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Review

Airway fire during tracheostomy: prevention strategies for surgeons and anaesthetists

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Airway fires are an uncommon but real and devastating complication of tracheostomy. One such fire in a 31-year-old man is described. Surgical fires are discussed, and 15 reported cases of tracheostomy fire are reviewed. A tracheostomy protocol, adopted by our department and designed to avoid this life-threatening complication, is described. Surgeons and anaesthetists involved in tracheostomy must understand the fire hazard and how to avoid it.

Key words: Fire – Tracheostomy – Airway – Surgery – Anesthesia – Anaesthesia

Although flammable anaesthetic agents are no longer used, fires in the operating theatre continue to be an occasional hazard, particularly with operations on the airway.[1–4] Thankfully, most such fires are evanescent and cause no harm, but unfortunately deaths do still occur. For example, in the two separate fatalities reported by Stouffer,[5] the fires spread uncontrollably with alarming speed and in one case the operating theatre had to be evacuated. Interestingly, tracheostomy fires tend not to be as catastrophic as other airway fires, possibly because the tracheostomy acts as a vent.[6,7]

In this article, we describe a tracheostomy fire experienced by the authors and draw attention to 15 similar cases reported in the literature (Table 1).[6,8–19] We discuss causative factors and suggest precautionary measures. For reviews on theatre fires see Macdonald,[2,3] ECRI,[1,20–22] Quincy,[23] Sidebotham *et al*.[24] and de Richemond and Bruley.[25,26] Complications associated with tracheostomy are discussed by Waldron *et al*.[27] and Wood.[28]

Case report

A 31-year-old man was admitted with respiratory failure due to obstructive sleep apnoea associated with morbid obesity (235 kg). Since a prolonged period of ventilation was expected, a tracheostomy was performed in a standard manner under general anaesthesia. However, in view of the obesity, the trachea was at a considerable depth (approximately 10 cm) and it was difficult to

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Table 1 Case reports of airway fire during tracheostomy

Author	Mechanism	Diathermy mode	Oxygen source	Oxygen conc	Action	Burns site	Burns severity
Bowdle *et al*. (1987)[8]	Divided thyroid isthmus	NK	Percutaneous transtracheal	100%	Drapes removed	Right neck Anaesthetist	2nd degree 2nd degree
Le Clair *et al*. (1990)[9]	Bleeding tracheal vessel cauterised	NK	ETT	100%	Manual pressure	Trachea	Superficial
Bailey *et al*. (1990)[10]	NK	NK	ETT	100%	Wet swabs	Trachea	Superficial
Mandych *et al*. (1990)[11]	Subcutaneous fat cauterised	Coagulation	Face-mask (LA)	5 l/min	Drapes removed	Chin, neck	Partial thickness
Aly [et al]. (1991)[12]	Incised trachea	NK	ETT	NK	NK	Trachea	Superficial
Lew *et al*. (1991)[13]	Incised trachea	Cutting	ETT	100%	Manual pressure, Saline down ETT	Hypopharynx, trachea	Death: 13 days
Marsh & Riley (1992)[14]	Incised trachea	Coagulation	DL ETT	100%	Wet swab	Skin	'Charring'
Wilson *et al*. (1994)[15]	Incised trachea	Cutting	ETT	100%	Manual pressure	None	None
Michels *et al*. (1994)[16]	Incised trachea	NK	ETT	100%	NK	None	None
Lim *et al*. (1997)[17]	Bleeding tracheal vessel cauterised	NK	ETT	100%	Saline to wound	None	None
Chee & Benumof (1998)[6]	NK	Coagulation	ETT	100%	Saline down ETT	Skin	Superficial
Thompson *et al*. (1998)[18]	Bleeding tracheal vessel cauterised	Coagulation	Bronchoscope	50%	Manual pressure	Lower neck	2nd degree
Thompson *et al*. (1998)[18]	Bleeding tracheal vessel cauterised	Coagulation	ETT	NK	Manual pressure	None	None
Thompson *et al*. (1998)[18]	Bleeding tracheal vessel cauterised	Blend	ETT	100%	Wet swab	None	None
Baur & Butler (1999)[19]	Incised trachea	NK	ETT	100%	Manual pressure, saline to wound	Larynx, epiglottis, trachea	Death: instant

NK, not known; ETT, endotracheal tube; DL ETT, Double-lumen endotracheal tube; LA, local anaesthetic.

control completely the persistent oozing of blood from the intervening adipose tissue with diathermy. Following a period of 100% oxygen, the 2nd, 3rd and 4th tracheal rings were divided vertically with a scalpel.

The PVC endotracheal tube was then partially withdrawn so the tip was just above the tracheal hole, and manual ventilation was temporarily suspended. At that moment, a small bleeding vessel on the edge of the tracheal incision was diathermied (monopolar coagulation) and the operative field ignited, producing a 50 cm jet of flame arising vertically from the wound. The endotracheal tube was quickly disconnected from the anaesthetic machine. Attempts were made to extinguish the fire using the drapes and manual pressure. However, a small flame persisted and this was quickly extinguished by emptying a bowl of sterile saline over the wound site. The wound was quickly sucked dry. The endotracheal tube was pushed further down the trachea so the cuff was below the tracheal hole. The cuff on the endotracheal tube had not been damaged and the patient was able to be ventilated adequately, The endotracheal tube was then partially withdrawn again, and a tracheostomy tube inserted uneventfully.

Flexible bronchoscopy revealed no visible airway damage. The patient suffered no subsequent airway problems. The tracheostomy was ultimately removed and the patient discharged from hospital.

A significant factor (apart from the diathermy and 100% oxygen) is thought to have been the unusually deep and fatty tracheostomy wound, which may have allowed a flammable/explosive mixture to build up during intermittent diathermy. It is well-known that gases arising from diathermied fat will burn when made hot enough or if mixed with sufficient oxygen.[22]

Discussion

Although tracheostomy is a relatively common surgical procedure, airway fire is not usually listed among the intra-operative complications in standard texts, and many practitioners may not fully appreciate its potential to occur.[28,29] The three elements of an airway fire are the fuel (*e.g.* endotracheal tube, drapes, swabs, alcoholic solutions, vapourised adipose tissue), a source of oxygen (*e.g.* oxygen, nitrous oxide) and heat (diathermy, laser, static electricity, hot light bulb).[30,31] During a tracheostomy, unlike other airway surgery,[32] these three elements can usually be kept quite separate from one another and so this operation is not generally considered to carry a high fire risk.[10]

These three elements are now considered in turn, attention being focused on those relevant to tracheostomy.

Oxygen

Oxygen, of course, will always be present, but the inspired oxygen concentration (FIO_2) should be as low as possible commensurate with an adequate oxygen saturation.[33–35] Some authorities even suggest using only air during the critical period, but this is usually unrealistic. While the usual method is to adjust the FIO_2 using an air/oxygen mixture,[10,16,19,35] helium has been shown to be significantly better than nitrogen in reducing the likelihood of ignition for a given oxygen concentration.[36]

Although the risk of tracheostomy fire is reduced with a lower FIO_2, care still needs to be taken since one reported case occurred using 50% oxygen[18] and experiments demonstrate that endotracheal tubes can be ignited in an atmosphere of 25% oxygen.[37] In practice, many patients undergoing tracheostomy are also critically ill and require a high FIO_2.[14,17] Furthermore, in view of the potential for a period of apnoea during the operation, anaesthetists commonly switch to 100% oxygen just before insertion of the tracheostomy.[15,17]

Note that nitrous oxide supports combustion as readily as oxygen[35,37] and should not be used during potentially high risk periods.[38]

Fuel

Endotracheal tubes are generally made of PVC because of their low implant toxicity and pliability. PVC endotracheal tubes are known to ignite in an oxygen-rich environment but are flammable in oxygen concentrations as low as 25%.[25,33] PVC is slightly less flammable than the currently available alternative materials of rubber or silicone.[33] Perhaps fire-resistant tubes should be used routinely during tracheostomy, as in laser surgery. For example, in a trial of PVC, red rubber, and laser-resistant tubes, Sosis and Braverman showed that the silicon/metallic LaserShield endotracheal tube (Xomed, Jacksonville, USA) was the only tube not to be ignited by electrocautery.[34]

It is essential that only cuffed endotracheal tubes be used in tracheostomy in order to prevent oxygen leaking into the zone where the hole is made in the trachea.

Consequently, efforts should be made to avoid puncturing the cuff, for example by pushing the tube further down the trachea close to the carina before making the tracheal hole.[14,15,17] This may require using a particularly long tube and using a fibre-optic bronchoscope to check that the tube is as far down as possible without entering one of the bronchi. Double-lumen tubes are contra-indicated as the tracheal cuff cannot be advanced sufficiently close the carina.[14] If a double-lumen endotracheal tube is in place, then it should be changed for an appropriate single-lumen tube before tracheostomy. A further precaution is to inflate the tracheal cuff with saline to prevent ignition should the cuff be punctured by diathermy.[39]

Although the older flammable and/or explosive anaesthetic agents (ether, cyclopropane, ethylene, ethyl chloride) are no longer used in the UK, it may be necessary for surgeons in some countries to check that they are not being used.

Heat

Cutting, coagulation and blend modes of diathermy are all known to have caused airway fires (Table 1). In practice, the risk of diathermy causing an airway fire before the trachea is incised is minimal if a cuffed endotracheal tube is *in situ*. Obtaining a meticulously dry field prior to opening the airway is imperative.

The trachea should be incised with either a scalpel, scissors or harmonic (ultrasonic) knife.[40] There is no reason to use diathermy to incise the trachea since, in addition to the fire hazard, diathermy is neither efficient in cutting through calcified tracheal rings nor effective at preventing bleeding from the mucosa.[41]

Cutting mode diathermy is particularly hazardous as it generates higher temperatures than coagulation mode.[8] Even coagulation mode on a low-power setting is known to have caused two fires[18] and cannot be recommended.[17] Bipolar diathermy is recommended by some authors as being a safer alternative,[10,12] but the risk of ignition is still present since some arcing or sparking at the electrode-tissue interface is possible.[17]

Unfortunately, the dangers associated with diathermy appear not to be widely appreciated.[42]

Recommendations

1. All theatre staff should be aware that an airway fire may occur during tracheostomy. Have a bowl of saline and drapes available on the surgical instrument trolley at all times.[19] Have a fire extinguisher immediately available. In practice, a carbon dioxide fire-extinguisher will be the usual choice. Halon fire extinguishers are significantly better for operating theatre fires but their use is declining owing to environmental concerns.[1,22]
2. Have a self-inflating ventilation bag (*e.g.* Ambu bag) available in case it becomes necessary to ventilate the patient with room air.
3. Do not use nitrous oxide or any of the flammable/explosive anaesthetic agents.
4. Use a single-lumen endotracheal tube which is long enough to allow the tip to be advanced to the carina (the carina is approximately 24–25 cm from the teeth in an average male). Change any *in situ* double-lumen endotracheal tube for a single-lumen tube before tracheostomy.
5. Use saline to inflate the endotracheal cuff. Make sure there is no leak of anaesthetic gases past the endotracheal cuff.
6. Use the lowest safe FIO_2 in either nitrogen (air/oxygen mixture) or helium.
7. If the tracheostomy wound is significantly deep (*e.g.* in an obese patient), use a suction device to clear any build up of diathermy products from within the wound.
8. Before the trachea is opened, advance the endotracheal tube down the trachea so the tip is close to the carina in order to minimise the likelihood of damage to the cuff when the trachea is incised. Consider using a fibre-optic bronchoscope to position the tip of the endotracheal tube close to the carina. If the tube is too short, consider changing it for a longer one.
9. Control all bleeding points and obtain a meticulously dry operative field. Incise the trachea using either a scalpel, scissors or a harmonic knife. Never use diathermy to cut through the trachea.
10. Once the trachea has been opened and the surgeon is ready to insert the tracheostomy tube, stop ventilating, deflate the endotracheal tube cuff and withdraw the endotracheal tube carefully under direct vision until the tip is just above the tracheal hole (do not remove the tube completely at this stage). Be prepared to push the endotracheal tube back down the trachea to secure the airway if there are any difficulties, either while inserting the tracheostomy, or during the initial ventilation through the tracheostomy.
11. If bleeding occurs once the trachea has been incised, first ensure that the airway is secured with either a tracheostomy or endotracheal tube with the cuff inflated. If there is cuff leak from the trachea, then temporarily stop ventilation and ligate or suture. If unavoidable, use bipolar diathermy while using suction to clear oxygen and products from the wound.[18,34] Consider pushing damp swabs into the wound to occlude any air leak.
12. Once the tracheostomy tube is secure in the trachea, inflate the tracheostomy cuff and suck out the tube using a suction catheter, checking that the suction tube passes easily through the whole length of the tube. If this is satisfactory, then commence ventilation through the tracheostomy.
13. In the event of fire, immediately disconnect the patient from the anaesthetic machine, switch off the anaesthetic gas flow, disconnect the gas pipelines and ventilate with room air using a self-inflating bag.[7] Use an airway filter if there is smoke in the theatre. Extinguish the fire. Consider flushing saline down the endotracheal tube to extinguish any intraluminal fire.[43] Consider removing or changing the tube to minimise the inhalation of toxic products of combustion and spread of fire into the tracheobronchial tree.[7,9,12,44] However, changing the tube may be more risky than leaving it in if the patient was previously difficult to intubate or the airway has become oedematous.[6]

Conclusions

Tracheostomy is an operation performed by a variety of surgical specialities. Airway fires during tracheostomy do occur and all clinicians involved in this procedure should be aware of the causes of airway fires and how to prevent them.

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