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REVIEW

Cutaneous steam burns and steam inhalation injuries: a literature review and a case presentation

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Abstract

Scald is one type of burn that s often mentioned alone and occurs mostly in the paediatric population. Inhaled steam is mostly cooled off in the airways, why thermal damage is rarely seen. A sudden exposure to hot steam/inhalation can cause a thermal inhalation injury. A scoping review was performed, with the aim to summarize all published papers in English, about steam-related injuries. The search was conducted using the PubMed® and Cochrane libraries on 19th of May 2021, without a set time period. Out of a total of 1186 identified records, 31 were chosen for review. Burns related to the contact with steam are generally rare and can be both minor and severe. The more severe cases related to steam exposure are mostly workplace accidents and the minor injuries reported in the literature are often related to steam inhalation therapy, especially in the paediatric population. This review describes the challenges that can be found dealing with patients suffering from cutaneous steam burns and/or steam inhalation injuries. A steam injury to the airways or the skin can be directly life-threatening and should be treated with caution. This type of injury can lead to acute respiratory insufficiency and sometimes death. A case of a male patient with extensive cutaneous steam burns and a steam inhalation injury who passed away after 11 days of treatment is also presented to illustrate this review.

Level of evidence: Level V, Therapeutic; Risk/Prognostic Study.

Keywords Scalds · Steam burns · Steam inhalation

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Introduction

A burn injury can be defined as a thermal injury where the temperature of the tissue (the skin commonly or any other organ) has exceeded the harmful level and the tissue gets damaged or dies. For the human skin, the pivotal temperature often mentioned is approximately 43 °C [1–3]. Also, the relationship between time and temperature is crucial [4, 5].

The term burn however includes several different types of injuries with different traumatogenesis that can be intentional or non-intentional. There are the obvious flame and contact burns, with the increased temperature as common denominator—not only thermal burns but also friction, chemical, radiation, and electrical burns. Even though these entities have different traumatogenesis and medical courses, the treatments are mainly parallel to the one of thermal burns.

A scald can be viewed as a certain type of contact burn even though they often are mentioned alone. A scald occurs when the skin (or other tissue/organ) comes in contact with hot steam or liquids. Many scalds occur at home and the majority involve the paediatric population [6]. Most scalds in the paediatric population are minor and can successfully be treated in an out-patient setting; scalds can however occur in all ages. Steam inhalation therapy, vide infra, sometimes causes scalds and a number of cases have been reported during the last decades [7–10].

Inhaled steam, or hot air, is usually effectively cooled off in the airways, why thermal damage is rarely seen below the glottis. Explosive combustion and presence of hot steam,—especially if induced with pressure or during an inhalation/gasp—can create a situation where the capacity of cooling down the inhaled air is exceeded and thermal inhalation injury occurs even below the glottis. Scalds in the facial region should increase the suspicion of inhalation of hot air/liquid.

The, since long, used steam inhalation therapy is supposed to treat/prevent upper respiratory tract infections (URTI) as common cold or bronchiolitis. Steam inhalation therapy was recommended as early as 1926 by the Surgical Catalogue, to be used with water pipes or kettles for inhalation [11]. This briefly helps a blocked nose but shows no curative effect on common colds according to a Cochrane review [12]. Reports of scald injuries related to steam inhalation therapy have, however, been described in numerous papers, rarely involvement of the respiratory tract is seen. [7–10, 13–22].

Pathophysiology of steam burns and steam inhalation injuries

Inhalation injury is a broad term that includes tissue damage as well as systemic toxic effects due to inspiration of steam or combustion products such as smoke and its contained chemicals. The presence of an inhalation injury can be suspected not only from the patient history, for example in the event of smoke exposure in an enclosed space, but also from clinical findings such as burns to the face and mucosa of the nose and mouth, as well as carbonaceous sputum and changes in the voice. Bronchoscopy is usually required to confirm the suspicion [23]. The definitive diagnosis, however, is somewhat subjective and requires an experienced clinician.

A concomitant inhalation injury is associated with a worse prognosis in burn patients, with longer hospital stay and higher mortality. The more extensive the burn is, the higher the risk of a concomitant inhalation injury. In patients with a burn extent < 20% total body surface area (TBSA), the prevalence of inhalation injury is approximately 2%. In patients with a burn extent > 80% TBSA, however, the prevalence is > 14% [24], in some reports as high as 85% [25, 26]. Difficulties in diagnosing inhalation injury likely contributes to the variation in reported prevalence. Three clinical types of inhalation injury exist (and can exist together):

Upper airway injury (above glottis)

Airways above the larynx, i.e. the uvula, pharynx, and epiglottis, are damaged. The tissues may swell considerably and thus this always involves the risk of acute total upper airway obstruction. Inhalation of hot gases, hot liquids, or chemicals is usually the traumatogenesis.

Lower airway injury (below glottis)

Epithelial damage, inflammation, abundant secretion, and obstruction occur when injurious substances reach below the larynx and the airway and lung parenchyma can be damaged.

Toxic effects

Inhalation of toxic gases results in more systemic effects. The scope of the damage depends on factors as, e.g. solubility and concentration of the toxic or noxious substances.

Smoke chemicals, larger particles, and hot air often injure the upper airways, while water-soluble materials and smaller particles often also cause damage more distally [27]. The mucosa of the airways is affected by steam similar to other tissue with the heat leading to denaturation of proteins causing complement activation leading to oedema [27]. The upper airway plays an important role in the conditioning of inspired air, in normal circumstances heating and humidifying it. Inhaling dry air, with a low capacity of maintaining heat, makes the upper airways act as a heat exchanger turning most gases to body temperature before they reach the lower airways [28, 29]. Steam, however, allows for inhalation of a greater amount of thermic energy resulting in the ability to transport steam further down the respiratory tract.

Smoke inhalation also increases the blood flow [30] associated with a change in permeability to proteins and small particles as well as changes in pressure conditions leading to inflammation and oedema. These factors together with a smooth muscle hyperreactivity [27] can lead to a life-threatening total obstruction of the lower airways [31, 32]. After the initial acute response, the more long-lasting effects are similar to those of a bronchopneumonia.

Inhalation of heated air with a high humidity, i.e. steam, specifically, is a topic that is less explored. Humid air cools, as formerly explained, slower than dry air/gas when passing down the airway, potentially leading to more heat reaching the lungs with humid hot air [29]. Moritz et al. describe that the heat transfer to the respiratory mucosa when inhaling 500 cc of dry air at 142 °C, assuming that it would be cooled to 38 °C at exhalation and would add up to around 13 cal of heat to the body. This is significantly less than the 200 cal that would be transferred when inhaling the same volume of a steam–air mixture at 125 °C, again assuming that the temperature at exhalations would be 38 °C [29]. In their experimental animal study from 1944, they describe that none of their subjects sustained pulmonary injury from the inhalation of oven-heated air. In the groups inhaling flames from a blast burner and steam, however, the rate of pulmonary injury was as high as 20% and 67%, respectively [29]. The most vulnerable part of the lung seems to be the central part of the parenchyma, due to the direct connection with the primary bronchi [29]. With extensive thermal injury, histopathological analysis shows a destruction of bronchial mucosa and haemorrhagic oedema of peripheral and central lung parenchyma [29]. Aviado et al. also described a rise in aortic blood temperature shortly after the inhalation of steam, reflecting the uptake of heat [33]. They also noted several other physiological changes, including an immediate apnoea and bradycardia followed after a minute by a polypnea and tachycardia [33].

Pathophysiology of cutaneous steam burns

The exact mechanism of skin damage during accidental exposure to steam is not fully understood. Cutaneous steam burns can be due to accidents related to direct contact, e.g. sudden explosions of steam pipes. Another cause of cutaneous steam burn described is when firefighters are exposed to external heat together with sweat in the clothing layers which start to evaporate, and a condensation process occurs on the skin. The condensation of the steam takes place on the colder environment on the skin then the heat of the vaporization of water is released, eventually leading to an increased temperature of the skin which can cause a cutaneous steam burn [34, 35]. The mechanism of the skin damage has been studied before, when exposed to dry heat [36] and hot water [37]. Less studies are found about cutaneous steam burns [38]. As described above, the protective clothing of firefighters and its mechanism with temperature water vapour diffusion has been studied thoroughly [34, 35, 39, 40]. Some believe that cutaneous steam burns are more severe than dry air, due to the dermis, which is damaged, without any significant indication of damage to the epidermal layer. This theory was confirmed by Zhai et al. [38] in an ex vivo porcine model, investigating the mechanisms of cutaneous steam burns and the response of the skin when in contact with high-temperature steam. It showed that the steam penetration in the porcine model damaged the dermis earlier than the epidermal layer, which could explain why cutaneous steam burns are usually more severe than dry heat burns to the skin [38].

Objective This scoping review aims to conclude and summarize published papers in English about steam-related injuries and we present a clinical case of a 26-year-old man with severe steam inhalation injuries and cutaneous steam scalds.

Review A search was conducted using the PubMed® and Cochrane libraries on 19th of May 2021, without a set time period. The search terms were synonyms of "steam", "vapor"," burns", "inhalation injury", "pulmonary insufficiency", and "lung injury". The exact search strategy used can be seen in Figs. 1 and 2. The total literature search identified 1198 articles written in English and after duplicates were removed, 1186 articles remained (Fig. 3). The papers were screened for relevance and eligibility. The inclusion criteria used were all papers describing a case, or cases, involving a steam inhalation injury or burn. A total of 31 articles were included and analysed based on year of publication, type of paper, number of patients involved, age, gender, type of injury/event, treatment, and outcome (Table 1).

Fig. 1 The search strategy on PubMed®

Database: *Pubmed* **Date: 20210419**

Search nr	Term	Results	Comment
Concept 1			
#1	Steam [MeSH]	3,238	
#2	Steam* OR Vapor [Title/Abstract]	49,920	
#3	#1 OR #2	50,580	
Concept 2			
#4	Burns OR Burns, Inhalation OR Lung Injury OR Pulmonary Valve Insufficiency OR Wounds and Injuries [MeSH]	961,974	
#5	Burn* OR Injur* OR Pulmonary Incompetence OR Pulmonary insufficienc* OR Pulmonary Regurgitation [Title/Abstract]	968,293	
#6	#4 OR #5	1,566,470	
Final results	#3 AND #6	1,172	

Fig. 2 The search strategy in the Cochrane Library

Database: *Cochrane Library* **Date: 20210419**

Search nr	Term	Results	Comment
Concept 1			
#1	Steam [MeSH]	38	
#2	Steam* OR Vapor [Title/Abstract/Keywords]	464	
#3	#1 OR #2	464	
Concept 2			
#4	Burns OR Burns, Inhalation OR Lung Injury OR Pulmonary Valve Insufficiency OR Wounds and Injuries [MeSH]	27460	
#5	Burn* OR Injur* OR Pulmonary Incompetence OR Pulmonary insufficienc* OR Pulmonary Regurgitation [Title/Abstract/Keywords]	72368	
#6	#4 OR #5	82379	
Final results	#3 AND #6	26	

Case report

A 26-year-old man was referred to the Burn Centre at Uppsala University Hospital due to an extensive burn contracted while working on the central heating of his house. Due to a mechanical failure, there was a large explosion-like release of steam, within the enclosed quarters of his basement.

The initial assessment of the patient estimated that a mix of deep dermal to full-thickness burns covered 55% TBSA. The burns included face, upper and lower extremities, and the back (Fig. 4). The front of the trunk was surprisingly spared from injury (Fig. 5). There was no soot present in the mouth or pharynx; however, there were signs of damage to the buccal mucosa, most probably due to inhaled steam. The 26-year-old was intubated upon arrival to the referring hospital and subsequently promptly transported to our department. During transport, he was unstable and had no urine production despite receiving 15 l of crystalloid solutions (Ringer's acetate) during the first 10 h, as well as a noradrenaline infusion.

Upon arrival, fiberbronchoscopy showed redness similar to mucositis in the buccal mucosa, gingiva, tongue, and palate continuing down into the trachea. Escharotomy was performed on the forearms and hands due to circumferential burns, and enzymatic debridement (NexoBrid ®, MediWound Ltd, Israel) was initiated to treat the burns on the lower extremities.

On day 2, the patient was tachycardic with an acute renal failure and continuous renal replacement therapy (CRRT) was initiated. The following day (3), he deteriorated respiratory and circulatory with a greater need of continuous noradrenalin infusion, a metabolic acidosis, and a lactate of 5 mmol/l. During days 4 and 5, the patient recovered circulation, and the noradrenaline infusion was removed, but with respiratory worsening with increased O_2-demands and increased PEEP of 14 cm H_2O.

Excision of the burns on his hands and upper extremities as well as placement of a tracheostomy was done on day 6. Due to further respiratory deterioration, the patient was placed in prone position with a slight improvement. Muscle relaxation was used to handle CO_2-retention and asynchronous breathing. On day 9 post admission, the plastic enclosure to the UniPerc® cannula (Smiths Medical Inc, MN, USA) of the tracheostomy was found broken and the inner canula was replaced using video laryngoscopy and a tube exchange guide wire due to the risk of accidental decannulation, in the presence of senior consultants from ENT and intensive care. At this point, a grayish white mucosa was noted in the pharynx and down to the laryngeal plane. Later the same evening and continuing to the next day (10), the patient continued to deteriorate with regard to respiratory parameters. Bronchoscopy was performed, showing a rift in the left side of the trachea at the outlet to the left main bronchus. Decision was made to initiate veno-arterial extracorporeal membrane oxygenation (VA-ECMO) treatment while placing a stent in the trachea and bronchus to cover the rift. After the stent, the same afternoon, the patient was moved from the burn ICU to the cardiothoracic ICU. Later that same afternoon, a flow of air from the nasogastric tube was noted as well as gastric contents in the tracheostomy. Bronchoscopy was again performed, showing a fistula from the left main bronchus to the oesophagus.

On day 11 post admission, a significant difference was seen in the oxygen saturation in the right arm when compared to the right foot, consistent with Harlequin syndrome [41] and a poor lung function. VA-ECMO was switched to

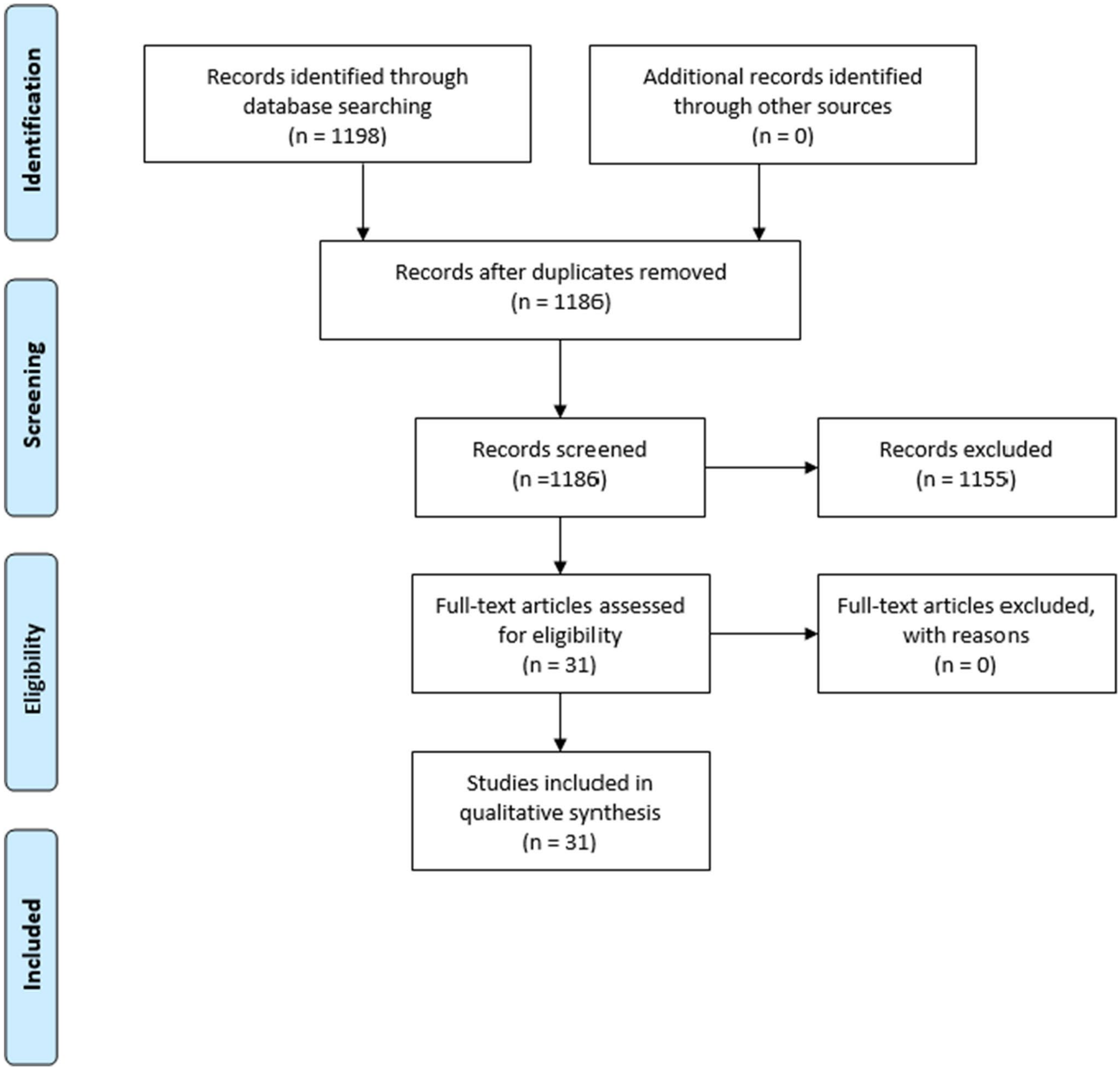

Fig. 3 Out of a total of 1186 identified records, 31 were chosen for review. Described more in detail in Table 1

veno-venous ECMO (VV-ECMO). Bronchoscopy at this point showed a satisfactory passage of air past the defect. Bronchial intubation was attempted bilaterally to increase oxygenation and an oesophageal stent was placed to decrease the contamination of the mediastinum. At this point, the ventilation of the right lung was successful, but despite this, in combination with ECMO treatment, the oxygen saturation was not satisfactory. The patient was severely unstable and suffering from multiorgan failure including renal and liver failure with hemolysis, disseminated intravascular coagulation (DIC), and sepsis. Even dressing changes were nearly impossible due the circulatory and respiratory deterioration when changing positions. At this point, a multidisciplinary team concluded that it was not possible to reverse the situation and saw no alternative for a long-term repair of the trachea even if supportive care was to be successful and the decision was made to switch to palliative care. The patient expired after 2 h.

At the autopsy, the burns previously described as well as remaining conditions after the previous treatment measures were confirmed.

During the internal examination, severely edematous organs were seen with thickening of the scalp as a result of the extensive resuscitation fluid therapy. Ordinary

Table 1 Literature review of the 31 articles included, analysed based on year of publication, type of paper, number of patients involved, age, gender, type of injury/event, treatment, and outcome

Literature review

Study (first author)	Year of publication	Type of paper	No. of patients included	Age	Gender	Type of injury—event	Treatment/prevention	Outcome
Smart [42]	1876	CS	21	UK	M	Gun-powder explosion	Local treatment—Carron-oil (linseed oil mixed with lime-water) on cotton-wadding, oxide of zinc, calamine ointment	15 survived
Kahn [43]	2012	RR	20	20–54 y	19 M 1 F	Fire fighter's faulty equipment, 70% TBSA from steam and hot liquid	Prevention with better equipment, education, and more large-scale studies	All survived with a mean hospital length of stay 2.45 ± 5.4 days
Takamura [44]	2004	Letter to the Editor	11	UK	UK	Steam leak accident at a nuclear power plant in Japan	Unknown	4 workers killed, 7 injured
Choi [45]	2016	CR	1	12 days	UK	Steam burn on nose by heated, humidified high-flow nasal cannula	Foam dressing and ointment, conservative treatment	Healed without complications after 8 days
Charles [46]	2014	CR	1	20 y	M	High pressure steam burn when working in an oil refinery	Sedated, intubated, resuscitated, and treated at a regional burn unit	Treated for 175 days and underwent several surgeries
Brywczynski [47]	2008	CR and brief review	1	17 m	M	Abdominal steam burn injury from "shower steamer"	Conservative treatment with ointment	The burn healed without complications
Greally [13]	1990	CS	2	10 m 4 y	M	12% TBSA 3% TBSA, steam inhalation therapy for viral croup	1st child -conservative treatment of the scalds and fluid resuscitation 2nd child – intubated due to worsened stridor, no fluid resuscitation	The burns healed without complications in the 1st child. The 2nd child was extubated after 3 days. Both discharged without complications
Hathaway [48]	1996	CR	1	40 y	M	High-temperature and pressure steam pipe rupture at work in an enclosed space, nuclear power plant, 60% TBSA	Intubated and fluid resuscitation	Extubated second hospital day, then suddenly dyspnoeic, hypoxic, and hypotensive, passed away despite CPR. Autopsy showed necrotizing laryngotracheobronchitis
Brewster [14]	2020	CS	6	2 weeks—UK	UK	Steam inhalation therapy	The most severe case had 8% TBSA scalds, requiring excision and skin graft	Unknown

Table 1 (continued)

Literature review								
Study (first author)	Year of publication	Type of paper	No. of patients included	Age	Gender	Type of injury—event	Treatment/prevention	Outcome
Brinkmann [49]	1978	CS	27	23–57 y	M	Steam pipe of main boiler explodes on a ship in harbor. The steam temperature was 283° C	12 men found dead on the scene, 15 died within the following days. Other treatment was unknown	All patients passed away due to different causes: cerebral trauma, fulminant shock syndrome, respiratory insufficiency, bronchopneumonia, pneumonia, and interstitial oedema with desquamative alveolitis
Murphy [15]	2004	CS	7	9 m–10 y	UK	Steam inhalation therapy	Excision and skin graft of one patient. None received fluid resuscitation/intervention for the airways	4 children will have permanent scars
O'Dowd [16]	1989	CR	1	UK	F	Mentholated steam inhalation therapy, exploded	Conservative treatment of the scalds on her face	Took 3 weeks for the scalds to heal
Baartmans [17]	2012	RR	49	0–82 y	UK	Steam inhalation therapy	Unknown	Average length of stay in the hospital was 6,3 days
Himdani [18]	2016	Retro-spective CS	16	1–15 y	10 F 6 M	Steam inhalation therapy	Only one patient received surgery with a skin graft. The remaining patients received conservative treatment	None of the patients had permanent scarring except the patient that underwent surgery
Aggarwal [21]	1995	CS	2	0–1 y	1 F 0 M	Partial thickness burns from steam vaporizers	Conservative treatment	Both scalds healed without complications
Still [50]	2001	RR	13	26–53 y	12 M 1 F	Work related steam pipes rupture 12 patients, cooking accident 1 patient	All patients with steam inhalation were intubated	One passed away. Hospital stays from 2–41 days. 1–5 operations per patient. 10 were discharged home, 2 were discharged to rehabilitation
Tekin [51]	2005	CS	15	23–53 y	M	Mass casualty incident from a boiler room steam explosion on a cruise ship	7 patients were intubated, 6 patients received escharotomy, 1 patient was operated due to abdominal compartment syndrome and cardiac tamponade	6 patients with burns > 80% TBSA and steam inhalation died, 1 patient with 99% TBSA died almost directly, 1 patient died in the operation room, 3 died of abdominal compartment syndrome, 1 patient died of sepsis. 3 survivors. Length of stay 1–26 days

Table 1 (continued)

Literature review

Study (first author)	Year of publication	Type of paper	No. of patients included	Age	Gender	Type of injury—event	Treatment/prevention	Outcome
Barich [7]	1972	CS	2	7 m 13 m	M F	Steam inhalation therapy	1st patient received fasciotomies of the hand, developed duodenal perforation 2nd patient took oral fluids and conservative management	1st patient developed seizures postoperatively and passed away 2nd patient's burns healed without complications
Lonie [8]	2016	RR	10	11 m–5 y	8 M 2 F	Steam inhalation therapy	5 children underwent surgery with skin graft. 4 had secondary reconstructions due to contractures	8 children with scar therapy with silicone, taping, splinting, and garments
Scarborough [9]	2021	RR	19	2 weeks–91 y	6 M 13 F	Steam inhalation injury	13 patients – conservative treatment with silver dressings 6 patient – underwent surgery with skin graft	Mean length of stay was 4.3 days, 3 patients developed infected burns and received IV antibiotics. No surgical complications
Wallis [10]	2008	RR	27	7 m–14 y	11 M 16 F	Steam inhalation injury	4 were admitted to hospital	4 children required surgery with skin grafts Length of stay was 1, 4, 7, and 25 days
Bhootra [22]	2005	CS	2	6 y 17 y	UK	Inhalation of steam in a closed room	No treatment was made, both children collapsed with difficulty breathing 1–2 min after the accident	Both children passed away
Robert [52]	2019	CR	1	62 y	F	Vaginal steam therapy (to reduce prolapse)	Conservative management with Polysporin antibiotic ointment	Healed without infection
Yeniocak [53]	2019	Letter to the Editor	1	40 y	F	Pressure cooker	Burn escharotomy and then secondary healing. No other surgery was performed	The burn healed after 4 weeks
Roh [54]	2000	RR	79	Mean 10.5 m	53 M 26 F	Electric rice cooker	81 hands included in 79 patients. 31 hands showed spontaneous healing, 36 requiring STSG, 14 requiring with FTSG	18 patients of 36 with STSG required secondary reconstruction due to contractures

Table 1 (continued)

Literature review

Study (first author)	Year of publication	Type of paper	No. of patients included	Age	Gender	Type of injury—event	Treatment/prevention	Outcome
Colombo [19]	1981	CS	2	13 m 2 y	F M	Steam inhalation therapy	1st patient – topical burn therapy, aerosolized isoproterenol, oral theophylline and IV penicillin 2nd patient – IV aminophylline, dexamethasone, and cephalothin	1st patient discharged after 3 weeks in good condition 2nd patient – discharged after 7 days
Ebrahim [20]	1990	RR	11	0–24 m Mean 15.1 m	6 M 5 F	Steam inhalation therapy	12.5% mean TBSA. 6 patients treated conservatively, 5 underwent skin grafting of the burns	All patients were discharged. Mean hospital stay 14.7 days. 5 patients had postburn problems with scars and contractures
Balakrishnan [55]	1996	CS	2	37 y 44 y	M	Steam pipe explosion causing steam inhalation injuries	1st patient – ARDS but improved in about 5 days. Allograft in stages until covered with cultured epidermal autografting and skin grafting 2nd patient – acute respiratory insufficiency 18 h after, improved day 7. Skin grafted	1st patient discharged after 4 months 2nd patient discharged after 5 weeks
Ray [56]	1992	CR	1	62 y	M	High pressure industrial steam washer injury	Full thickness burns of the right foot, presented 4 days after the injury, now infected. Finally resulting in amputation digit 5 and skin grafting	Discharged 50 days after the injury. Returned to work 2 months later
Woods [57]	1996	CR	1	32 y	F	Steam press hand burn	Full thickness burns to the dorsal and palmar surface of the hand. Excised and grafted with STSG	Follow up showed a full range of motion of the entire hand, except DIP joint of digit 4, 20° of flexion lost
Dahlin [58]	2008	CS	14	14–82 m Mean 43 m	7 M 7 F	Injuries due to steam roller press in laundries	7 of 14 children had signs of compartment and carpal tunnel syndrome, 3 with fractures. Fasciotomy, decompression, revision, STSG, and one pedicled ulnar flap	8 patients healed without complication. 6 with minor extension deficit of fingers or scar contractures

CS case series, *UK* unknown, *M* male, *RR* retrospective review, *Y* years old, *F* female, *TBSA* total body surface area, *CR* case report, *STSK* split-thickness skin graft, *FTSG* full-thickness skin graft, *ARDS* adult respiratory distress syndrome, *DIP* distal interphalangeal joint

Fig. 4 Part of the estimated 55% (TBSA) burn on the face, back, upper and lower extremities

Fig. 5 The front of the trunk which was spared from the burns. The genitalia and the tattoo of the left hand are covered

Fig. 6 The base of the tongue, the ragged epiglottis (↑), and the pharynx seen from above, with severe, fibrin-coated, tissue damage in the mucosa (†)

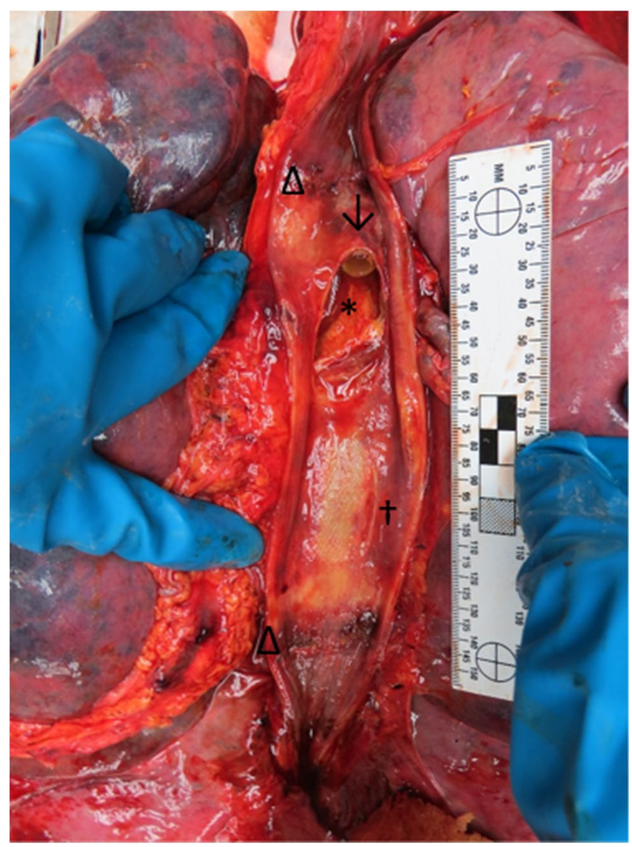

Fig. 7 The opened esophagus showing the longitudinal lesion between the esophagus and trachea (*) with the breathing tube slightly visible just above the carina (↓), the transverse chafing-like lesions at both limitations of the stent (Δ), and the longitudinal mucosal rift (†)

Fig. 8 Signs of broncholobular pneumonia in the lungs with scattered foci of yellowish consolidation and a generally red and solid section (↑)

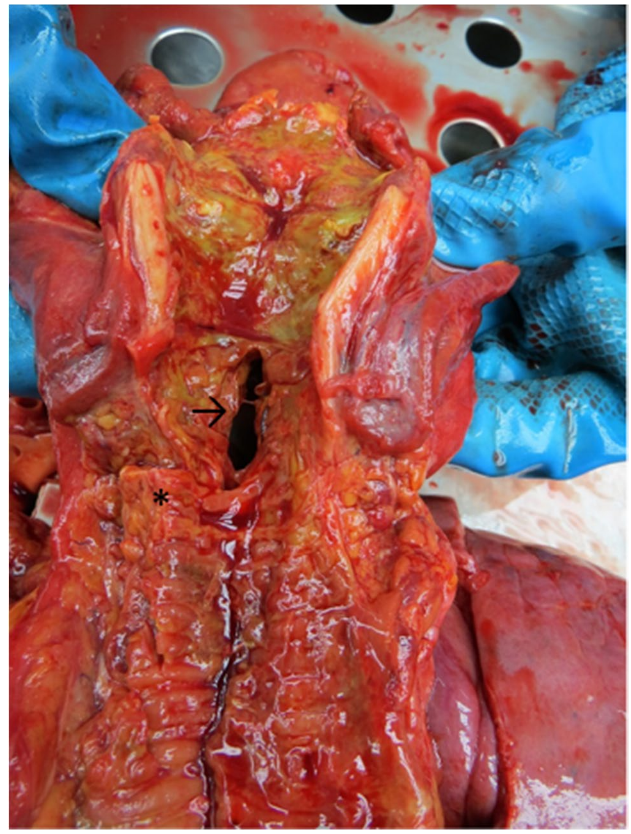

Fig. 9 The opened airways with severe mucosal damage and unprotected cartilage rings in the trachea (*). The lesion in the photography shows the place of the tracheostomy (→)

anatomical conditions were seen in the brain and the basal brain vessels.

Several discolorations were seen on the tongue, which in places were fibrin-coated, and a blood infiltration was noted in the tongue base. The upmost part of the epiglottis had a ragged tear in its frontal aspect (Fig. 6). Upon opening the oesophagus, at both limitations of the inserted stent (12.5 cm in length), transverse chafing-like lesions were seen in. Beneath the stent, a continuous lesion, measuring about 5 × 2.5 cm (L × W), communicating with the trachea was seen. Additionally, two longitudinal mucosal tears were noted in the oesophagus (Fig. 7).

The pleurae were shiny without adhesions or foreign material. The lungs were greatly increased in consistency, compact, and heparinized almost in the whole, with a weight > 1600 g each (normal approximately 500 g). At incision, a yellowish tissue with light clearings similar to broncho-lobular pneumonia was seen (Fig. 8). Stretching from the trachea down into the peripheral parts of the airways, a yellow-coloured, sometimes wounded, mucous membrane with varying depths of damage and occasional bleeding was seen in both lungs, with the cartilage rings completely unprotected in places showing laryngotracheobronchitis (Figs. 9 and 10). Corresponding to the tissue defect in the oesophagus, a similar defect was seen in the wall of the trachea just above the carina where the surrounding tissue was brittle and thin.

The heart was slightly enlarged (450 g, normal 350–400 g) but without obvious edematous appearance and no further pathology. The kidneys, spleen, pancreas, and adrenal glands were normal although edematous. The liver was fluid-filled with a rounded anterior edge, heavy (3050 g, normally approximately 1500 g), and had a grainy, buttery tissue at incision.

In the histopathological examination of the brain, hyperemic tissue was seen in the cerebrum. In the hippocampus, corresponding to the CA1 area, pycnotic, dark-coloured nuclei were seen, indicating acute oxygen deficiency. Regarding the lungs, tissue samples were taken from all lobes, the two main bronchi, the macroscopic haemorrhages in the two bronchi and from the trachea. In the left lung, the alveoli were almost completely filled with erythrocytes and neutrophilic granulocytes (Fig. 11). Hyaline membranes were also seen in several places as signs of acute respiratory distress syndrome/diffuse alveolar damage (ARDS/DAD) (Fig. 12). The mucosa of the left main bronchus was completely absent, and the underlying cartilage tissue was infiltrated by fungal growth with surrounding pus. In the right

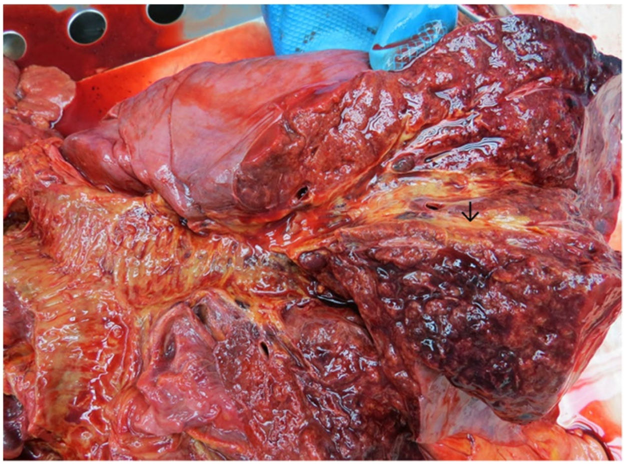

Fig. 10 Fibrin-coated airways down into the peripheral parts of the lungs (↓)

lung, a similar picture was noted with not only extensive acute inflammation and fungal growth in the cartilage parts but also several bleeding foci (Fig. 13). In the alveoli, fibrin was seen, as in late stages of pneumonia (Fig. 14). Several abscess formations were noted in the right lung (Fig. 15).

All oesophageal tissue samples showed damaged mucosa and even deeper damage of the circular muscle layers in some sections. Acute inflammatory cells were mainly seen in the adventitia, compatible with mediastinitis.

Besides putrefactive transformations in the liver and kidneys, no abnormal histopathological findings were found.

In summary, the autopsy and subsequent histopathological examination showed extensive external burns, residual conditions after treatment with escharotomies, amputations, skin transplants, and edematous organs. Extensive mucosal damage was seen throughout the bronchial tree, the oesophagus, and the mouth, and discoloration and tissue defects were seen on the tongue and epiglottis. In the lungs, a bilateral pneumonia was seen where characteristics from all four classical stages could be found as well as signs of diffuse alveolar damage. The conclusion was that the death was due to the complications after extensive scalding injuries in the airways in combination with the tissue defect between the trachea and oesophagus. It is not completely clear if the defect between the trachea and oesophagus was due to the thermal damage or due to an iatrogenic injury caused on day 9 post admission, when they changed the UniPerc® cannula.

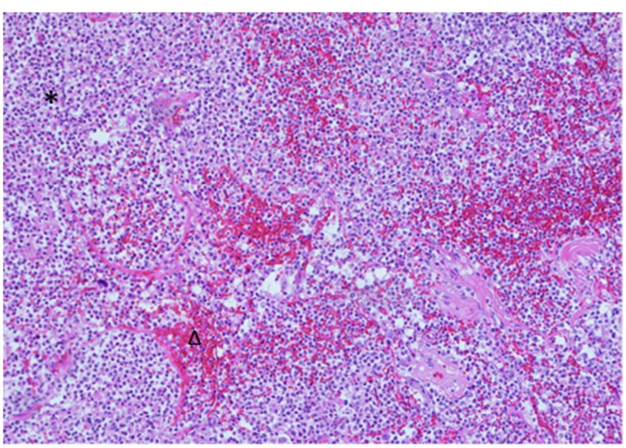

Fig. 11 Lung tissue showing severe infiltration with neutrophil granulocytes (*) as well as erythrocytes (Δ) in the alveoli compatible with early stage of pneumonia (Hematoxylin–eosin, × 10)

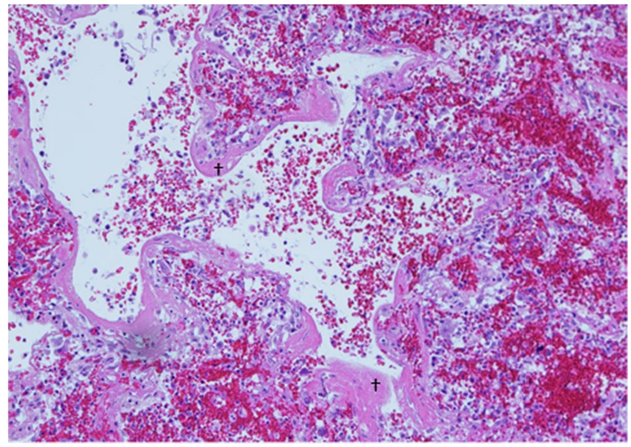

Fig. 12 Lung tissue with formation of hyaline membranes (†) compatible with diffuse alveolar damage (DAD) as well as alveolar bleeding (Hematoxylin–eosin, × 10)

Discussion

Burns related to the contact with steam are generally rare and can be both minor and severe. The more severe cases related to steam exposure are mostly workplace accidents

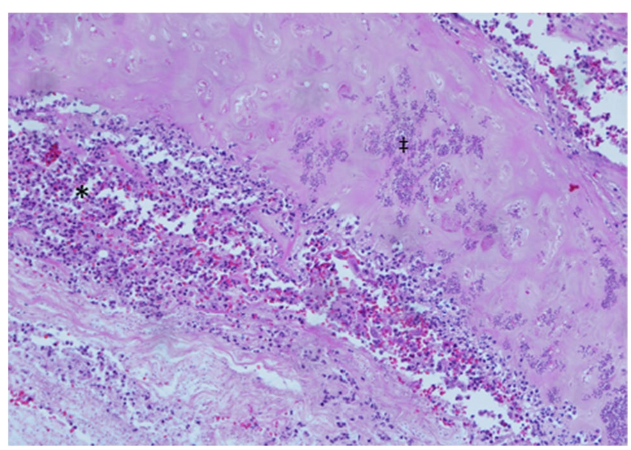

Fig. 13 Bronchial cartilage with fungal growth (‡) and surrounding neutrophil granulocytes (*) (Hematoxylin–eosin, × 10)

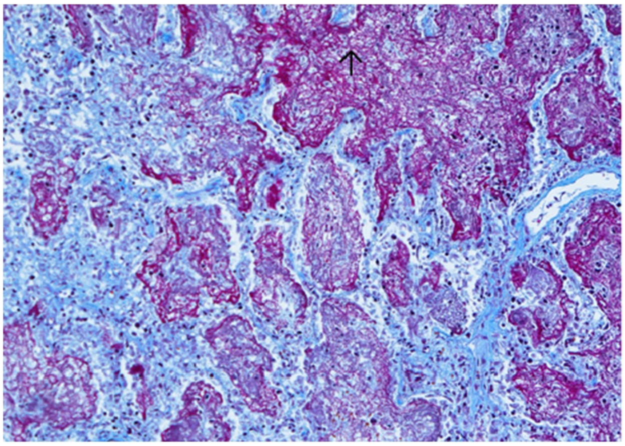

Fig. 14 Alveoli´s filled with fibrin (↑) compatible with late stage of pneumonia (Pikro-Mallory, × 10)

[50] and the minor injuries reported in the literature are often related to steam inhalation therapy, especially in the paediatric population [7–10, 13–18, 18–22].

Our literature review found 8 case reports, 13 case series, 8 reviews, and 2 letters to the Editor. We included a total of 31 papers in our review related to our inclusion criteria described above. The case reports/series described different cases ranging from steam inhalation therapy injuries with minor injuries to severe high-pressure steam burns with major injuries [7–10, 13–22, 42–58].

Hathaway et al. (1996) [48] have reported a case, with a similar mechanism of injury as in our current paper: a high-pressure steam pipe ruptured, and the patient sustained 60% TBSA burns with a steam inhalation injury. In both Hathaway et al.'s patient and ours, extensive mucosal damage was seen throughout the bronchial tree with severe necrotizing laryngotracheobronchitis, found in the autopsy.

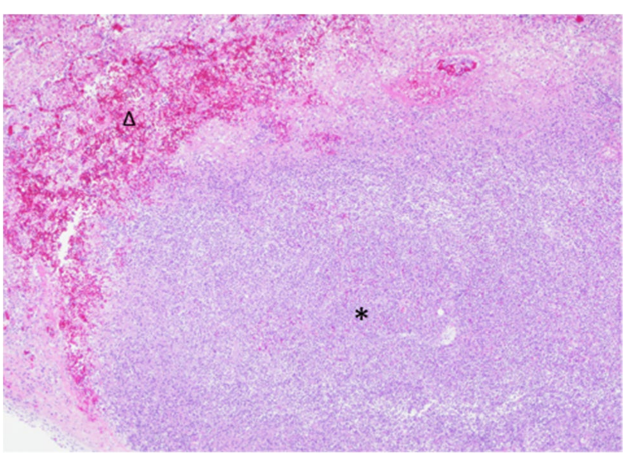

Fig. 15 Lung tissue with abscess formation (*) and surrounding alveolar bleedings (Δ) (Hematoxylin–eosin, × 4)

Below the glottis, this type of burns to the airway are rare unless inhalation of steam is involved [49]. In the case series by Brinkmann et al. (1978) [49], a steam tube on a ship exploded causing both cutaneous steam burns and severe steam inhalation injuries with similar pathological findings were described. In total, 27 men died, at different intervals. In the victims who died on the scene, coagulative necrosis could be found in the trachea, bronchial walls, and at the level of the lungs. The parenchyma of the lungs demonstrated oedema and desquamation of the alveoli and alveolar epithelial cells. These patients most probably died from acute pulmonary failure and shock. In the patients surviving the accident, some other complications were described: respiratory distress syndrome (RDS), desquamative interstitial pneumonia, and confluent bronchopneumonia. The macroscopical findings of the respiratory tract described the mucosa as "of greyish colour" and almost 50% had subpleural haemorrhages. Brinkmann et al. [49] concluded that the acute changes in these patients were due to severe lesions of the lungs and the alveolar-capillary membrane leading to hypoxia and shock.

Preventive measures to avoid the potential life-threatening situation with inhalation of high-temperature steam to the respiratory tract and death have been studied by the French Navy [46]. The exposure to this mechanism of injury is higher on nuclear ships or submarines and a laboratory was designed to study different protective equipment and fabrics. According to the French Navy, the study showed that water vapour impermeable garments had a better protection when it comes to steam exposure. The ventilator treatment in acute lung injury due to steam inhalation injuries has been studied in animals by Wang et al. (2006) [59], concluding that high-frequency oscillatory ventilation (HFOV) could be an optional treatment. According to this study, the HFOV stops the decrease in oxygenation and the compliance of the lungs and also decreases the inflammatory process and tissue damage in the lung.

Steam inhalation therapy has long been an accepted alternative treatment of upper respiratory tract infections (URTI). The earliest description of the dangerous and negative impact of steam inhalation therapy we found in our review dates back to 1972 [7], then later again described in 1981 [19], 1989 [16], and 1990 [13]. These three papers describe the underrecognized risk of scalding, especially in children when receiving humidified air to treat or prevent URTI. These scalds can be severe causing full-thickness burns, leading to surgery and skin grafts which lead to permanent scarring [15]. The cost can be high when dealing with steam inhalation scalds and most of these studies recommend an increased awareness of these scalds for future prevention [8, 9]. The retrospective review by Baartmans et al. (2012) [17] included 49 patients with burns related to steam inhalation therapy. It is proposed that steam inhalation therapy should not be used and considered as a dangerous procedure. This is due to the lack of proven benefit and the risk of serious complications as scalds.

Mass casualty events related to cutaneous steam burns and steam inhalation injuries have been described throughout history until present day [42, 44, 49, 51, 60, 61]. One of these events was included in our review by Tekin et al. (2005) [51] describing a boiler room steam explosion on board a cruise ship and injured 15 employees on the cruise ship. Of these 15 employees, 6 had severe cutaneous steam burns over 80% TBSA, together with steam inhalation injuries and all these patients unfortunately passed away.

Iatrogenic steam burns are generally rare; a case report by Choi H et al. (2016) [45] describes a 12-day-old infant at the neonate intensive care unit which presented with a deep dermal cutaneous steam burn to the nose due to a heated, humidified high-flow nasal cannula (HHHFNC) with a failure when setting the temperature.

A tragic and rare event involving steam occurred in 2005 and is described by Bhootra et al. [22] and involves 2 children, 6 and 17 years old, who watched their mother inhale steam for her URTI; the older child accidently spilled the boiling water which caused a huge amount of steam in their enclosed room. According to the mother, the children started to struggle with their breathing within 1–2 min and both subsequently passed away. The autopsy showed microscopical injuries to the respiratory tract with inflammatory response, coagulative necrosis, lung congestion along with haemorrhages, and oedema.

Conclusions

This case and the literature review demonstrate the challenges that can be encountered when handling patients with cutaneous steam burns and/or steam inhalation injuries. A steam injury to the airways or the skin can be directly life-threatening due to its severity and should be treated with caution. Many studies highlight the danger of steam to the respiratory tract and its vulnerability to this type of injury that can lead to acute respiratory insufficiency and sometimes death. This is also demonstrated in the case report described above.

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Declarations

Informed consent A written informed consent was obtained from the patient's wife who approved this study.

Conflict of interest Sebastian Holm, Olof Engström, Marielle Melander, Monika CS Horvath, Filip Fredén, Miklós Lipcsey, and Fredrik Huss declare no competing interests.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. According to the Swedish law no ethical approval is required for case reports.

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