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Endotracheal tube fires still happen – A short overview

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Abstract

Laser generated operating room fires have been reported ever since lasers have been used for therapeutic indications. This occurs because, when an ignition source such as the laser, is used in the vicinity of high oxygen concentrations, and materials, such as the endotracheal tube (ETT), can then be easily ignited. This paper shows examples of ETTs after such a fire, together with the severe injuries incurred. Even though over the years a great deal of experience has been collected in the management and handling of these patients, accidents with ETT fires still occur.

Many different materials have been tested for ETTs with regard to their incendiary characteristics, and special constructions of ETTs for use with lasers have been developed accordingly. Whereas wrapping the ETT with metal foil gives a false sense of safety, the so-called 'laser-tubes' exhibit an increased resistance to damage by laser radiation. However, even using these, ETT fires have still occurred due to contamination with blood or because the laser has hit the connection of the cuff with the shaft of the tube. These particular aspects have recently been investigated, and international standards are being prepared, which will hopefully promote the development of proven laser-suited ETTs in an effort to reduce the frequency of these severe accidents.

Keywords: Endotracheal tubes; Airway fires; Laser tubes; Cuff; Standardization

Introduction

The most severe accidents occurring during medical laser applications are fires of the endotracheal tube (ETT) in the patient's airways. The mechanisms of such catastrophic events have been investigated for more than a quarter of a century. The comprehensive "Surgical Fire Chronological Bibliography 1949–2009" [1] even includes publications from the decade before the laser was invented. Electrosurgical devices were the ignition source then and also in recent years electrosurgical or radiofrequency devices have been the most frequent reason for ETT fires in Germany [2]. In addition to a number of operating room fires caused by other ignition sources, such as endoscopic light sources and defibrillators, a large number of publications deal with laser generated fires. These occur easily in procedures on or close to the body surface, such as in dermatology [3], eye surgery [4], facial [5] and maxillofacial surgery [6] or neurosurgery [7], as well as in endoscopic procedures in gastroenterology [8],

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laparoscopy [9] or proctology [10]. The most frequent and hazardous fires however, occur during laser treatments of the pharynx, larynx or trachea [11–16] respectively at the site of a tracheostoma [17–22]. These are examples of ETT fires with the CO_2 laser. However, other lasers have also been reported as ignition sources such as the Nd:YAG laser [23–28], the frequency-doubled Nd:YAG laser, often called "KTP" laser [29], the diode laser [30] and the dye laser [31–33]. Although many of these publications date back to the 1980s and 1990s, more recent accidents have been statistically evaluated [34], and there are new reports on ETT fires with the diode laser [30], CO_2 laser [35] or "KTP" laser [36] in the years 2006–2009 from the Far East and developing countries.

Technical and procedural causes of ETT fires

The so-called 'fire-triad' requires that three elements come together to develop into a surgical fire [37], which incidentally was number 5 in the Top 10 of Health Technology Hazards in 2008 [38]:

(1) An oxidizer (such as oxygen or nitrous oxide),
(2) An ignition source (lasers, electrosurgical units, fiber optic light sources, defibrillators, etc.)
(3) Fuel (solid, liquid or gaseous material, oxidizing in exothermal chemical reaction):
  (a) Endotracheal tubes, other tubing, drapes, gauzes, plastic or textile material,
  (a) Alcoholic solutions, volatile compounds such as ether or acetone, anesthetic gases,
  (a) The patient's hair, skin, gastrointestinal gases, tissue carbonized by thermal treatment.

There are numerous other examples that can be added to each of these lists. A normal room atmosphere with about 21% of oxygen will maintain a fire. However, the higher the oxygen concentration, the easier it is for a fire or explosion of fuel substances to be ignited by an ignition source. Such conditions occur easily in the medical environment, where various ignition sources are used in the proximity of an oxygen-enriched atmosphere. This is classified as a "high-risk procedure" by the Task Force on Operating Room Fires in the American Society of Anesthesiologists [37]. A distinction is made between operating room fires occurring on or near the patient, surgical fires occurring on or in the patient, and airway fires occurring in the patient's airways or the attached breathing circuit.

The plastic material of ETT and other tubing absorbs the energy of the laser beam either directly or when contaminated with blood. The concentrated oxygen flow in the ETT results in immediate combustion of the tube. Some materials such as polyvinyl chloride (PVC, melting point: 100–260 °C) have relatively low melting temperatures and can generate a tremendous combustion energy of approximately 18 kJ/g [39]. At 100% oxygen flow, a torch-like flame of 10–15 cm length is generated (Fig. 1). The tube decomposes rapidly and the inside of the tube is completely covered with soot (Fig. 2) [40].

When an ETT fire with torch-like flame and destruction of the tube happens during the treatment of a patient, it is one of the most traumatic events in laser medicine. The flame is directed into the patient's airways; pieces of decomposed tube material may drop as foreign bodies into the patient's airways or lead to a toxic gas impact. The pressure wave of a sudden flame transports combustion products into distal areas of the lung and causes pathologic reactions. Hydrogen chloride (HCl) gas from the thermal degradation of PVC combines with the humidity of the lung mucosa, to form hydrochloric acid, which destroys the alveoli. In addition to the fire accident, both the foreign bodies and the toxic gases present an additional hazard due to combustion products and laser generated air contaminants (LGACs) [41–43].

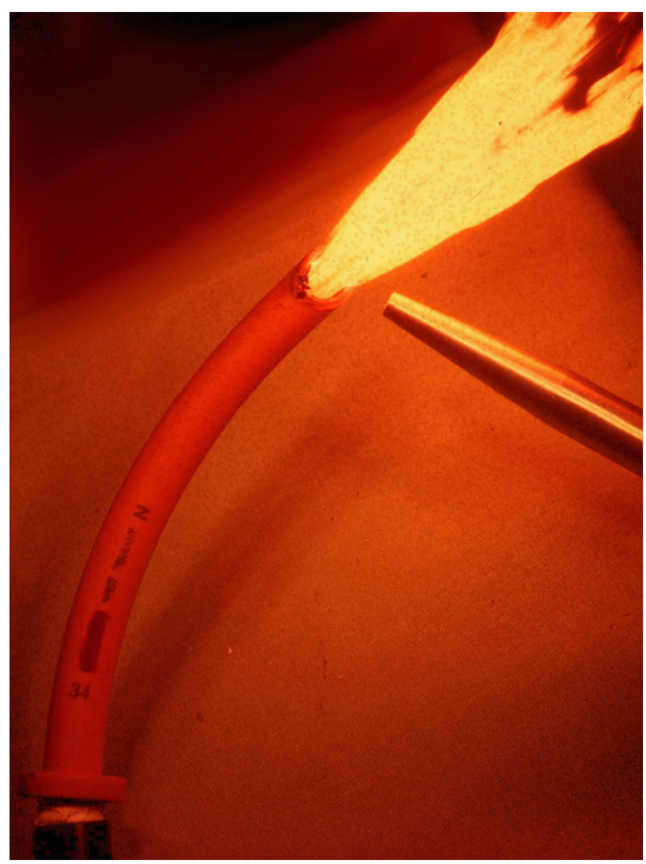

Fig. 1. Red rubber tube with 100% oxygen flow, ignited with 2 W argon-ion laser radiation.

Three documented cases

ETT fires and their consequences can cause the patient's death [43]. It is therefore remarkable that the majority of patients involved in ETT fires in fact survive the accident [34]. In Fig. 3 part of a patient's face is shown after an ETT fire which was caused by an electrocautery device [40]. Even though the cheeks, lips and moustache, nose and tongue, together with the pharyngeal and laryngeal mucosa, were severely burnt, the patient recovered without consequential damage.

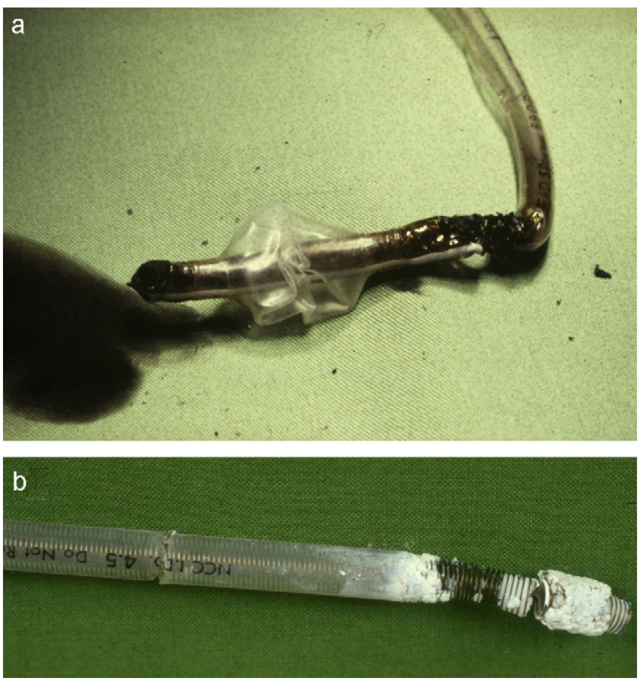

Fig. 2. ETT after experimental ignition. (a) PVC tube and (b) silicone tube.

Fig. 3. A patient's mouth and surrounding area after an ETT fire.

In another case [44], a patient who had previously had surgical treatment for laryngeal cancer, opted for CO_2 laser surgical treatment in order to avoid a laryngectomy. During this procedure an ETT fire occurred, causing extensive burns to his oro- and hypopharynx, larynx and upper trachea (Fig. 4). During stationary care following the incident, the patient received daily endoscopic documentation of his status. Large areas of the mucosa in the oro- and hypopharynx, as well as in the larynx, were covered with fibrinous layers after the burn. Despite adequate analgesic medication, it was not possible to ensure the patient was getting sufficient oral nutrition, and major uptake of nutrients was effected via a nasogastric tube. However, the injuries caused by the ETT fire were so severe that he had to undergo a laryngectomy several months later, because of his dysphagic ailments and the pain he was still suffering.

In a third case, this time of a tracheal papilloma, an Nd:YAG laser was applied via a glass fiber inserted into a flexible endoscope, which was introduced through the ETT. During laser ablation, combustion occurred and the patient was rapidly extubated. After a period of intensive care, he recovered from the accident. The instrumentation set used [45] is shown in Fig. 5. The ETT is filled with soot, and the distal end of the endoscope has burst; the distal fiber end is broken into pieces. The heat shrink tubing of the fiber connector is torn off, which is something that may happen, especially if the fiber which is classified for single use, is re-sterilized. Inert gas, which passes near to the fiber connector to rinse the fiber at the distal end, does not reach the fiber end, but escapes via the torn off heat shrink tubing. Instead, with a high concentration of oxygen, i.e. 90%, air in the patient's trachea will creep from the distal end into the space for rinsing the fiber, but now without inert gas flow. If not rinsed, a drop of blood or tissue debris can easily contaminate the distal fiber end and will be heated to glowing with the next laser pulse, and the plastic fiber cladding will be ignited in the oxygen-enriched surroundings. As long as there is enough oxygen available, this burning will go back up into the fiber and will heat up the black sheath of the endoscope, releasing carbon particles until an explosive mixture develops and detonates.

Management and patient care

In all such severe accident cases, the main concern is the appropriate care of the patient, who is usually transferred to the intensive care unit and subjected to a lavage of his airways. The removal of all foreign bodies produced by the fire is of major importance. Detailed guidelines for the management and the care of the

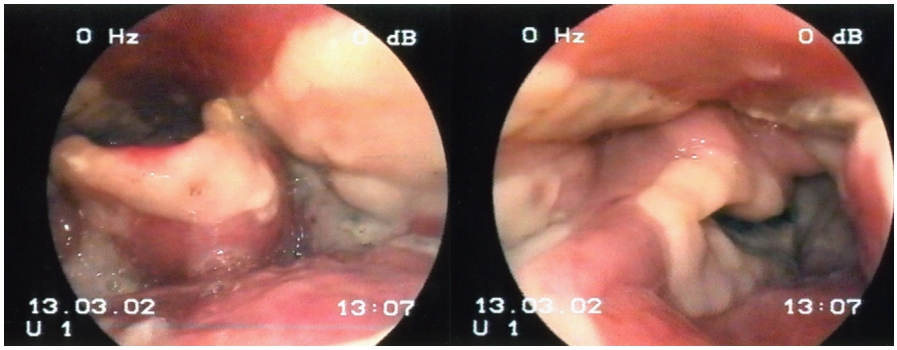

Fig. 4. Endoscopic documentation of mucosal burns after an ETT fire on the left side of the epiglottis (left) and from the epiglottis to below the vocal cords in the trachea (right).

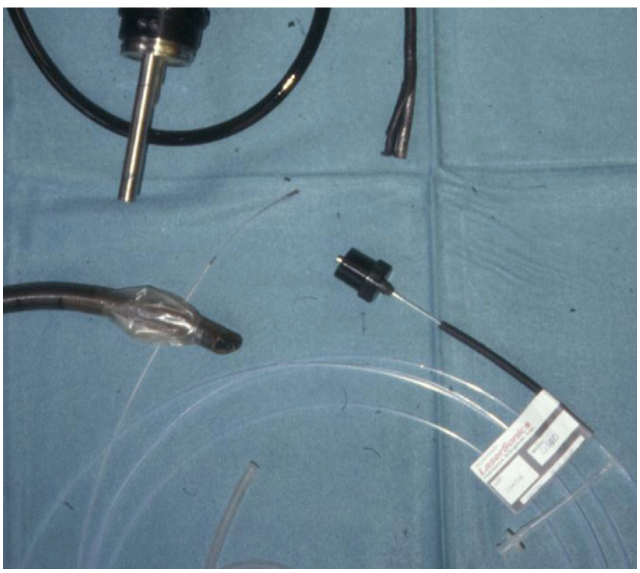

Fig. 5. Instrumentation set for Nd:YAG-laser surgery of a tracheal papilloma, after the combustion. The ETT is filled with soot, the distal end of the endoscope has burst, the distal end of the fiber is broken, and the sheath of the fiber has been torn off the fiber plug connector.

patient after an ETT fire were published as early as 1981 [46]. The use of other lasers was also covered [26], and improved knowledge [47] was also included in a technical report of the International Standardization Organization [48]. However, ongoing experience with ETT fires has led to the development of further recommendations [49], with consideration of the special conditions in pediatrics [50], and finally to a clinician's explicit guide entitled ''A clinician's guide to surgical fires'' [51].

In the discussion of the cases demonstrated above the question that arose was 'What has been learnt from the accidents?' [45]. However, six years later, more ETT fires were documented [44] and statistically evaluated. A university-based inquiry for cases of ETT fires at 152 ENT-departments in Germany was responded to by 86 clinics covering 20,000 laryngeal CO_2-laser surgeries from 1976 to 2001. Fifteen ETT fires were observed, two of them had been fatal, and another two resulted in long-term complications [34]. However, since only device failure reports are compulsory, there are probably quite a number of unknown cases of ETT fires. In the USA, the Food and Drug Administration (FDA) has various data bases, Medical Device Reports (MDR) up to 1996, and later on the 'Manufacturer and User Facility Device Experience Database' (MAUDE). There were 13 cases of ETT fires found from 1991 to 2001, at least two of them fatal [51,52]. Taking recent publications [36] into account, it has to be said that ETT tube fires still occur. There is increased knowledge of the mechanism of such events documented in the literature and databases on this issue, and the necessary management and care for the afflicted patient in these cases has significantly improved. But after a more recent ETT fire, it was asked, 'When will such accidents cease?' [53].

Attempts to protect the tube and laser tubes

It was found that CO_2-laser radiation ignites ETTs of different materials [40], something which was confirmed in later investigations [54], and also again recently [55]. As a consequence, it is less hazardous, if the general anesthesia is carried out with jet ventilation, and an ETT is not used at all. This procedure, however, may only be applied, if the patient's condition allows it. The jet ventilation should be strictly applied alternately with the laser application, otherwise the strong air flow will press combustion products, generated by the laser-tissue interaction, deep into the patient's airways and lungs. Particularly in the case of virus infected tissue, as with papillomas, this would widely disseminate virus carrying particles [56]. However, airway fires have been observed even, when jet ventilation has been used [57,58]. This can only be completely avoided

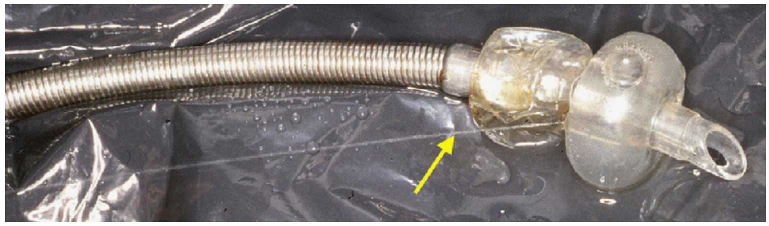

Fig. 6. Metal ETT with two cuffs (Mallinckrodt Laser-Flex®); the proximal one (left) being deflated, the distal one (right) is perforated and ejects saline (arrow).

with subglottic jet ventilation or, as suggested for endoscopical laser application, with the airflow in the auxiliary line of the laser fiber [59].

Already after the first ETT fires, users tried to protect the plastic or rubber material of the tube against the impact of laser radiation. For this purpose, metallic tapes were wrapped around the ETT [60]. However, there are strong arguments against the use of metallic tapes [61], since the sharp edges of the tape may cut into the mucosa [34]. Moreover, the tape can move a little, when the tube is being inserted, leaving parts of the tube surface unprotected. This can lead to a false sense of security. Remarkably, the use of metallic tape was still being suggested in 2004 [62]. There were also various foils compared, using the "KTP" laser [63]. Only when the metal foil is industrially fixed and covered with fabric [64] or Merocel® foam [65], which has to be soaked with saline, is there a definite safety advantage.

As early as the 1980s, various products of so-called 'laser-safe ETT' were brought on to the market, and their incendiary characteristics were investigated [66]. The improvement of resistance against laser radiation is different [67], but with better resistance, e.g. with metallic tubes [68], the ETT often is less flexible and has a smaller inner diameter. The safety of a number of products was compared [69] and the laser resistance evaluated [70]. Meanwhile, test methods to determine the laser resistance of the shaft of ETT suited for laser application have been standardized [71].

The most vulnerable part of an ETT is the cuff, a balloon at the distal end of the ETT, which is inflated after insertion of the ETT, in order to block the patient's airway. If the cuff is hit by laser radiation, it bursts, the blockage is lost, and a fire may be ignited [72]. There was a suggestion as early as 1991 to fill the cuff with saline instead of air [73]. At present, most manufacturers of laser tubes specify that the cuff should be filled with saline. This method is also used in products with laser tubes, using two cuffs, one inside the other or in-line. With the latter (Mallinckrodt Laser-Flex®), the proximal cuff is a protection for the distal cuff, which effects the block. Once the proximal cuff is perforated and deflates, the patient needs to be re-intubated, since the next hit of the cuff by the laser beam would end the blocking (Fig. 6).

Another idea was the insufflation of nitrogen into the patient's aerodigestive tract outside of the block [72,74], in order to reduce the flammability due to the lack of oxygen. This approach, however, was not accepted. The question, whether or not wet pledgets protect the cuff [75], was positively answered [76].

Despite all this knowledge, ETT fires have kept on happening, even with the use of "laser-safe" tubes [51,52]. One explanation, obvious in the case of "KTP" lasers, was the contamination of the ETT with blood [77], which is not an uncommon situation during surgery. Also, it was stated for a laser-resistant ETT that it was of no clear advantage [78]. Only in recent years has it become evident that the proximal connection of the cuff with the shaft of the ETT is the weak point, where the impact of a laser beam can cause an ETT fire even with laser-suited ETTs [79]. Therefore, test methods for this fact have been defined and investigated and are described in a new standard as a part 2 of the above mentioned ISO standard [71]: "Optics and optical instruments – Lasers and laser-related equipment – Determination of laser resistance of tracheal tubes – Part 2: Tracheal tube cuffs" [80], which is expected to be published soon.

Conclusion

Secondary hazards during medical laser treatment are no less important than primary hazards due to laser radiation. Especially laser-generated operating room fires on or in the patient can cause the patient's death. Accidents of this scenario have occurred most often with the endotracheal tube, which, once ignited, has caused severe burns of the mucosa in the patient's airways. Many attempts have been undertaken to develop "laser-safe" ETTs. With these, the application of lasers has been improved by reducing the risk of accidents. However, fires have not only happened with laser ETTs, but also during anesthesia in jet ventilation without ETTs. This leads one to the conclusion that extreme precaution is necessary not only, whenever laser radiation is applied in the vicinity of the ETT, but also generally during laser treatments of the upper aerodigestive tract. Surgeons as well as anesthetists should be made aware of this hazard. They should be trained in the prevention of ETT fires together with immediate management of such adverse events. An excellent introduction for this purpose is given in [81]. The publication of new standards should also stimulate the development of new models of proven laser-suited ETTs, which help to reduce a remainder risk.

Zusammenfassung

Endotrachealtubusbrände kommen immer noch vor

Durch Laser erzeugte Feuer im Operationssaal wurden in der Literatur beschrieben, seit Laser für therapeutische Indikationen angewendet werden. Der Grund für solche Brände ist die Situation, in der eine Entzündungsquelle in der Nähe hoher Sauerstoffkonzentrationen angewendet wird, unter der viele Substanzen, wie die eines Trachealtubus' (Endotracheal Tube, (ETT)), leicht entflammt werden können. In dieser Arbeit werden einige durch Feuer beschädigte Tuben demonstriert, ebenso wie die schweren Verletzungen, die Patienten dadurch davontragen. Im Laufe der Jahre wurden viele Erfahrungen im Umgang und der unmittelbaren Versorgung der betroffenen Patienten gesammelt. Jedoch kommt es auch heute noch zu Unfällen durch Tubusbrände.

Viele verschiedene Materialien für ETTs wurden hinsichtlich ihrer Entflamm-Eigenschaften getestet und spezielle Konstruktionen von ETTs für den Einsatz mit Lasern entwickelt. Während die Umwicklung des Tubus mit Metallfolie zu einer vermeintlichen Sicherheit führt, erreichen die sogenannten Lasertuben einen verbesserten Widerstand gegen Zerstörung durch Laserstrahlung. Allerdings kann es auch bei Lasertuben zu einem Feuer kommen, bspw. durch Kontamination mit Blut, oder indem die Verbindungsstelle zwischen Cuff und Tubusschaft getroffen wird. Diese speziellen Aspekte werden in jüngster Zeit untersucht, und internationale Normen werden erarbeitet, die hoffentlich die Entwicklung nachweislich lasergeeigneter ETTs anregen, um die Häufigkeit solcher schweren Unfälle zu verringern.

Schlüsselwörter: Trachealtubus; Atemwegsfeuer; Lasertubus; Cuff; Normung

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