Airway Fire

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QUESTIONS
Before continuing, try to answer the following questions. The answers can be found at the end of the article, together with an explanation. **Please answer True or False:**

1. The use of the following may pose significant safety concerns during airway surgery:
   a. Supplemental oxygen delivered to the patient
   b. Nitrous oxide as a carrier gas delivered to the patient
   c. Helium as a carrier gas delivered to the patient
   d. An open breathing circuit for delivery of gases to the patient
   e. Carbon dioxide gas in close proximity to the patient/surgical field

2. With regards to the immediate management of an airway fire:
   a. The first step should be to evacuate the operating theatre
   b. The fire should be extinguished by applying manual pressure to the surgical site
   c. Once the fire has been extinguished, the patient should be oxygenated with high-flow 100% oxygen until airway control is re-established
   d. The anaesthetist is solely responsible for removal of any airway device
   e. If initial attempts to extinguish the fire are unsuccessful, a water-containing fire extinguisher should be used

3. With regards to the morbidity and mortality associated with an airway fire:
   a. Injuries are restricted to the immediate surgical field and proximal airway *only*
   b. A chest x-ray is the investigation of choice to assess the extent of any injuries incurred
   c. Despite the potential for critical loss of airway during an airway fire, mortality is extremely rare
   d. It is recommended to keep the patient's trachea intubated and lungs mechanically ventilated for further assessment on the intensive care unit
   e. The use of a specially designed laser-resistant endotracheal tube will prevent airway fires during laser airway surgery

Key Points

- Airway fires rarely occur but the consequences may be catastrophic
- The main factors in airway fires are the use of high concentrations of supplemental oxygen and electrocautery or a laser at or within the larynx or trachea
- Prevention depends on the sharing of awareness and responsibility by the anaesthetist, surgeon, and nursing staff
- Effective management depends on the immediate, coordinated and pre-determined actions of team members who should have clearly designated roles

INTRODUCTION

An airway fire is a fire that occurs within a patient's airway or involves an in-situ airway device or contiguous breathing circuit. Operating-room fires (airway- or non-airway-related) are rare events, with a reported incidence of between 50 and 200 per year in the United States according to the 2013 ASA Task force.[1] Fires in the airway have become less common due to the discontinuation of the older, more flammable anaesthetic agents (ether and cyclopropane[2]), but they have the potential for devastating patient morbidity and mortality,[3] despite their fleeting nature.

AETIOLOGY

In order for an airway fire to occur, the essential elements of the classical fire triad *must* be present:

1. An ignition source
2. An oxidiser
3. A fuel source

Ignition sources

These include electrocautery and lasers utilised in Ear, Nose and Throat surgeries. Other potential sources are static electricity, heated probes, drills and burrs, argon beam coagulators, fibreoptic light sources and cables, and defibrillator pads and paddles.[1]

Oxidisers

The use of supplemental oxygen or nitrous oxide in anaesthetic gases delivered via closed or semi-closed breathing circuits creates an oxidiser-enriched environment within patients' airways and breathing apparatus. This increases the likelihood and intensity of combustion.[1] A potent atmosphere can also be created locally if open-breathing circuits are used, such as facemasks or nasal cannulae, or inappropriately configured surgical drapes that trap oxygen and allow it to pool near the surgical site and potential sources of ignition. In a case review of 18 tracheostomy fires, all were associated with the use of supplemental oxygen.[4]

Fuel sources

The most common source of fuel for airway fires are endotracheal tubes, followed by surgical drapes.[4] Other sources include alternative airway devices, breathing circuits, scavenging tubes, suction catheters, wound drains, surgical packs, dressings, pledgets, sponges and gauze.

Some surgical procedures are inherently risky because the presence of all three fire-causing elements is unavoidable. The formation of a surgical tracheostomy is one example, whereby the surgical field becomes oxidiser-enriched as soon as the tracheal aperture is created.[5] Specific risk factors identified from case reports[1] include high fractional inspired oxygen concentrations (often required in intensive care patients to maintain adequate oxygenation), use of electrocautery for incision of the trachea specifically,[5] and the presence of deep soft tissues as diathermied adipose tissue will burn if hot enough.[1] Laser airway and vocal cord surgeries are also especially hazardous as there is an ignition source (the laser), an oxygen-enriched environment (the air–oxygen mixture delivered to the patient) and a fuel (the endotracheal tube or breathing circuit).[6]

Morbidity and mortality

Most airway fires are brief, but the injuries to the patient can be significant, and are often underestimated. Direct injury to the mucosa of the upper airway is common, but the lower tracheobronchial tree can also be burned extensively, particularly if there is venting through the tracheal aperture during formation of a tracheostomy.[7] Such injuries predispose patients to:

- Infection
- Loss of fluid and electrolytes
- Heat loss (related to the surface-area of the affected tissues)
- Life-threatening airway obstruction
- Severe inhalational injuries and widespread pulmonary infiltration from the toxins released by burning materials (especially plastics)[5]

Patient prognosis following an airway fire is guarded and is dependent upon the extent of the fire and the injuries incurred. This can range from no injury/minor insignificant damage to prolonged and complicated stays in intensive care, requiring extensive reconstructive surgery (e.g. tracheal and bronchial stenting of stenoses) and sometimes death - which can be immediate or late.

Prevention of airway fires

The key is prevention rather than management, therefore the anaesthetic, surgical and nursing teams should be aware that fires may occur, identify high-risk situations, know what immediate actions to take, and put in place suitable strategies to minimise risks by focusing on the essential elements of the fire triad.

1. Remove ignition sources

All theatre staff must be vigilant about potential sources of ignition and use safe practices when dealing with electrical equipment. All light source cables (e.g. fibreoptic) should be secured before activation, and all electrical equipment should be placed in standby mode when not in use or when being disconnected.

With regards to safe use of electrocautery:

- It should be avoided where possible, but where absolutely necessary, the lowest effective voltage should be used [8]
- Cutting diathermy mode poses greater risk as it generates higher temperatures than the coagulation mode [9]

- Bipolar is preferable to monopolar diathermy due to an increased risk of electric current leakage with monopolar diathermy. However, ignition can still occur with bipolar diathermy due to arcing at the electrode-tissue interface[10]
- It should be avoided when making the tracheal incision for tracheostomy formation – scalpels, scissors or ultrasound knives are safer and should be used [11]
- It should be avoided when fractional-inspired oxygen levels are above 50% [5]
- It should be operated by a single person

With regards to safe use of surgical lasers:

- The output should be at the lowest clinically effective power density and pulse duration
- The active tip should be:
  - Visible at all times
  - Held away from bronchoscopes and endotracheal tubes before activation
  - Deactivated before removal from the surgical site
  - Placed in a sheath away from the patient when not in use
- Surgical instruments and surrounding surfaces should be non-reflective (matt) to minimise reflection of the laser beam

2. Avoid oxidiser-enriched environments

Flammable gases
Nitrous oxide should be avoided because it supports combustion as readily as oxygen.[1]

Supplemental oxygen
As long as safe oxygenation levels can be maintained in room air alone, supplemental oxygen delivery to the patient should also be avoided. When this is not possible (e.g. in most intensive-care patients undergoing surgical tracheostomy), then the lowest possible fractional-inspired oxygen concentration should be used, starting at 25% and titrating upwards as required.[6] Lower oxygen concentrations have been shown to increase the time to ignition of surgical drapes.[12] Usually, this is achieved by adjusting the inspired oxygen/air gas mixture, although helium has also been shown to reduce the risk of ignition for any given oxygen concentration when compared with nitrogen.[13]

Ideally, supplemental oxygen should be discontinued *at least one minute* before using electrocautery or a laser, which requires good communication between surgeons and anaesthetists. The gases in the oropharynx can be 'scavenged' using a metal suction device, and the surgical field of patients requiring high levels of supplemental oxygen can be flooded with carbon dioxide.

Endotracheal tubes and cuffs
Delivering supplemental oxygen via a closed circuit or secure airway is preferable to an open circuit. Leakage from around uncuffed endotracheal tubes have been shown to contribute towards electrocautery-induced fires,[14] therefore cuffed endotracheal tubes, optimally placed and with a good seal, are preferable.

In most non-airway procedures, cuffs should be inflated to the lowest possible volume necessary to reduce significant leakage. However, in high risk procedures involving electrocautery or laser to the airway, it is prudent to ensure that the cuff pressure is sufficient to eliminate oxygen leakage into the surgical field, especially when the inspiratory ventilation pressures are high – not uncommon in the critically ill patient requiring a tracheostomy.[1]

Efforts should also be made to avoid inadvertent cuff puncture from scattered laser beams or scalpel incision during tracheostomy formation. This can be achieved by ensuring an adequate distance between the cuff of the endotracheal tube and the vocal cords, such that the tip of the endotracheal tube is placed more distally in the trachea than is usual, whilst still maintaining a safe distance from the carina.[15] Additionally, cuffs can be filled with saline to avoid ignition in the event of cuff puncture.[16]

Draping of surgical site
Particular care must be taken with surgical drapes, to avoid accumulation of oxidiser-enriched gases near the surgical site. One option is to use specially designed adherent incise drapes to isolate the incision site from the atmosphere. Another option is an open arrangement of drapes over the rest of the patient, which can reduce the pooling of oxygen.[17] Furthermore, air can be delivered separately (at a rate of five to ten litres per minute) to wash out any oxygen that is building up beneath the drapes.

3. Remove potential fuels

The airway device is a source of fuel for airway fires, therefore it is preferable to have the patient breathing spontaneously in room air, or to use an alternative ventilation strategy such as supraglottic/infraglottic jet ventilation or an intermittent-apnoea technique (however, "tubeless" techniques bring problems of their own).

Endotracheal tubes
While no endotracheal tube can absolutely prevent an airway fire,[18] the risk can be minimised through careful tube selection. Tubes made of polyvinyl chloride (PVC) are preferable to those of rubber or silicone because they are slightly less flammable.[19] For airway laser surgery, there are several specially designed laser-resistant tubes including double-cuffed tubes like the *Mallinckrodt Laser-Flex*™ (which has a proximal cuff filled with saline, tinted with methylene blue to alert the surgeon of a rupture, and a second cuff to maintain a secure airway) and the *Bivona Fome-Cuff*® (with a sponge cuff to maintain the seal in the case of rupture). A less expensive alternative to these specially designed endotracheal tubes is to utilise metallic foil for endotracheal tube wrapping, e.g. *Sheridan Laser-Trach*® although the cuff remains vulnerable in this case.[6]

Other measures
Other steps to minimise the risk of ignition include:

- Soaking up any pooled or spilled flammable agents
- Allowing alcohol-based skin preparation solutions to dry fully before applying drapes
- Applying water-soluble gels to the patient's facial hair and head hair
- Moistening surgical pledgets, sponges, gauze and anaesthetic throat packs with water or saline[1]
- Keeping wound drains, packs and dressings, suction catheters, breathing circuits, nasal cannulae and scavenging tubes as far away as possible from the surgical field

MANAGEMENT

Effective management of airway fires depends on the immediate and coordinated actions of the anaesthetist, surgeon and nursing staff. Theatre team members should be pro-active and immediately adopt their previously assigned and rehearsed roles – *without* waiting for other team members to take action. The pre-determined sequence of actions will prevent significant injury to patients and staff members. Effective management steps include:

1. Maintaining vigilance

Early recognition of an airway fire is crucial. Early signs, delineated from case reports, include: a flame or flash, an unusual sound (a pop or a snap), an odour, unexpected smoke or heat, unexpected movement or discolouration of the breathing circuit or surgical drapes, and unexpected movement of the patient.[1]

2. Immediate coordinated response

The coordinated response should involve the following:

- Whoever notices the fire first must announce it out loud *immediately*
- The **surgeon** should stop the procedure *immediately* (with cessation of lasers and electrocautery) and remove any endotracheal tube/other airway device
- The **anaesthetist** should stop the flow of all airway gases by disconnecting the breathing circuit (temporarily)
- *Another* **team member** should extinguish the fire by flooding the site with sterile saline or water (a container of saline or water and wet swabs must *always* be available on the instrument trolley for this purpose)
- The **surgeon** should remove any segments of burnt airway devices or smouldering debris
- The **anaesthetist** should re-establish a secure airway (or commence facemask ventilation) using room air *only*, initially, via a self-inflating bag
- If the fire remains active, theatre staff should use a carbon dioxide extinguisher *without* delay, whilst another team member activates the fire alarm
- If the situation *remains* unsafe for the patient *or* staff, the theatre should be evacuated, and a full fire-drill implemented

3. Next stage of care

When the environment has been made safe, any bleeding should be controlled. The airway should be examined thoroughly for residual materials, assessed for thermal or smoke inhalational injuries, and the appropriate treatment instituted. The rigid bronchoscope is preferable[1] to the flexible bronchoscope for assessing the airway.

All airway devices and equipment should be retained for examination, and endotracheal tubes should be closely inspected to ensure no fragments have been left behind in the patient's airway.

If the fire was significant, it is recommended to keep the patient's trachea intubated and lungs ventilated, with transfer to the intensive care unit for bronchoscopy, lavage and ongoing assessment of their respiratory function, as any lung injuries incurred may worsen over the following forty-eight hours. Other post-operative management may include dexamethasone for reducing airway oedema, and humidified oxygen.[6]

4. Reporting adverse events

Local protocols should be followed for reporting adverse events. A clear, understandable fire safety protocol should be in place throughout the institution, and easily visible in areas where a fire triad may occur. All multidisciplinary team members should receive regular formal fire-safety education, including fire drills and simulations.[1]

SUMMARY

- An airway fire results from the combination of three elements comprising the fire triad: an ignition source, an oxidiser, and a fuel source
- The extent of thermal and inhalational injuries to the tracheobronchial tree is often underestimated, so thorough bronchoscopic assessment is needed to enable appropriate treatment and follow-up
- Prevention of fires depends on the vigilance and shared responsibility of all theatre staff acting in a simple coordinated fashion, without hesitation
- All staff must be well-rehearsed and have specific roles assigned in advance

ANSWERS TO QUESTIONS

1. The use of the following may pose significant safety concerns during airway surgery**:**

a. **True:** supplemental oxygen (especially in high concentrations) is often implicated in airway fires, due to the creation of an oxidiser-enriched environment
b. **True:** nitrous oxide supports combustion as readily as oxygen
c. **False:** helium reduces the risk of combustion for any given oxygen concentration when compared with nitrogen
d. **True:** closed breathing circuits are preferable because they minimise leakage of oxidiser-enriched gases into the surgical field
e. **False:** carbon dioxide fire extinguishers are recommended for second-line management of airway fires, and can also be used to flood the surgical field when high supplemental oxygen concentrations have been used

2. With regards to the immediate management of an airway fire**:**

a. **False:** the first step in managing an airway fire is to declare its presence aloud
b. **False:** the recommended method of extinguishing an airway fire is to flood the area with sterile water or saline
c. **False:** immediately after extinguishing a fire, it is safest to ventilate the patient in room air, providing titrated supplementary oxygen only when it is necessary to maintain adequate oxygenation (in order to minimise the risk of further combustion)
d. **False:** the surgeon is the most likely staff member to remove any airway devices because of their immediate proximity to the patient's airway; airway devices must be removed *without hesitation* if a fire occurs
e. **False:** if initial measures fail to extinguish the airway fire, the use of a carbon dioxide fire extinguisher is recommended

3. With regards to the morbidity and mortality associated with an airway fire**:**

a. **False:** direct thermal injuries to the immediate airway mucosa may be most apparent, however there may also be injury to the distal part of the bronchial tree from venting or from toxins released from burned materials
b. **False:** rigid bronchoscopy is recommended for evaluating injury to the bronchial tree; a chest x-ray should also be performed routinely although it is not very useful in the acute setting
c. **True:** mortality is extremely rare, however morbidity may be significant; all efforts must be made to minimise secondary injuries through careful evaluation of the extent of any injuries to guide appropriate management
d. **True:** injuries are often underestimated at the time of the fire; if the fire is significant, the safest approach is to keep the patient's trachea intubated and lungs ventilated to enable proper assessment and further management in the intensive care unit
e. **False:** even the correct usage of a laser-resistant endotracheal tube cannot fully eliminate the risk of an airway fire

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