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Upper Airway Sequelae in Burn Patients Requiring Endotracheal Intubation or Tracheostomy

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During a period of 11½ months, 41 of 217 adult burn patients admitted to the U.S. Army Institute of Surgical Research Burn Center required endotracheal intubation or tracheostomy for management of the airway and/or ventilatory assistance. Permanent upper airway sequelae were recorded and related to presence of inhalation injury, duration of tube placement, cuff pressure, and pulmonary compliance. An "inhalation injury scoring system" based upon history, physical examination, bronchoscopic findings, and abnormalities at ^{133}xenon lung scan correlated well with postinjury alteration in compliance and subsequent sequelae. Significant inhalation injury was found in 35 patients. Seventeen of the study patients survived (Group I) and 24 patients expired (Group II). Group I patients were screened for permanent airway sequelae by fiberoptic bronchoscopy, xeroradiograms, and spirometry undertaken an average of 11 weeks after extubation or decannulation. Four patients developed tracheal stenosis and five patients had significant tracheal scar granuloma formation. Sequelae were generally more frequent and more severe after tracheostomy than after translaryngeal intubation, and duration of tube placement and presence of a tracheal stoma were the most important etiological factors in permanent damage. For initial respiratory support, we favor the use of translaryngeal (nasotracheal) tubes for periods up to 3 weeks. Fiberoptic bronchoscopic examination is the most reliable follow-up method for detecting anatomic damage in such patients. Spirometry can be used as a noninvasive screening test and xeroradiograms are helpful in assessing the degree of tracheal stenosis.

VENTILATORY SUPPORT is frequently necessary for the treatment of critically ill patients. Such treatment may be lifesaving, but several adverse effects have also been recognized.[1,2] Among these are damage to the larynx and upper trachea from the prolonged use of endotracheal (translaryngeal) or tracheostomy (transtracheal) tubes.[1-9] Although development of tubes made of "tissue compatible" material with high volume/low pressure cuffs apparently has reduced the incidence of tracheal stenosis,[7,10-13] and damage to the upper airway, a frequency of tracheal stenosis of up to 85% has been reported after tracheostomy when accurate methods of investigation have been used.[3] When high volume/low pressure cuffed tracheostomy tubes are used, stenotic changes most often occur at the stoma level and not at the cuff level.[1,6,8-10] The use of translaryngeal tubes seems to be associated less frequently with permanent damage to the airways, even after relatively long-term intubations.[5,10,12] Reversible hoarseness is the most common complication after translaryngeal intubation, and the nasotracheal route is slightly less troublesome than the orotracheal.[1,4,11] There is so far no agreement on how long a nasotracheal tube may safely be left *in situ*, but the trend is towards longer periods, even months.[12] Still, tracheostomy is often performed in patients needing ventilatory support for more than 1–3 weeks or when there are specific problems with the endotracheal tube.

Patients who have sustained major burns differ in several respects from other ICU patients. Relatively large volumes of intravenous fluids are required for resuscitation of patients with extensive cutaneous burns. This often leads to local as well as generalized edema formation that also may affect the airway and lungs. If inhalation injury is combined with cutaneous burns, as is the case in 10–35% of burned patients in reported series, there is a significant increase in the need for ventilatory support.[14] This prospective study documents the sequelae, particularly upper airway injury and tracheal stenosis, of airway intubation and mechanical ventilation in 41 burn patients.

Materials and Methods

All adult patients treated in this Burn Center from July 1981 to June 1982 requiring endotracheal intubation

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and/or tracheostomy for maintenance of the airways or ventilatory support were included in this study. Of a total of 217 admissions (mean burn size 30.3% of the total body surface (TBSA), 16.6% third degree burns) during this period, 41 needed an artificial airway for more than 24 hours. Of these 41 patients, ten were female, 31 male, and the mean age was 44 years (range 18–87). All 41 patients suffered cutaneous burns (mean burn size 45% TBSA, range 17–94%, mean third degree burns 32% TBSA, range 0–80%).

Initial fluid resuscitation consisted of lactated Ringer's solution estimated on the basis of 2 ml/kg body weight/per cent TBSA burn, and administered at an infusion rate adjusted to achieve an adequate urinary output (30–50 ml/hr). Flow directed pulmonary artery catheters were used in a few patients where additional monitoring was necessary to guide fluid therapy. Wounds were initially debrided and treated with alternating topical antimicrobial creams (mafenide acetate and silver sulfadiazine) and cleansed daily. Surgical excision and autografting were carried out from the first week when indicated and when the patient's condition was stable enough to allow general anesthesia and surgery. Prophylactic systemic antibiotics were not used. Microbiological surveillance, including wound biopsies, was routinely used. Steroids were not given. Nasogastric tubes were used routinely immediately postburn and removed when gastrointestinal motility returned. Small caliber feeding tubes were inserted when prolonged tube feeding was necessary.

For documentation of possible inhalation injury, flexible fiberoptic bronchoscopy[15] was performed initially in all 41 cases. ^{133}Xenon lung scintigraphy[16] was done if the findings on bronchoscopy were inconclusive or if inhalation injury was suspected from history and routine physical examination. In some cases a ^{133}xenon lung scan was not done if the patient was too unstable to move out of the burn-ICU to the scanning facility. A total of 17 patients had a ^{133}xenon lung scan.

For the evaluation of inhalation injury severity we established an "inhalation injury scoring scale." All patients were classified according to this scale as follows:

1. *History:* Up to 0.5 points were given with a history positive for injury sustained in a closed space (0.2), existence of flames or fumes (0.05), choking or coughing (0.1), and loss of consciousness (0.15).
2. *Physical examination:* Up to 0.5 points were given for findings of facial burns (0.05), singed nasal vibrissae (0.1), mucosal injury in nose, mouth, or pharynx (0.15), and carbonaceous sputum (0.2).
3. *Bronchoscopy:* Zero to two points were assigned to the evidence of mucosal injury (erythema, edema, ulceration, or sloughing) and the extent of positive findings (0.5 points to patients with injury in larynx, 0.5–15. points to patients with involvement of trachea down to carina, and 1.5–2.0 points when mainstem and/or segmental bronchi were involved).
4. *^{133}Xenon lung scan:* Zero to one point was given according to the distribution and degree of delayed "wash-out" (0.5 points with slight to moderate findings on one side only, 0.5–1.0 points when both sides were involved or when there was marked retention uni- or bilaterally).

Since more than half of all patients did not have ^{133}xenon scans performed, the correct inhalation injury scores for those patients could have been up to 1.0 points higher than the listed scores.

The indications for endotracheal intubation, tracheostomy, and initiation of mechanical ventilation were: (1) airway obstruction in nine cases, (2) retained secretions in five cases, and (3) respiratory insufficiency in 27 cases. Prophylactic intubation or artificial ventilation was not used.

For nasotracheal intubation, high volume/low pressure cuffed tubes (National Catheter Co., Ohio Medical Products, and Portex Co.) were used. Intubation customarily was accomplished by the nasotracheal route using the fiberoptic bronchoscope. A few patients were intubated transnasally without a bronchoscope or with a rigid laryngoscope and Magill's forceps. Nasotracheal tubes were not changed unless mandated by major problems with patency or difficulty in passing suction catheters (which was infrequent).

Although tracheostomies were performed early in some cases with obvious severe inhalation injury, most were carried out late when long-term support was anticipated. Low pressure cuffed tracheal tubes (Shiley Corp.) were used in all patients requiring tracheostomy. All endotracheal and tracheostomy tubes were made of polyvinylchloride. The surgical technique for tracheostomy included transverse incision of the skin, longitudinal incision of the second and third or the third and fourth tracheal rings without removal of tracheal tissue. Traction sutures were placed on both sides of the longitudinal incision in the tracheal wall to facilitate insertion and early change of tubes. All tracheostomies except one were performed electively in the operating room after a period of translaryngeal intubation.

A volume-cycled ventilator (Bennett Model MA-2) was used for mechanical ventilation. Cuff pressure was routinely adjusted to "minimal leak"[12] and kept below 25 cm H_2O, if possible. Tracheobronchial suctioning, postural drainage, and chest physical therapy were utilized on a regular basis. Fiberoptic and rigid bronchoscopy were used to remove excessive amounts of secretions

TABLE 1. *Patient Characteristics*

	Age* (Years)	Total Burn Size:* Per cent 2nd. + 3rd. Degree	Burn Size:* Per cent 3rd. Degree	Fluid Volume First 24 Hours* $ml \cdot kg^{-1} \cdot \%\ Burn^{-1}$	Duration of Hospital Stay (Days)*
Group I (survivors)	36.5	37.5	23.5	5.2	110.6
n = 17	(18–65)	(17–68)	(10–61)	(2.1–9.4)	(36–266)
Group II (nonsurvivors)	51.5	49.7	36.6	5.6	30.0
n = 24	(19–87)	(17–94)	(0–80)	(1.6–13.0)	(5–215)

* Mean (range).

or endotracheal debris and whenever microbiological samples were needed.

The duration of intubation or tracheostomy and of mechanical ventilation were recorded in all cases. Pulmonary complications resulting in decreased pulmonary compliance (pneumonia, pulmonary congestion/edema, pleural effusion, pneumothorax, restriction due to full thickness circumferential chest burns) were recorded. Pulmonary compliance (together with airway resistance) was categorized in all patients by measuring peak airway pressure during intermittent positive pressure ventilation (IPPV) as follows:

1. Peak airway pressure < 20 cm H_2O defined as normal compliance;
2. Peak airway pressure 20–25 cm H_2O defined as minimal reduction of compliance;
3. Peak airway pressure 26–35 cm H_2O defined as moderate reduction of compliance; and
4. Peak airway pressure > 36 cm H_2O defined as severe reduction of compliance.

All airway pressures were determined when the patients were being ventilated in a quiet state and not coughing (sedatives, but not muscle relaxants, were used).

The survivors (Group I) underwent the following special investigations at the time of discharge from the hospital:

1. Flexible fiberoptic bronchoscopy with photographic documentation of any positive findings;
2. Xeroradiograms[17,18] of the upper airway; and
3. Spirometry[19] measuring forced vital capacity (FVC) and forced expiratory flow ($FEF_{25-75\%}$) with results given as per cent of predicted normal values.

TABLE 2. *Diagnosis of Inhalation Injury—"Inhalation Injury Score"*

	Group I (Survivors) n = 17	Group II (Nonsurvivors) n = 24
Doubtful = 0–1.0 point	3 Patients	3 Patients
Minimal = 1.1–2.0 points	6 Patients	3 Patients
Moderate = 2.1–3.0 points	3 Patients	9 Patients
Severe = 3.1–4.0 points	5 Patients	9 Patients

Flow-volume loops were recorded for each patient. In nonsurvivors (Group II), autopsy was performed in 12 of 24 patients (50%).

Results

Seventeen (41%) of the study patients survived (Group I) and 24 (59%) expired (Group II). Values for age, burn size, duration of hospitalization, and resuscitation fluid volume given during the first 24 hours postburn are presented in Table 1 for both groups. Group I had an overall lower age, smaller burn size, and longer stay in the hospital. All patients in Group I were male.

Of the 41 study patients, 35 were considered to have inhalation injury and received "inhalation injury scores" from 1 to 4 (Table 2). No patient received a score of 0, but in six cases (15%) the diagnosis was uncertain with scores from 0.5 to 1.0. Of these six patients, three patients in Group I were intubated because of laryngeal edema. The course of one of these patients, who had an epiglottitis (*Haemophilus influenzae*), is presented in the discussion. The three cases in Group II with low scores were all intubated several days postburn because of severe pneumonia.

Data concerning the types of tubes used, as well as duration of intubation/tracheostomy and duration on IPPV, are presented in Table 3. Most patients were intubated on the first or second postburn day. Nearly half the patients in each group had a nasotracheal tube placed for the entire period during which they needed ventilatory support (2 to 28 days). With one exception, all tracheostomies were performed after a period of translaryngeal intubation. In one patient in Group II, tracheostomy was placed for initial access to his obstructed airway. All patients in both groups required mechanical ventilation, the duration of which ranged from two to 160 days (Table 3).

When on the ventilator, all patients' peak airway pressures were recorded. Results of the gross estimation of pulmonary compliance (and airway resistance) are presented in Table 4. As seen from this table, a decrease in compliance occurred in both groups, being more common and more pronounced in Group II. This corresponds well with the more common findings of

TABLE 3. *Duration of Intubation/Tracheostomy/Intermittent Positive Pressure Ventilation*

	Group I (Survivors) n = 17)	Group II (Nonsurvivors) n = 24
Only endotracheal (TL)* tube, n	10	12
Duration, days (range)	9.9 (2–28)	14.8 (5–26)
IPPV‡-duration, days (range)	8.0 (2–26)	14.6 (5–26)
Only tracheostomy (TT)† tube, n	0	1
Duration, days (range)	—	7
IPPV-duration, days (range)	—	7
Secondary tracheostomy, n	7	11
TL-days prior to TT, days (range)	7 (2–15)	6.6 (1–12)
TL + TT duration, days (range)	49.1 (15–87)	42.4 (7–204)
IPPV-duration, days (range)	25.6 (2–51)	29.0 (7–106)

* TL = Translaryngeal (endotracheal) tube.
† TT = Transtracheal (tracheostomy) tube.
‡ IPPV = Intermittent positive pressure ventilation.

TABLE 4. *Reduction of Pulmonary Compliance when on IPPV*

	Group I (Survivors) n = 17	Group II (Nonsurvivors) n = 24
Normal (peak airway pressure < 20 cm H_2O)	6 Patients	0 Patients
Minimal (peak airway pressure 20–25 cm H_2O)	1 Patient	5 Patients
Moderate (peak airway pressure 26–35 cm H_2O)	6 Patients	12 Patients
Severe (peak airway pressure > 36 cm H_2O)	4 Patients	7 Patients

Peak airway pressures are measured at normoventilation with the patient in a quiet state.
The division into categories by level of peak airway pressure reflects not only pulmonary compliance, but to some degree also the airway resistance.

pulmonary congestion/edema, pneumonia, and atelectasis in Group II. No correspondence was found between the degree of compliance reduction and the incidence of tracheal stenosis.

The results of the follow-up investigations in Group I (survivors) are listed in Table 5. The mean interval between extubation or decannulation and the follow-up study was 78 days (range 20–150). Fiberoptic bronchoscopy was done in 16 patients (one patient declined the procedure), xeroradiograms in 14 patients, and spirograms in 13 patients. Three patients with normal findings on bronchoscopy did not receive xeroradiograms. Flow-volume loops were recorded and FVC and $FEF_{25-75\%}$ calculated in 13 cases. The findings using these three main follow-up investigations are listed separately for patients in whom tracheostomy was performed and for those treated with translaryngeal tubes in Table 6.

Table 7 correlates the duration of tube placement with the incidence of documented airway sequelae (*i.e.*, positive findings on bronchoscopy and/or xeroradiograms) in patients who survived. The incidence of sequelae was higher among the patients with more than three weeks duration of tube placement.

Respiratory failure was the immediate cause of death in 18 of the 24 patients in Group II. Of the remaining six patients, four had burn wound infection/invasion with septicemia, and two patients had acute myocardial infarction as the immediate cause of death. Autopsy was performed in 12 cases. The findings at autopsy in the larynx and trachea are listed in Table 8. Generally, the degree of injury to larynx and vocal cords was less than that to the upper third of trachea (tracheostoma level and cuff level). Tracheoesophageal fistula was suspected clinically in two cases, but neither contrast radiograms nor bronchoscopy/esophagoscopy could verify this diagnosis. In one case (nonsurvivor), there were major management problems related to recurrent dislogdement of the tracheostomy tube, but such did not contribute to the death of the patient.

The effects of nasotracheal tubes on the nasal mucosa and septum were not specifically recorded, but in no case was such injury of clinical significance. No episode of abnormal bleeding caused by the artificial airway was noted in either of the groups.

As expected, pneumothorax was more common in the nonsurvivor group (10 patients) than in the survivor group (3 patients). Nine of the 13 cases complicated by pneumothorax occurred in patients with tracheostomy. Empyema developed secondary to pneumothorax in three cases. In three other patients, pneumothorax was considered to be a significant cause of death—tension pneumothorax in two cases and bilateral pneumothorax in one.

Bacteriological samples of tracheal secretions were taken when indicated. Except for the tendency to find gram positive bacteria early (first and second week) and

TABLE 5. *Group I: Follow-up Investigations*

Total number of patients	17
Bronchoscopy, total	16
Patients with positive findings	
Stenosis	3
Granuloma, scar, etc.	6
Xeroradiograms	14
Severe stenosis*	1
Mild stenosis†	3
Spirograms	13
Pathological	6
Normal	7

* Reduction of the transverse air-column diameter by 79%.
† Reduction of the transverse air-column diameter by 24, 26, and 42%.
Spirograms were considered normal when FVC and $FEF_{25-75\%}$ given in per cent of predicted normal values were 100 ± 25%.

TABLE 6. *Group I: Findings at Follow-up Correlated to Type of Artificial Airway Tube*

		Bronchoscopy			Xerograms		Spirograms	
		Positive			Positive			
	n	Stenosis	Other*	Normal	Stenosis	Normal	Positive	Normal
Total number of patients	17	3	6	7	4	10	6	7
TL-tube only†	10	0	2	7	1	7	2	4
Primary TL + secondary TT‡	7	3	4	0	3	3	4	3

* Prominent scar or granuloma inside trachea.
† TL = Translaryngeal (endotracheal) tube.
‡ TT = Transtracheal (tracheostomy) tube.

gram negative bacteria later in the course, no specific conclusions could be made from these data.

Discussion

This study population had sustained severe burn injury with a burn size significantly greater than for all patients treated at this burn center during the same period (45% TBSA *vs.* 30% TBSA). In addition, most (85%) of the study patients had associated inhalation injury. The mortality rate was high (59%), and 75% of the deaths were caused by pulmonary complications. This is in agreement with figures previously reported.[13] In extensively burned patients with mucosal injury to the upper airways, reduction of both local and systemic resistance to infection and the often inevitable use of artificial airways and ventilatory support may combine to cause adverse effects on pulmonary function. Any differences in injury severity or complication rate found between methods of management in these patients might, therefore, be of potential value when evaluating alternatives in the respiratory care for other patients as well.

The relatively large volume of resuscitation fluid needed during the first 24 hours in the study patients may be explained by the fact that most patients with the combination of cutaneous burns and inhalation injury require a volume of resuscitation fluid in excess of the estimated amount.[20] Such patients may be further disposed to pulmonary edema and other pulmonary complications. In this respect, our patient material may be a selected one.

We found a significant correlation between long duration (more than 21 days) of tube placement and development of airway sequelae (Table 7). As pointed out before, the translaryngeal and the tracheostomy groups in this study are not fully comparable and, in general, the patients with tracheostomies were intubated for a longer period of time, an average of 49 *vs.* 10 days (Table 3). Other authors have reported similar findings which, in part, may be related to a greater reluctance to wean patients with tracheostomies from ventilatory support as compared to patients with translaryngeal tubes.[5] In our material the difference in the frequency of airway sequelae between the tracheostomy and the translaryngeally intubated patients appears to be related to duration of intubation (Table 7). The fact that translaryngeal intubation preceded tracheostomy in all but one patient, in whom tracheostomy was performed for initial airway access, confounds assessment of any specific effect of the method of airway intubation but emphasizes the importance of duration of intubation. In these study patients, airway sequelae were less frequent in those in whom a translaryngeal tube was in place for less than 10 days as compared to those in whom intubation exceeded 21 days, *i.e.*, those in whom tracheostomy followed translaryngeal intubation. Follow-up examina-

TABLE 7. *Effect of Duration of Intubation on Occurrence of Sequelae in Survivors*

	Translaryngeal Intubation		Translaryngeal Intubation Followed by Tracheostomy	
	Duration		Duration	
	0 to 21 Days	More than 21 Days	0 to 21 Days	More than 21 Days
Sequelae	2 (5)	0 (0.5)	1 (0.5)	6 (3)
No sequelae	7 (4)	1 (0.5)	0 (0.5)	0 (3)

( ) = Random expectation.

TABLE 8. *Group II: Autopsy Findings in Larynx and Trachea*

	Mild Pathology*	Moderate Pathology†	Severe Pathology‡
TL-tube§ only (n = 7)	1	3	3
Initial TL-tube with subsequent TT-tube‖ (n = 5)	2	3	0
Total	3	6	3

* Mild pathology = Minor erosions, mild tracheobronchitis.
† Moderate pathology = Ulcerations, moderate tracheobronchitis.
‡ Severe pathology = Loss of substance down to cartilage, severe tracheobronchitis.
§ TL = Translaryngeal (endotracheal).
‖ TT = Transtracheal (tracheostomy).

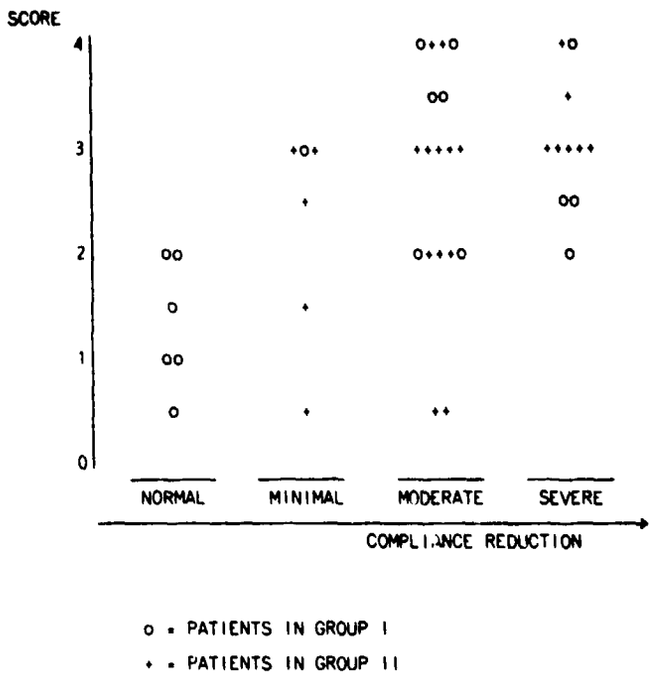

FIG. 1. Comparison of compliance reduction with inhalation injury score.

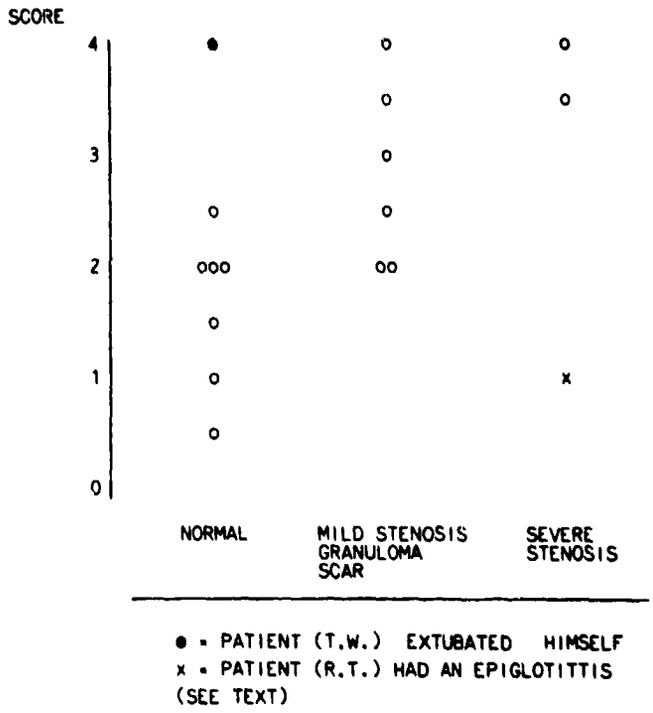

FIG. 2. Airway sequelae according to findings on follow-up bronchoscopy plotted against inhalation injury score (Group I).

tion to identify late sequelae and assess the anatomic status of the airway, therefore, should be carried out in all patients requiring airway intubation for more than 3 weeks.

The "inhalation injury scores" were significantly correlated with the reduction in pulmonary compliance (Fig. 1). Kendall's correlation coefficient for both groups ($n = 41$) was $r = 0.3864$ ($p = 0.001$), for Group I ($n = 17$) $r = 0.5112$ ($p = 0.006$), and for Group II ($n = 24$) $r = 0.3796$ ($p = 0.018$). When the "inhalation injury score" in Group I patients was compared to the degree of permanent tracheal damage as judged by bronchoscopy (Fig. 2), good correlation between high scores and tracheal pathology was found except for two cases. One patient had a low score (1.0) but developed severe stenosis. This patient developed *Hemophilus influenzae* epiglottitis as a possible contributory cause of stenosis (Fig. 3). The other patient had a high "inhalation injury score" (4.0), but extubated himself accidentally after only 2 days when he was still on the ventilator. He did surprisingly well, being able to breathe spontaneously at a time when by clinical assessment he was not considered a candidate for weaning from the ventilator. This illustrates that inhalation injury *per se* does not necessarily lead to tracheal stenosis when endotracheal or tracheostomy tubes are not required for prolonged periods and emphasizes once again the imprecision of clinical evaluation of ventilatory adequacy and the importance of limiting the duration of intubation. If the two special cases mentioned are excluded, we found significant ($p = 0.002$) correlation between high scores and severe sequelae (Kendall's correlation coefficient r

FIG. 3. Bronchoscopy photograph showing a web-like tracheal stenosis below the vocal cords (stoma level). Large structures at periphery of field are the vocal cords. The central triangular aperture is formed by the tracheal web.

FIG. 4. Xeroradiogram showing severe tracheal stenosis at the stoma level.

= 0.6701). In this study we were unable to demonstrate any correlation between the inhalation injury score and the duration of the subsequent ventilatory support. The fact that several patients with high scores expired early postburn may explain that finding.

Cuff pressures were not recorded routinely. In a total of seven patients in whom we had some difficulty in achieving an effective airway seal, cuff pressures above 25 cm H_2O were measured. Four of these seven patients were in Group I, and three out of these four patients developed verified tracheal sequelae (two with stenosis, one with granulomata). Although investigators have been more concerned about the duration of tube placement than cuff pressure,[5,6,11] we feel that these results emphasize the real danger of high cuff pressure injury to the underlying airway. Most authors seem to consider high volume/low pressure cuffs to exert similar effects when used with either endotracheal or tracheostomy tubes. Comparing currently used tracheostomy tubes and endotracheal tubes, there are obvious differences in the size and design of the cuffs. The endotracheal tubes have markedly bulkier cuffs and it is possible to achieve a seal in the trachea with less transmural cuff pressure than is the case with tracheostomy tubes. There is, however, a greater area of contact between the cuff of an endotracheal tube and the tracheal wall. This may result in more extensive denudation of tracheal mucosa.[8,21]

Our autopsy findings, as noted in Table 8, support that proposed mechanism of injury. With tracheostomy tubes, the contact area between the cuff and the tracheal wall may be smaller, but the pressure per unit airway area necessary to achieve an adequate seal may be considerably higher and thus cause greater tracheal injury. None of the surviving patients who had tracheostomies had normal findings on follow-up bronchoscopy The tracheostomy wound *per se* appears to be of even greater importance in terms of postintubation airway stenosis, since in all three of the patients with tracheostomies who developed tracheal stenosis, the narrowing occurred at the level of the stoma.

Although the grading of each variable comprising the inhalation injury score is in part based on what can only be considered subjective clinical assessment, the good correlation of that score with reduction in compliance, severity of tracheal injury, and subsequent sequelae is encouraging. Further studies will be necessary to verify the accuracy, reliability, and clinical usefulness of this scoring system.

Fiberoptic bronchoscopy was the most useful follow-up investigation in Group I (survivors), as it seemed sensitive enough to document all sequelae of clinical importance. The xeroradiograms were not sufficiently sensitive to identify minor yet symptomatic sequelae. Although xeroradiograms deliver a relatively high radiation dose to the patient,[17] they may be useful in quantifying the degree of stenosis that is relatively difficult to assess accurately by bronchoscopy. A reduction of the transverse air column diameter of the trachea greater than ten per cent in a distinct short segment has been proposed as a definition for tracheal stenosis by Stauffer et al.[1]

Five cases in the survivor group were of particular interest. One patient developed such severe tracheal stenosis that dilatation was required two times before the patient was discharged. In this case, the stenosis was detected both by bronchoscopy and by xerograms (Fig. 4). This patient had actual third degree burns to the soft palate and epiglottis. The four other patients illustrate the limitations of xeroradiography. In one case, the xerograms were completely negative, but a severe web-like stenosis at the tracheostoma level was confirmed by bronchoscopy (Fig. 3). In this patient a complication of epiglottitis (*Hemophilus influenzae*) may have contributed to the subsequent stenosis. To detect such a web-like stenosis, tomographic xeroradiography might be helpful.[18] In the third patient, several small granulomas on the anterior wall of trachea were detected by bronchoscopy (Fig. 5), but not on xerograms. Falsely negative xerograms also occurred in two additional patients who had positive findings (prominent scar, focal granuloma formation) by bronchoscopic examination.

Spirometry with registration of flow-volume loops was found to be the least reliable method for detection of upper airway sequelae in our study. Two patients had falsely positive and two others had falsely negative

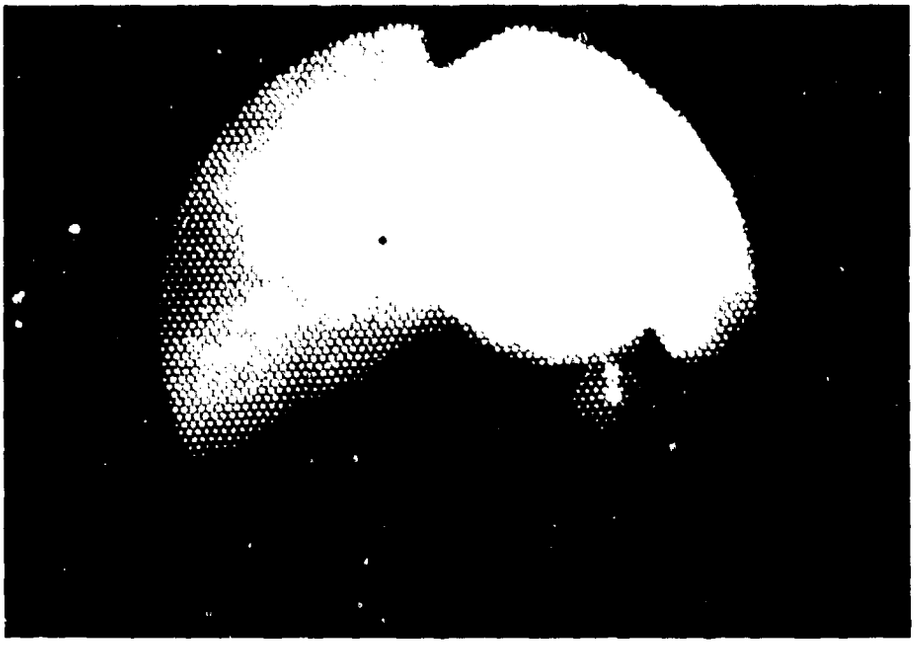

FIG. 5. Bronchoscopy photograph showing a granuloma protruding on the anterior wall of trachea.

spirograms (compared to findings by bronchoscopy/xeroradiography). This is in agreement with Stauffer et al.[1] who found this method not sensitive enough to detect minimal stenosis. Abnormal spirometry results may be due to nonoptimal patient cooperation, preexistent pulmonary disease, or the sequelae of direct injury to either the upper or lower airway. In this study, all three patients with severe tracheal stenosis had abnormal pathological spirometric indices. As a noninvasive technic, spirometry is attractive for screening patients likely to have significant airway narrowing. Whenever spirometry is positive, the diagnosis must be confirmed by fiberoptic bronchoscopy.

According to Dane and King,[6] the symptoms of tracheal stenosis usually start after an average 30-day free interval following extubation or decannulation (range 2–24 weeks). All but one patient in Group I had the follow-up investigations carried out 33 or more days (mean 78 days) after removal of the tube. There is still the possibility of later scar contraction and subsequent development of stenosis. A long-term follow-up was not included in this study but would identify any patient with later onset of stenosis.

It was remarkable that autopsy findings in 12 patients included significant destructive lesions in the airway of all patients. All these patients died with their artificial airway tubes *in situ*. The common finding was tracheobronchitis of various degrees with denudation of the mucosa in the upper third of the trachea (Table 8). The location of mucosal injury corresponded to the area of contact with the tracheal tube and particularly the cuff. The more frequent finding of severe tracheal destruction in the translaryngeally intubated patients may be explained by the severity of the inhalation injury in these patients, as all patients in Group II with translaryngeal tubes expired relatively early postburn with the tube *in situ*.

On the basis of both the clinical and autopsy findings in this study, it appears that duration of intubation is the predominant factor influencing development of late airway sequelae, with route of intubation exerting no discernible effect. The ease of translaryngeal intubation and the early complications associated with tracheostomy make the former means of intubation the route of choice for initial airway access. Tracheostomy is subsequently performed to reduce nasopharyngeal and laryngeal trauma and the risk of sinusitis[22] and to facilitate lower airway toilet in those patients in whom airway intubation will be required for more than 3 weeks.

Although they are easier to insert, nasotracheal tubes are usually considered to be more difficult to manage than tracheostomy tubes, especially in terms of adequate suctioning of the airways. In adult patients, our experience is that as long as the nasotracheal tube is not smaller than size 8 (the most common size used in this study was 8), we had no problem with suctioning. In this respect, even tubes of size 7 rarely were problematic. The fiberoptic bronchoscope can be passed easily through a number 8 tube (with certain precautions) when necessary for examination or toilet of the lower airway. On

the other hand, we did have major difficulties managing the tracheostomy tube in one patient. Because of tracheomalacia, we finally had to pass a tube meant for nasotracheal use through the stoma to achieve an adequate airway seal.

Conclusions

An inhalation injury score based on history, physical examination, bronchoscopic examination, and scintiphotographic findings correlates well with severity of airway injury and the subsequent occurrence of tracheal sequelae. On the basis of this study, we favor the use of nasotracheal tubes for initial airway intubation to avoid the early complications of tracheostomy in any burn patient requiring intubation. The incidence of late complications is directly related to duration of intubation which should be kept to a minimum regardless of the means of intubation. Follow-up fiberoptic bronchoscopy to document any airway injury/sequelae should be applied routinely to all patients in whom the duration of intubation exceeds 10 days. Xeroradiograms may provide additional information about the degree of tracheal stenosis. Although somewhat insensitive, spirometry, including assessment of flow volume loops, may be useful as a noninvasive screening method to identify patients with significant airway narrowing.

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