on the underside and dousing them with water will not extinguish the fire. Having sources of battery powered portable lighting available is also extremely important.

Types of OR Fires

Operating room fires can be classified into two types: those that occur in the patient and those that occur on the patient. Fires that occur in the patient would include airway fires such as by ignition of an endotracheal tube or a fiberoptic bronchoscope or intra-abdominal fires. Fires occurring on the patient include ignition of drapes or surface fires that are fueled by supplemental oxygen.

One of the primary sources of ignition in the operating room is the laser. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. The laser light is produced when energy is aimed at the "lasing medium". The lasing medium then becomes the name of the laser. For instance, electrical energy aimed at carbon dioxide molecules is a carbon dioxide laser. The light produced by a laser is known as coherent radiation. Coherent light can be focused into small spots with very high power density.

There are a number of different types of lasers. These include the argon laser which is used in eye and dermatologic procedures. The energy produced by this laser is absorbed by hemoglobin and melanin and has a tissue penetration of 0.5 to 2.0mm. The KTP (frequency doubled YAG) laser produces energy that is absorbed by hemoglobin and has a tissue penetration of 0.5 to 2.0mm. The dye laser has wave lengths that are tunable for different applications. The Nd:YAG laser has tissue penetration of 2-6mm and can be used for tumor debulking particularly in the tracheal-bronchial tree. Its energy can be transmitted through a fiberoptic cable which enables it to be used in a "contact" mode. The CO_2 laser produces energy that is absorbed by water. It is used where precision is needed and has negligible tissue penetration. Also there is minimal heat dissipated to the surrounding tissues. The helium neon laser (He-Ne) is a very low power laser. Its red light is used for aiming the CO_2 and the Nd:YAG lasers.

Fires in the Patient

The most serious fire in the patient is an endotracheal tube fire. Although the ET tube can be ignited by electrocautery, it is more common for a fire to occur as a result of it being struck by a laser. Wolf and colleagues showed that the red rubber, the polyvinyl chloride (PVC), and the silicone endotracheal tubes all have a flammability index of less than 25% oxygen. Therefore, these tubes are not appropriate when doing surgery in and around the airway.

Before specific laser resistant tubes were developed, many practitioners wrapped endotracheal tubes with various kinds of foil or copper tape. Today, this is a dangerous practice and should be avoided. There are many complications associated with wrapping tubes which include kinking of the tube and having unprotected parts of the tube exposed where layers of tape fail to overlap. In the event that an endotracheal tube should be set on fire, it is important to immediately disconnect the tube or the inspiratory hose from the anesthesia machine. This will usually result in the fire going out since the oxidizer has been removed from the fire. The ET tube is then removed, the patient is mask ventilated and then reintubated so that the airway can be inspected and any pieces of foreign material removed. These fires can be quite devastating as an endotracheal tube ignited by a laser with high concentrations of oxygen essentially turns into a "blow torch" with resultant burns to the lungs, trachea, and esophagus.

Upper Airway Surgery

When anesthetizing patients for upper airway surgery, a number of anesthetic techniques are possible. One can use jet ventilation either through a metal bronchoscope or a catheter inserted through the cricoid membrane. In this circumstance, there is no tracheal tube in the airway to burn. However, the FIO_2 is not controllable as it is dependent on a venturi mechanism that entrains room air which is delivered to the patient. Complications of this technique include hypoventilation, barotrauma and aspiration. The surgery can also be performed using an endotracheal tube that is specifically resistant to the type of laser being used. The tube should have two cuffs and they should be filled with saline that has been colored with methylene blue. This allows the surgeon to know when one of the cuffs has been ruptured.

If the carbon dioxide laser is being used, then the LaserFlex™ (Mallinkrodt) ET tube is an excellent choice. The tube consists of a double cuff and a flexible metal shaft that is highly resistant to the CO_2 laser. This tube, however, is not resistant to the Nd:YAG laser. If the Nd:YAG laser is to be used in the upper airway, then a special laser resistant tube called Lasertubus™ (Rusch, Inc.) can be used. The Lasertubus™ consists of a soft rubber shaft that is covered by a corrugated silver foil which is then covered by a Merocel™ sponge covering. The Merocel™ is moistened with saline which will then consume laser energy if it is struck. It also dissipates the laser light and the silver foil prevents the laser light from penetrating the shaft of the tracheal tube. This tube also consists of a double cuff design. Only a portion of the tube is laser resistant and it is important that this part of the tube always remains in the surgical field.

The electrocautery can also be a source of ignition during upper airway surgery. A typical example would be during a tonsillectomy on a child with an uncuffed tracheal tube. The anesthetic mixture, which may contain oxygen and nitrous oxide, can readily leak around the tracheal tube and be present in significant concentrations that the electrocautery could cause a fire at the operative site. In these cases, it is recommended that oxygen be mixed with air and the FIO_2 be kept as low as possible. The surgeon can also put wet pledgets around the tracheal tube; however, it must be remembered that if the pledgets dry out they can also be a source of fuel for a fire.

Lower Airway Surgery

When doing surgery on the lower airway, the Nd:YAG laser is frequently employed. The surgeon usually passes a laser fiber through the suction port of the fiberoptic bronchoscope. This bronchoscope may then be passed either through a PVC tracheal tube or through a rigid metal bronchoscope. If the fiberoptic bronchoscope is passed through an tracheal tube it is best to use an unmarked PVC tube. This is because the dye in the ink markings on the tube attracts Nd:YAG energy. There is no special tube for this type of surgery. Indeed the fiberoptic cable passes through the inside of the tracheal tube. Therefore, it is essential to keep the inspired oxygen as low as possible and titrate the oxygen saturation to between 90-95%. Also, the endotracheal tube should be placed just below the vocal cords so that the tip is as far away from the operative site as possible.

If the rigid metal bronchoscope is used, then obviously there is no tracheal tube in the airway. The patient is then ventilated with a form of venturi which will entrain room air. Therefore, the inspired oxygen is not precisely controllable. The FIO_2 will usually vary between 40-60%. It should be remembered that in either circumstance, the cover of the fiberoptic bronchoscope is plastic and can easily burn especially in an oxygen enriched environment.

Laser Safety

There are other safety considerations when using the laser. Reflected laser light can cause retinal damage. The patient's eyes should be covered with wet eye packs and all personnel in the room must wear goggles that are specific for the laser being used. These goggles frequently have a color tint, which may make it difficult to monitor skin color changes. Also, all windows should be covered with black window shades and warning signs should be posted on all doorways to the operating room. There is also potential damage to the respiratory track from vaporized tissue which may contain chemical toxins or virus particles in the laser "plume". It is recommended that special (high filtration) masks be worn by OR personnel during these types of procedures.

Another place where a fire could occur in the patient, is during laparoscopic surgery. Even though the abdomen is inflated with CO2,after about 30 minutes of nitrous oxide anesthesia, the N2O can diffuse into the abdomen and reach levels that could support combustion. Neuman et al studied this phenomenon and found that at 30 minutes the mean nitrous oxide concentration was 36%. However, in certain patients, the nitrous oxide concentration was as much as 47%. Bowel gas contains two potentially flammable gases. These are methane and hydrogen. The reported maximum concentrations of methane in bowel gas is 56% and hydrogen 69%. 56% methane would require 47% nitrous oxide in carbon dioxide to support combustion. Since that was the maximum concentration found in the study, this presents a relatively small hazard. However, 69% H_2 will burn in concentrations of nitrous oxide of 29% or greater. Therefore, if the surgeon should accidentally enter the bowel during laparoscopy which contained a high percentage of hydrogen, a fire could occur. The nitrous oxide would support combustion, the hydrogen would be the fuel, and the electrocautery would provide the heat source. Greilich et al reported a fire in which a tank of 14% carbon dioxide and 86% oxygen was accidentally used to inflate the abdomen instead of pure carbon dioxide. When the surgeon activated the electrocautery, a fire ensued. The pin index for tanks with 100% CO_2 is the same for any tank with greater than 7% CO_2.

Another kind of fire that occurs in the patient is the ignition of a tracheal tube during a tracheostomy. A critically ill intubated patient will be receiving supplemental oxygen. Many surgeons use the electrocautery to enter the trachea. This is an extremely dangerous practice since the tracheal tube is frequently in the field while supplemental oxygen is being delivered to the patient. The ESU then provides a source of heat and a number of fires have resulted. Decreasing the inspired oxygen would obviously be a safety factor; however, this may not be possible in this patient population. Also, unless the patient is ventilated with a decreased inspired oxygen content for at least a minute, the higher concentration of oxygen will continue to be present in the trachea. It is far better that the surgeon use a scalpel or scissors to enter the trachea, instead of the ESU. This will greatly reduce the risk of a tracheal fire.

Fires on the Patient

The other type of operating room fire is one that occurs on the patient. Most commonly these are associated with monitored anesthesia care (MAC) for head and neck cases where the patient is administered supplemental oxygen either by a face mask or a nasal cannula. The surgeon then drapes the field such that there is a build up of 100% oxygen under the drapes and in close proximity to the operative site. This oxygen, in certain circumstances, can then diffuse directly into the operative site so that when the electrosurgery pencil or the laser is used, a fire can be started.

There are many potential objects that could provide fuel for the fire. These include paper drapes, gauze sponges, plastic tubing from the oxygen mask, and even the patient's facial hair. It is important to remember that oxygen is a drug. Therefore, the need for supplemental oxygen as well as the concentration of oxygen needs to be titrated in each patient. Frequently, by reducing the amount of sedation given to the patient, the amount of supplemental oxygen needed is greatly reduced. The oxygen can be diluted with room air and titrated to keep the patients oxygen saturation between 90-95%. The drapes should be arranged so that the oxygen does not build up underneath the operative site. The drapes should be arranged in a fashion that forms an open tent so that the oxygen will be diluted with room air. Since oxygen is slightly heavier than room air, as long as there is some way for the oxygen gas to get in and out, it will tend to flow towards the ground.

Another potential strategy to minimize the risk of fire is to discontinue the use of supplemental oxygen several minutes before the surgeon uses the laser or the ESU. This will give any oxygen that has built up time to dissipate which would greatly reduce the risk of fire. However, this may be difficult to do if there is frequent use of the ESU or laser.

Volatile prep solutions provide another potential source of fuel for a fire. Solutions such as isopropyl alcohol used to be used frequently by the surgeons as a skin prep. These solutions could pool in certain areas and remain liquid for a considerable period of time. Additionally, these solutions will vaporize and the resulting vapor, especially in an oxygen enriched atmosphere, is highly flammable.

DuraPrep™ is a recently introduced skin prep that is becoming very popular in many hospitals. It consists of Iodofor and 74% isopropyl alcohol. It appears that the very high concentration of alcohol is not appreciated by many surgeons and operating room personnel. If the solution is not allowed to dry completely before beginning surgery, then the alcohol will provide a potential fuel for a fire. In 2001, Barker & Polson reported on just such a case. A patient was having a burr hole craniotomy under MAC anesthesia. The patient was receiving supplemental oxygen and the head was prepped with the Iodofor and alcohol solution. When the surgeons made the skin incision, the electrosurgical unit was activated and a "pop" sound was heard. In very short order, smoke and a ball of flames engulfed the patient's head and shoulders. The fire was quickly extinguished, but the patient suffered burns to the face and neck area. In a laboratory re-creation of the event, Barker and Polson discovered some interesting facts. By duplicating the setup in the operating room, they were able to re-create the fire. However, if there was no flow of supplemental oxygen, there was no fire. If the alcohol-based prep solution was not used, again there was no fire and finally, if the closed space where the oxygen was allowed to built up was not present, again there was no fire. This points out the essential fact that although operating room fires are a rare event, when the key elements come together at precisely the same time, a fire is easily started. Also, in the presence of an oxygen enriched atmosphere, the fire will spread almost instantaneously.

Recently 4 cases of fires in the CO_2 canister of the anesthesia machine have been reported. These canisters have melted or actually caught on fire. In at least one case there was a serious patient injury. The common elements included use of a CO_2 absorbent that was desiccated (Baralyme™), Sevoflurane™, and low O_2 flows. Apparently a breakdown of Sevoflurane™ occurred, and this was a very exothermic reaction, which caused a fire. Laster et.al. demonstrated that when desiccated Baralyme™ interacts with Sevoflurane™ there is a sustained temperature increase to 200 degrees C, and in one case to over 300 degrees C. In contrast, with Isoflurane™ and Desflurane™ there was only a transient increase in temperature to 100 degrees C. Amsorb™ is a newer CO_2 absorbent that does not contain strong alkali, and does not react with Sevoflurane™. Therefore, it would not pose a fire hazard.

Extinguishing a Fire

If a fire should develop, it is important to know how to extinguish it as rapidly as possible. Breaking the fire triad is extremely important. Therefore, removing the oxidizer by disconnecting the oxygen or the circuit from the patient, will frequently extinguish the fire. Burning drapes should be removed as quickly as possible and once on the floor, they can then be extinguished. It should be remembered that impervious paper drapes will repel water and the fire will actually burn on the underside of the drapes. Therefore, attempting to throw water on these burning drapes, would be useless. Although most operating rooms have a sprinkler system, the sprinklers are frequently not activated in cases of OR fires. This is because the sprinklers are rarely located over the operating room table, and they are also heat activated. OR fires tend to give off a lot of smoke and toxic products but not necessarily enough heat to immediately activate the sprinklers.

It is important that all operating room personnel be familiar with fire extinguishers. They are classified into three basic types. Class A are used for wood, paper, cloth and plastics. Class B are used to extinguish flammable liquids or

grease, and Class C are used for energized electrical equipment. Many fire extinguishers are classified to be used in two or all three types of fires. Halon is a fire extinguisher commonly found in operating rooms. It is bromofluorohydrocarbon and can be used on Class B & C fires and on many Class A fires as well. It is a highly effective fire extinguisher and can be used safely around electronic equipment. However, because it is a fluorocarbon, it is no longer being manufactured. Newer, environmentally friendly substitutes are now available. Carbon dioxide fire extinguishers are useful for Class B & C fires and can also be used in Class A fires. The blast of carbon dioxide gas has a liquid and solid component that rapidly vaporize, which leads to a cooling and smothering of the fire. Carbon dioxide extinguishers do not leave a residue which could damage electronic equipment, but the cold may cause freezing if it came into contact with exposed skin. Pressurized water can be used in hand held fire extinguishers or from the large fire hoses located in the operating room corridors. If a corridor fire hose is used, it can deliver up to 50 gallons of water a minute. These devices are best used by the fire department unless a patient or OR personnel is in need of immediate rescue. Obviously, these devices would cause extreme damage to electronic equipment. All fire extinguishers have advantages and disadvantages.
When considering all of these factors, the CO_2 fire extinguisher is probably the best for an operating room fire.

When using a fire extinguisher, the acronym "PASS" should be remembered. This stands for Pull the pin to unlock the handle of the fire extinguisher; Aim the nozzle of the fire extinguisher at the base of the fire; Squeeze the handle to activate the fire extinguisher and release the agent; Sweep the stream of the extinguisher over the base of the fire.

Case Studies

A couple of case scenarios of actual OR fires will help to illustrate some of the points that have been made. In one instance during a neurosurgical procedure, the laser and the electrosurgery unit were both in use during the case. The surgeon picked up the ESU while the laser was lying on the drapes. He mistakenly stepped on the laser pedal which immediately ignited the drapes and subsequently the mattress and gel pad. A fire was started which produced a very toxic smoke which forced all of the OR personnel to leave the OR. They subsequently had to crawl back into the room, disconnect the patient from the anesthesia circuit and pull the patient and the table out of the room. This case illustrated the value of being absolutely certain of which pedal activates which device. Also, when a laser is in use, once it is set down, the laser should be put in the standby mode immediately. Similarly, when an electrosurgery unit is not in use, the pencil should be placed in a plastic holder.

Another case involved a trauma patient for an exploratory laparotomy. The electrosurgical pencil became draped over the side of the table and the button was inadvertently activated. This immediately set the drapes on fire. Although initially the fire appeared small, within a few seconds the flames had engulfed the left side of the patient. Attempts by the OR staff to extinguish the fire were unsuccessful and the fire department arrived approximately 15 minutes later and extinguished the fire. A review of the incident revealed that the OR staff had no plan for dealing with the situation, they couldn't find the fire extinguishers, the fire cabinets were blocked by equipment and the OR sprinkler system was not activated. Once again, the fact that the ESU pencil was not placed in the holder contributed significantly to this fire.

All OR personnel must be vigilant to potential OR operating room fires. Clearly, prevention is better than trying to deal with an established fire. It is however, incumbent upon OR personnel to be prepared. This includes fire drills, being familiar with the type and location of fire extinguishers, having an evacuation plan, knowing where gas and electrical shutoffs are located, being able to rapidly call for help, sound a fire alarm and communicate with other OR personnel. Only by working together to keep all three legs of the fire triangle from coming together, can OR fires be prevented.

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