



Improved Survival of Burned Patients With Inhalation Injury

MAJ Loring W. Rue III, MC, USA; MAJ William G. Cioffi, MC, USA; Arthur D. Mason, MD;
COL William F. McManus, MC, USA; COL Basil A. Pruitt, Jr, MC, USA

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Objective: To study a cohort of patients treated at the same institution and to compare that patient population with that of a previous report documenting the comorbidity of inhalation injury and pneumonia. Specifically, we wanted to determine whether there had been an improvement in survival of patients suffering inhalation injury.

Design: A retrospective review.

Setting: The US Army Institute of Surgical Research, Ft Sam Houston, Tex, a 40-bed burn intensive care referral unit.

Subjects: One thousand two hundred fifty-six thermally injured patients treated between January 1985 and December 1990.

Main Outcome Measure: A comparison of pneumonia frequency and ultimate survival of the current cohort of patients as compared with a previously generated stepwise logistic analysis predicting mortality on the basis of 1980 to 1984 patient data.

Results: Of 1256 burned patients admitted between 1985 and 1990, there were 330 identified as having inhalation injury. These patients were older (35.0 vs 26.6 years) and had more extensive burns (41.1% vs 18.3%) and a higher mortality (29.4% vs 5.0%) than did the patients without inhalation injury. When compared with a mortality pre-

dictor generated from 1980 through 1984 patient data, patients in the most recent period had a lower mortality than predicted (29.4% vs 41.4%). Patients with less severe injury (positive xenon scan, negative results of bronchoscopy; n=85), although having a similar incidence of pneumonia (13.1% vs 19.5%) as the same group from 1980 through 1984, accounted for the most improvement in survival. The 3.6% mortality was significantly less than the predicted rate of 15.7%. Patients with positive results of bronchoscopy (n=245) also showed some improvement in outcome from that predicted (38.3% vs 50.2%) despite no change in the rate of pneumonia (46.9% vs 48.5%). Further improvement in survival was realized in those patients supported with high-frequency ventilation. Although their age (33.9 vs 36.3 years), burn size (46.0% vs 45.5%), and duration of intubation (16.8 vs 15.1 days) were similar to those of conventionally treated patients, mortality was significantly less than predicted (16.4% vs 40.9%) and less than that in patients treated with conventional ventilation (16.4% vs 42.7%).

Conclusions: The improvement in survival of patients with inhalation injury represents the aggregate effects of the general improvement and outcome of all burned patients, the prevention of pneumonia by high-frequency ventilation, and the reduced mortality from the pneumonias that did occur.

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From the US Army Institute of Surgical Research, Ft Sam Houston, Tex. Dr Rue is now with the Department of Surgery, University of Alabama at Birmingham.

IT HAS been estimated that as many as one third of burned patients have associated inhalation injury. This often lethal concomitant insult can initiate myriad respiratory complications. Typically, tracheobronchitis is caused by the inhalation of the products of incomplete combustion.² Tracheobronchial mucosal slough and airway obstruction from cellular debris lead to microatelectasis and pulmo-

nary septic complications. Indeed, pulmonary sepsis is the principal cause of death among burned patients today.³ The cutaneous burn induces the initiation of vari-

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PATIENTS AND METHODS

The records of 1256 thermally injured patients treated at the US Army Institute of Surgical Research, Ft Sam Houston, Tex, during the 6-year interval between January 1985 and December 1990 were reviewed. Routine demographic data were collected and included specific details regarding inhalation injury, such as the method of diagnosis, the need for and the mode of ventilatory assistance provided, the incidence of pneumonia, and the ultimate patient outcome. All patients received standard care regimens that were modified to satisfy individual patient requirements. The modified Brooke formula was used for resuscitation. All burn wounds were treated in a similar fashion with the topical application of silver sulfadiazine and mafenide acetate cream alternated every 12 hours. Patient care was undertaken in an open ward environment from 1980 through 1983 and in isolated temperature- and humidity-controlled rooms subsequently. Nutrition was initiated early after burn injury, almost exclusively via the enteral route. Excision and grafting were performed during the first week of hospitalization when indicated.

Clinical features, such as facial burns, expectoration of carbonaceous sputum, or receipt of burns while within an enclosed space, increased the suspicion of inhalation injury. In all patients, inhalation injury was definitively diagnosed by fiberoptic bronchoscopy and/or xenon 133 ventilation-perfusion scintigraphy. Positive bronchoscopic findings included carbon particles within the airway beneath the true vocal cords, mucosal erythema, edema, or ulceration. Xenon scintigraphy was considered positive when there was ventilation-perfusion mismatching or isotope retention for longer than 90 seconds.

Standard criteria for intubation and initiation of mechanical ventilation were followed. In the earlier years of the study, volume-limited ventilation was used. During the last 4 years, after meeting specific entrance requirements, many of the intubated patients with inhalation injury were treated with a high-frequency percussive ventilator as described in earlier reports from this institution.^{9,10}

During the critical care phase of illness, routine surveillance microbiologic cultures and daily chest roentgenograms were obtained in all patients. Pneumonia was defined as sputum leukocytosis (>25 white blood cells per high-power field), the lack of oropharyngeal contamination (<10 squamous cells per high-power field), the presence of a predominant organism on sputum culture, and an infiltrate on the chest roentgenogram. When clinically indicated, antibiotics were begun, the initial choice being directed by the results of Gram's stain of the sputum and later modified according to the culture results.

General statistical analyses for the differences between groups was performed by Student's *t* test or analysis of variance with the use of the BMDP statistical package. Mortality predictions were calculated on the basis of the stepwise logistic analysis of the 1980 through 1984 patient experience reported by Shirani et al⁷ and described by the following equations: $y = -3.4953 + 0.09589(\text{TBS}) - 0.19881(\text{Age}) + 0.0044788(\text{Age}^2) - 0.000020314(\text{Age}^3) + 0.59056(11) + 0.92530(\text{Pneumonia})$, where TBS indicates total burn as a percentage of total body surface area; Age, age in years; 11, absence or presence of inhalation injury (-1 or $+1$); and Pneumonia, absence or presence of pneumonia (-1 or $+1$); $P = e^y / (1 + e^y)$, where *P* indicates expected mortality (limits, 0 and 1).

ous inflammatory cascades, and the consequent uncontrolled intrapulmonary leukocyte and macrophage activation have an additive adverse effect on the lungs. A number of studies have demonstrated an increased incidence of nosocomial infection, length of stay, and cost of hospital care among patients who sustained inhalation injury.^{4,6} In a landmark study, Shirani and colleagues⁷ demonstrated that inhalation injury alone increased the age- and burn size-related mortality by as much as 20%. By means of a stepwise regression analysis, a mortality predictor for patients with inhalation injury was generated, with the major determinants of survival being age, burn size, and the presence of pneumonia and inhalation injury. That study also demonstrated that the combination of inhalation injury and pneumonia increased mortality by a maximum of 60% above that anticipated on the basis of age and extent of burn. Inhalation injury and pneumonia were found to be significant, independent additive comorbid factors of which the impact on mortality varied predictably with age and burn size.

Although fluid resuscitation, metabolic support, and wound management have contributed significantly to im-

proved survival in burned patients during the past several decades, inhalation injury remains a major obstacle to the successful outcome of the extensively burned patient. Indeed, our major therapeutic interventions, until recent years, provided only supportive care for the patient.⁸ To assess the effects of major improvement in ventilatory support and management, and recent advances in our understanding of the pathophysiologic characteristics of inhalation injury, we compared the complications and outcomes of a similar cohort of burned patients treated at the same institution with those described in the earlier study.

RESULTS

A total of 1256 thermally injured patients were admitted to the US Army Institute of Surgical Research during the 6-year period between January 1985 and December 1990. The mean ($\pm$ SEM) total body surface area burn for this cohort of patients was $24.3\% \pm 0.6\%$, and the mean age was 28.8 ± 0.6 years. One hundred forty-three patients (11.4%) died. Concomitant inhala-

Table 1. General Patient Demographics*

	Inhalation Injury	No Inhalation Injury
N	330	926
Age, y (mean±SEM)	35.0±1.0	26.6±0.6
TBSA burn, % (mean±SEM)	41.1±1.3	18.3±0.6†
Intubation frequency, % (No.)	79.5 (260)	11.4 (105)†
Pneumonia frequency, % (No.)	38.4 (127)	9.1 (84)†
Mortality, % (No.)	29.4 (97)	5.0 (46)†
Predicted mortality (1980-1984 predictor), % (No.)	41.4 (137)	7.3 (68)
95% CI, %	37.5-45.5	6.0-8.5

*TBSA indicates total body surface area; CI, confidence interval.

†P<.0001.

tion injury was identified in 330 patients (26.3%) by either fiberoptic bronchoscopy or xenon scintigraphy. **Table 1** compares the 330 patients with inhalation injury with the 926 patients without inhalation injury. In general, the patients with inhalation injury were older (35.0 vs 26.6 years) and had more extensive burns (41.1% vs 18.3%) than did those without inhalation injury. As expected, the patients with inhalation injury had a significantly higher mortality (29.4% vs 5.0%; $P<.0001$) than did the patients without documented airway injury. This 29.4% mortality was significantly lower than the 41.4% (95% confidence interval [CI], 37.3% to 45.5%) calculated by the predictor described above. Interestingly, there was a slight improvement over the expected outcome in patients without inhalation injury when compared with the mortality predictor generated from the 1980 through 1984 patient data. **Table 2** summarizes the patient demographic data of the two groups treated at different time intervals. Although the age (28.8 vs 31.0 years) and burn size (24.3% vs 30.7%) were similar between the two groups of patients, inhalation injury occurred less frequently (26.3% vs 35.5%) in the current group of patients, although the frequency of pneumonia was similar (17.3% vs 19.0%). Mortality was lower for the current group of patients than would be predicted from the 1980 through 1984 patient data (11.4% vs 16.2%; 95% CI, 14.6% to 17.9%).

The data were analyzed with respect to the presence or absence of inhalation injury. **Table 3** summarizes the comparison data for the groups with and without inhalation injury. Although the age (26.6 vs 27.0 years), burn size (18.3% vs 23.0%), and pneumonia frequency (9.0% vs 8.8%) were similar, patients without inhalation injury in the more recent period of review had a slightly lower mortality than predicted (5.0% vs 7.3%; 95% CI, 6.0% to 8.5%). For patients with inhalation injury, again, the age (35.0 vs 38.4 years), burn size (41.1% vs 44.8%), and pneumonia frequency (38.4% vs 37.8%) were similar between the two groups of patients. However, as previously noted, mortality was significantly lower than predicted

Table 2. Overall Patient Demographics*

	1980-1984	1985-1990
N	1058	1256
Age, y (mean±SEM)	31.0±0.9	28.8±0.6
TBSA burn, % (mean±SEM)	30.7±0.9	24.3±0.6
Inhalation injury, % (No.)	35.3 (373)	26.3 (330)
Pneumonia frequency, % (No.)	19.0 (201)	17.3 (217)
Mortality, % (No.)	22.6 (239)	11.4 (143)
Predicted mortality (1980-1984 predictor), % (No.)	...	16.2 (203)
95% CI, %	...	14.6-17.9

*TBSA indicates total body surface area; CI, confidence interval.

among the more recently treated patients (29.4% vs 41.4%; 95% CI, 37.3% to 45.5%).

Given the slight but significant improvement in predicted outcome for the patients without inhalation injury, but an apparent marked improvement in patients with inhalation injury, we sought to evaluate our cohort of patients with inhalation injury in greater detail and to compare specific outcomes with those of the earlier study. We defined patients with mild inhalation injury as those who had positive xenon scans but negative results of bronchoscopy, whereas patients with moderate to severe inhalation injury were defined as those with positive results of bronchoscopy. **Table 4** summarizes the findings with respect to inhalation injury severity in the recent patient cohort. Patients with less severe injury (N=85), although of a similar age (33.5 vs 35.6 years), had significantly smaller burns (26.2% vs 46.1%; $P<.0001$), significantly lower incidence of pneumonia (13.1% vs 46.9%; $P<.0001$), and significantly lower mortality (3.6% vs 38.4%; $P<.0001$) than did the patients with airway damage noted on bronchoscopy. These general demographic differences were sim-

Table 3. Data for the Inhalation Injury vs Non-Inhalation Injury Groups*

	No Inhalation Injury		Inhalation Injury	
	1980-1984	1985-1990	1980-1984	1985-1990
N	685	926	373	330
Age, y (mean±SEM)	27.0±1.0	26.6±0.7	38.4±2.0	35.0±1.0
TBSA burn, % (mean±SEM)	23.0±0.9	18.3±0.6	44.8±2.3	41.1±1.3
Pneumonia frequency, % (No.)	8.8 (60)	9.0 (84)	37.8 (141)	38.4 (127)
Mortality, % (No.)	9.6 (66)	5.0 (46)	46.6 (174)	29.4 (97)†
Predicted mortality (1980-1984 predictor), % (No.)	...	7.3 (68)	...	41.4 (137)
95% CI, %	...	6.0-8.5	...	37.3-45.5

*TBSA indicates total body surface area; CI, confidence interval.

†P<.05.

Table 4. Data for Patients With Inhalation Injury by Xenon Scan and Bronchoscopy Results*

	Xenon Scan Positive	Bronchoscopy Positive
N	85	245
Age, y (mean±SEM)	33.5±1.9	35.6±1.3
TBSA burn, % (mean±SEM)	26.2±1.8	46.1±1.6†
Intubation frequency, % (No.)	24.7 (21)	97.5 (239)†
Pneumonia frequency, % (No.)	13.1 (11)	46.9 (115)†
Mortality, % (No.)	3.6 (3)	38.3 (94)†
Predicted mortality (1980-1984 predictor), % (No.)	15.7 (14)	50.2 (123)
95% CI, %	10.5-21.5	45.6-55.1

*TBSA indicates total body surface area; CI, confidence interval.

†P<.0001.

ilar to those noted in the patient cohort treated between 1980 and 1984. Mortality in patients with both mild and moderate/severe inhalation injury was significantly lower than would be predicted from the earlier study.

Patients with mild inhalation injury made up a similar proportion of the total inhalation injury population in the current review as in the earlier report (25.8% vs 30.3%). **Table 5** summarizes the data. These patients

Mortality was significantly lower among the patients treated in the recent period

were of a similar age (33.5 vs 37.0 years) and had a similar burn size (26.2% vs 33.0%) and pneumonia frequency (13.1% vs 19.5%). However, the patients treated in the recent period had a significantly improved survival (3.6% observed vs 16.0% predicted mortality; 95% CI, 10.5 to 21.5%) compared with that estimated by the outcome predictor based on the 1980 through 1984 patient data. In fact, unlike in the previous report, these patients had a mortality similar to that seen in the non-inhalation injury group (3.6% vs 5.0%).

Similar improvements in outcome were noted for the bronchoscopically positive patients with inhalation injury (N=245) (Table 5). As with those patients with mild inhalation injury, similar age (35.6 vs 39.0 years) burn size (46.1% vs 50.1%), and pneumonia frequency (46.9% vs 48.5%) were noted for the patients with moderate to severe inhalation injury in both periods. Mortality, however, was significantly lower among the patients treated in the recent period (38.3% vs 57.7%; P<.05) and was significantly improved over that which would be predicted on the basis of the age, burn size, and pneumonia frequency (38.3% observed vs 50.4% predicted mortality; 95% CI, 45.6% to 55.1%).

Because pulmonary sepsis is a leading cause of mortality among the thermally injured patient with concom-

itant inhalation injury, and because we observed improved survival among the current cohort of patients despite an unchanged incidence of pneumonia, we sought to analyze the data from these patients in greater detail. Treatment regimens, in essence, were similar throughout the current study period, with the exception of the introduction of high-frequency percussive ventilation (HFPV) during the last 4 years of the study. We therefore sought to compare the patients with inhalation injury who required ventilatory support (N=260) with respect to the mode of ventilation used. **Table 6** summarizes the results. Although patients who received HFPV had a similar age (33.9 vs 36.3 years), burn size (46.0% vs 45.5%), and duration of intubation (16.8 vs 15.1 days) as conventionally ventilated patients, the incidence of pneumonia was significantly decreased in HFPV-treated patients (29.3% vs 52.3%; P<.001). In addition, mortality was significantly less than that of the patients treated with conventional ventilation (16.4% vs 42.7%; P<.002) and significantly less than would be predicted from the patient experience between 1980 and 1984 (16.4% vs 40.9%; 95% CI, 32.0% to 49.4%).

This subset of patients was further analyzed with respect to pneumonia frequency. Since HFPV was employed starting in 1987, we excluded patients treated in 1985 and 1986 from analysis. To define further the device-related pneumonia risk, we also excluded any patient in whom the diagnosis of pneumonia preceded intubation or occurred within 2 days of ventilatory support. In addition, pneumonias that occurred 10 days after extuba-

Table 5. Data for Patients With Mild and Moderate/Severe Inhalation Injury*

	Inhalation Injury			
	Mild		Moderate/Severe	
	1980-1984	1985-1990	1980-1984	1985-1990
N	113	85	260	245
% of total inhalation injury	30.3	25.8	69.7	74.2
Age, y (mean±SEM)	37.0±3.5	33.5±1.9	39.0±2.4	35.6±1.3
TBSA burn, % (mean±SEM)	33.0±3.1	26.2±1.8	50.0±3.1	46.1±1.6
Pneumonia frequency, % (No.)	19.5 (22)	13.1 (11)	48.5 (126)	46.9 (115)
Mortality, % (No.)	21.2 (24)	3.6 (3)†	57.7 (150)	38.3 (94)‡
Predicted mortality (1980-1984 predictor), % (No.)	...	16.0 (14)	...	50.4 (123)
95% CI, %	...	10.5-21.5	...	45.6-55.1

*Patients with mild inhalation injury had positive xenon scans and negative results of bronchoscopy; those with moderate/severe injury had positive results of bronchoscopy. TBSA indicates total body surface area; CI, confidence interval.

†P<.001.

‡P<.05.

tion were considered not to be related to the form of ventilatory support. In this subset of patients, HFPV-treated patients still had a lower incidence of pneumonia than conventionally treated patients (28.6% vs 36.9%), although the difference was not statistically significant. This comparison indicates a significant reduction in pneumonia frequency for all patients during the latter 4 years of the study.

The distinction between patients treated with conventional ventilation as compared with HFPV is even more apparent when only the patients with severe inhalation injury are considered. Again, similar ages (33.5 vs 36.2 years) and burn sizes (46.3% vs 46.4%) were noted in the two groups. However, patients with positive results of bronchoscopy who received support with HFPV had a significantly lower incidence of pneumonia (27.6% vs 53.6%; $P < .002$) and mortality (17.2% vs 45.3%; $P < .0005$) than did conventionally ventilated patients. Restriction of the analysis to patients treated from 1987 through 1990 revealed pneumonia rates of 29.0% and 38.8% for patients treated with HFPV and conventional ventilation, respectively ($P > .05$). Although some improvement in predicted outcome was observed in the conventionally ventilated group treated from 1985 through 1990 (45.3% observed vs 54.4% predicted mortality; 95% CI, 48.8% to 60.6%), the most pronounced improvement was noted among the HFPV-treated patients (17.2% observed vs 39.6% predicted mortality; 95% CI, 31.8% to 48.3%).

COMMENT

Numerous reports in the literature document disproportionately higher mortality when inhalation injury occurs concomitantly with burn injury.¹⁰⁻¹² A review by Merrell et al¹³ of 1458 patients noted three significant predictors of death after thermal injury: burn size, patient age, and the presence of inhalation injury. Zawacki and coworkers¹⁴ 1535-patient multifactorial analysis identified six independent factors that differentiated survivors from non-survivors after burn injury. Three of the six factors were related to the pulmonary subsystem: preexisting pulmonary disease, hypoxemia on admission, and airway edema noted on initial fiberoptic bronchoscopy. Thompson et al,¹⁵ in their report on the experience at the Shriners Burn Institute in Galveston, Tex, documented a significant difference in mortality when strict criteria for inhalation injury were applied to 1018 thermally injured patients. Those with inhalation injury had a 56% mortality, whereas those without inhalation injury had a 4% mortality.

Despite advances in fluid resuscitation, metabolic support, and wound management, all of which have contributed to improved survival of burned patients, the treatment of inhalation injury has been largely supportive and, as such, is thought to have little impact on patient outcome. Curreri and colleagues¹⁶ reviewed 937 burned patients treated between 1975 and 1979 and noted that in-

Table 6. Data for Patients With Inhalation Injury Given Conventional vs High-Frequency Percussive Ventilatory (HFPV) Support*

	Conventional	HFPV
N	199	61
% (No.) with moderate/severe inhalation injury	90.9 (181)	95.1 (58)
Age, y (mean $\pm$ SEM)	36.3 $\pm$ 1.6	33.9 $\pm$ 1.8
TBSA burn, % (mean $\pm$ SEM)	45.5 $\pm$ 1.8	46.0 $\pm$ 2.3
Pneumonia frequency, % (No.)	52.3 (104)	29.3 (17)†
Mortality, % (No.)	42.7 (85)	16.4 (10)‡
Predicted mortality (1980-1984 predictor), % (No.)	52.9 (105)	40.9 (25)
95% CI, %	47.6-58.3	32.0-49.4

*TBSA indicates total body surface area; CI, confidence interval.

† $P < .001$.

‡ $P < .002$.

halation injury was a major cause of death in 13% of admissions. When patients treated between 1975 and 1977 were compared with those treated between 1978 and 1979, the mortality for patients with concomitant inhalation injury decreased to a lesser extent than did that for patients with cutaneous injury alone.

The object of this study was to compare our recent experience with thermally injured patients suffering concomitant inhalation injury with the previous report from this institute.⁷ Although the patient age (28.8 vs 31.0 years), total body surface area burn size (24.3% vs 30.7%), and pneumonia frequency (17.3% vs 19.0%) were similar, the incidences of inhalation injury (26.3% vs 35.3%) and mortality (11.4% vs 22.6%) were lower in the cohort of patients treated in the more recent time interval. On first inspection, it might appear that the decrement in mortality could be attributed to the lower frequency of inhalation injury. However, mortality in all patient groups, with and without inhalation injury, was lower than would be predicted on the basis of data obtained from the earlier cohort of patients (11.4% observed vs 16.2% predicted mortality; 95% CI, 14.6% to 17.9%).

Despite recent reports to the contrary, improved outcome can be demonstrated among thermally injured patients who suffer concomitant inhalation injury. Many factors may account for this apparent improvement in survival, such as general advances in intensive care management, use of strict isolation-type infection control measures (including single-patient rooms), early accurate diagnosis and prompt effective antibiotic therapy of pneumonia once established, and improved ventilatory support for both prophylaxis and treatment of the sequelae of inhalation injury.

The significant improvement in survival among patients with mild inhalation injury (3.6% observed vs 16.0% predicted mortality; 95% CI, 10.5% to 21.5%), few of whom required ventilatory support, perhaps best reflects

improvements in overall intensive care management and the reduction in pneumonia lethality, given its similar frequency compared with the earlier study (13.1% vs 19.5%). As reported by Shirani et al,¹⁷ the use of patient isolation techniques, including single-bed intensive care rooms, has been associated with an overall improvement in survival among infected burned patients. In fact, unlike in the previous report, patients in the recent cohort with inhalation injury confirmed only on the basis of a positive xenon scintigram had no appreciable increase in mortality from that associated with the thermal injury alone (3.6% vs 5.0% mortality).

THE PATIENTS with moderate to severe inhalation injury, by virtue of the fact that gross airway damage is present, are at a higher risk for the complications of pulmonary sepsis and subsequent mortality than those patients with mild injury. This is supported by the data that showed a higher incidence of pneumonia (46.9% vs 13.1%) among the patients with moderate to severe airway insult. Nevertheless, improvement in survival was also noted in this group of patients, almost all of whom required mechanical ventilatory support. Although the incidence of pneumonia was similar to that of the earlier group of patients with moderate to severe inhalation injury (46.9% vs 48.5%), a significant decrement in mortality was realized (38.3% observed vs 50.4% predicted mortality; 95% CI, 45.6% to 55.1%) in these patients as well.

Further improvements in survival were observed among patients who required mechanical ventilatory support. For the conventionally ventilated patients, mortality was lower than predicted (42.7% vs 52.9%). This is considered to reflect general advances in the critical care of these patients during the past decade. More impressive, however, was the significant improvement in survival of patients treated with HFPV (observed mortality of 16.4% vs predicted mortality of 40.9%; 95% CI, 32.0% to 49.4%). In fact, it would appear that this new mode of ventilatory support is a significant factor responsible for the improvement in outcome of all patients with inhalation injury.

Sobel et al,¹⁸ in a comparison of two cohorts of patients treated at different time intervals (1977 to 1978 vs 1987 to 1988), claimed a decade without progress in the treatment of inhalation injuries. In this series, when all patients with inhalation injury were considered, the mortality decrease from 44.9% to 34.8% between the time periods was not a statistically significant difference. The authors decried these results in light of the "improvement" in pulmonary management during the decade of study. These improvements included routine invasive hemodynamic monitoring, arterial oxygen saturation monitoring, and aggressive pulmonary toilet; however, the ventilatory support devices used in that study were the conventional volume-limited type. In our recent patient cohort, even if one ex-

amines only the patients with severe inhalation injury during 1987 through 1990, marked improvements in outcome were noted among the patients treated with HFPV. Although the frequency of pneumonia decreased for patients treated with both types of ventilators, patients treated with HFPV had a significantly lower mortality (17.2% vs 35.7%; $P < .05$). Moreover, in the patients with severe inhalation injury, mortality was significantly less for the patients treated with HFPV than would be predicted on the basis of the earlier patient experience (17.2% observed vs 39.6% predicted mortality; 95% CI, 31.8% to 48.3%).

The use of HFPV may achieve comparable oxygenation at lower inspired oxygen concentrations and adequate ventilation at lower peak and mean airway pressures than does conventional ventilation.¹⁹ It is also thought to improve the clearance of endobronchial secretions and cellular debris.^{20,21} The combination of these factors tends to minimize the device-related pulmonary insult and maximize the therapeutic benefit of ventilatory support. In a previous report from this institute, Cioffi et al¹⁰ showed a significant decrement in pneumonia frequency (24%) and mortality (18.5%) among the first 54 patients with inhalation injury treated with prophylactic HFPV than would be predicted from the 1980 through 1984 patient experience. Consequently, we advocate the prophylactic use of HFPV in all patients with documented inhalation injury who require mechanical ventilatory support.

Current techniques of wound care and generic improvements in critical care have reduced the mortality of all burned patients, as evidenced by the increased survival of the comparison group of patients without inhalation injury. Although inhalation injury remains a lethal comorbid factor in thermally injured patients, its impact has been lessened during the latter half of the 1980s. This is especially evident during 1987 through 1990, when the frequency of pneumonia decreased significantly compared with 1980 through 1984 or 1985 through 1986. This decrement in pneumonia cannot be attributed to the type of ventilatory support but reflects our overall improvement in pulmonary care. Significant improvement in outcome for patients with mild inhalation injury has been noted in recent years, such that these patients have no appreciable increase in mortality from that associated with the cutaneous injury alone. Improvements in outcome were also realized among patients with severe in-

More impressive, however, was the significant improvement in survival of patients treated with HFPV

halation injury. The data presented suggest that the prophylactic use of HFPV was an important factor in the decrement in mortality among these patients. This ventilatory mode appears to have therapeutic benefits that facilitate the removal of endobronchial secre-

tions and cellular debris and thereby lessen the risk of life-threatening complications and increase the survival of burned patients with inhalation injury.

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DISCUSSION

Cleon W. Goodwin, Jr, MD, New York, NY: Dr Rue and his colleagues have continued the tradition of progressive improvement in burn care and survival, which began with the introduction of the burn center concept by the US Army and which this institute has extended by the generalized acceptance of large-volume crystalloid resuscitation to prevent burn shock and the use of topical antimicrobial chemotherapy to reduce the incidence of burn wound infection. Recent improvements in outcome have been more gradual and are related to the growing stature of surgical critical care and the direct provision of such complex care by the burn surgeon. In this report today, much of the clinical success is attributed to the use of high-frequency ventilation in patients with inhalation injury. Almost hidden behind this new technology is improved survival among the other patients treated by the US Army burn unit.

This paper poses a potential threat to those of us who work in urban burn centers. Patient outcome specialists, whether they be government agents or plaintiff attorneys, soon will be demanding that we adopt this expensive technology and that we equal these spectacular survival statistics. At the present time, most urban burn centers cannot equal the success presented here. Therefore, my questions are directed toward delineating reasons for our differences. A large proportion of our patients are in full cardiac arrest at the fire scene, have AIDS, are drug abusers, or have high carbon monoxide levels. This last comorbid condition causes intractable shock and early resuscitation failure. The US Army burn unit treats patients who usually are young active-duty soldiers or are civilians who by their ability to tolerate prolonged air medical evacuation represent a cohort of patients highly selected for survival. Do you have any data that demonstrate that your late-1980s patient group is equivalent to the early-1980s patient group? I point out that age, burn size, and the possibility of inhalation injury may not allow you to detect these distinctions.

The second question relates to the diagnosis of inhalation injury. You have introduced a new concept not previously used by your institute, including the early-1980s patient group. What are the physiologic bases for differentiating between mild inhalation injury documented by xenon scan from severe inhalation injury demonstrated by fiberoptic bronchoscopy? In fact, is xenon scanning of any prognostic significance given your finding of similar mortalities of patients with no inhalation injury and those with xenon-positive inhalation injury only? Xenon scanning is quite expensive and is not used in most civilian burn centers. In our burn center, patients who would be xenon positive and bronchoscopy negative would be lumped together demographically with the noninhalation patients in our injury statistics.

Lastly, these studies comparing conventional ventilation with high-frequency ventilation required a sustained, intense commitment to the pulmonary care of these patients. In a burn center with 12 full-time respiratory therapists for 20 ICU beds and with highly competent critical care surgeons, how much of these improvements in survival is due to the increased attention by the staff during the most recent period of study, the so-called Hawthorne effect?

I enjoyed the paper. It lends support to our efforts to improve care and expertise in our surgical critical care units. In spite of the tenor of my questions, I believe you have demonstrated effective new treatments as the burn survival curve incrementally creeps toward universal survival. I hope that government cost-containment policies do not define an injury severity that is too expensive to treat and thus prevent such studies as presented here today by Dr Rue and his colleagues.

David M. Heimbach, MD, Seattle, Wash: The authors compare mortality from burns in 1980 through 1984 to that in 1985 through 1990 and conclude that while there is an overall modest improvement, there is specific improvement in patients with moderate and severe smoke inhalation, which they attribute mostly to the institution of high-frequency jet ventilatory support.

I needn't remind anyone of the dangers of comparing two time frames during which the greatest advances in burn mortality in the history of burn care have been made. The advent of early burn excision and closure, sensible techniques to prevent cross-contamination, and provision of early and adequate nutrition by the enteral route have dramatically improved outcome throughout the country. While the authors minimize these other changes in their current study, in reality their overall mortality has improved by a factor of 2 (11% vs 23%), their mortality in patients without smoke inhalation is also twice as good (5% vs 10%), and their mortality in patients with smoke inhalation is not quite twice as good (29% vs 47%).

Pulmonary care is an art, and improved treatment may be as much dependent on the artistry, enthusiasm, and increased attention paid by the artist as to the technique that is selected. High-frequency ventilation was introduced in the early 1980s with enthusiastic reports of its efficacy in almost every setting where mechanical ventilation was required. However, subsequently there has been considerable disappointment in the results. In most ICUs, the technique has now been abandoned and the ventilators sit awaiting a new clinical setting where they might be useful. Have we found one? The proof of the pudding must await controlled trials. As do all interesting and clinically provocative papers, this one raises several questions.

1. The USAISR is unique among burn centers in using xenon 133 scans to diagnose smoke inhalation, as it is cumbersome, expensive, and requires the patient to leave the ICU. What data are available that abnormal scans with

normal bronchoscopy are due to acute smoke inhalation, and not to cigarette smoking or preexistent mild but otherwise asymptomatic pulmonary disease? The fact that there is no appreciable difference between your scan-positive group and patients not considered at risk for smoke inhalation implies that xenon scans by themselves are not very useful in identifying a group at risk.

2. There is a nonsignificant difference in the incidence of pneumonia with severe smoke inhalation (37% without HFPV and 31% with HFPV). In neither this nor your previous paper are we told of selection criteria for use of HFPV. One hundred eighty-one patients were not selected while 62 were. Some were treated before HFPV was available, but that is only during the first 2 years of the 6-year series. Have there been any randomized protocols in your patients? This series ends in 1990. Why have you not included your patients treated during the past 2 years?

3. This clearly is the sort of technique that requires a prospective study controlled for the type of ventilation with both modalities administered by the same group of impartial surgeons. I implore you not to fall into the same pitfall as our friends who run hyperbaric oxygen (HBO) chambers who now tell us it would be unethical to perform a randomized trial of HBO for carbon monoxide poisoning because "the data are so clear that HBO works."

4. Finally, will this technique survive after those surgeons currently most enthusiastic about it depart for other climes?

George Block, MD: The next discussant is Dr Flint. I don't know if he is going to discuss Dr Pruitt's paper or Dr Heimbach's paper; they are both of equal length.

Lewis Flint, MD, New Orleans, La: This is the first paper I am aware of that makes a claim for a specific pattern of ventilation resulting in improved outcome. Whenever this occurs it piques the interest of practitioners of surgical critical care and makes us wish to raise some corollary questions. Has the nature of inhalation injury changed over time? In other words, have the patients who sustained inhalation injury been inhaling different injuring substances in the later phases of your study as opposed to the earlier phases of the study? Certainly the ratio of severe lung injury to mild lung injury might give you some insight as to whether the nature of the injury has changed, but do you have some information regarding the type of inhalation that the patient had? Furthermore, have other practices changed in your unit along with the introduction of high-frequency ventilation, such as different kinds of surveillance for infection and different antibiotic use practices, different rates of intervention for the management of airway problems, such as therapeutic bronchoscopy, different types of intubation practices, such as the use of earlier tracheostomy? All of these might have had an impact on the results and need to be figured in before we have a blanket acceptance of

high-frequency percussive ventilation as the way to go in treating lung injury patients.

C. Edward Hartford, MD, Denver, Colo: As indicated, this paper suffers from the errors inherent in all longitudinal studies, and I think it is a leap of faith for us to accept some of the conclusions of the paper. For instance, in terms of the improved outcome, how did the authors correct for differences in organisms in the two groups or were they the same? Was there a use of different antibiotics? I think they changed the facilities during this period, and how did they correct for things such as changes in general pulmonary care and surgical care of their wounds?

The second question has to do with reemphasis on the point of xenon scanning as a valid tool for the establishment of inhalation injury. In the original paper from the Institute of Surgical Research there were some questions that this paper raised in terms of specificity and sensitivity, and I wonder if the authors have any additional information that corroborates whether or not this is an effective tool in establishing the diagnosis of inhalation injury.

Dr Pruitt: Dr Goodwin asked about the Hawthorne effect, and certainly that may be evident in terms of the overall improvement in all of the groups that were reviewed. Even so, there is a statistically significant effect in terms of outcome that is related to mode of ventilation. Sixty-six percent of our patients were received within the first 24 hours. We are the referral center for all of south Texas and receive many medically indigent patients because we are the burn center of last resort in this area. Consequently, our population is not much different than that of other urban centers. The indications for xenon scan can be confined to those patients in whom bronchoscopy is negative. It is possible to have distal airway injury and a negative bronchoscopic exam because of the small size of an aerosol's particles, which determines the site of deposition within the airway. Consequently, it would only be in those patients in whom there is a high suspicion of inhalation injury and a negative bronchoscopy that xenon scan would be relied on. That is our definition of a relatively minor injury as compared with a major injury, that is, a negative bronchoscopy and a positive xenon scan. In both the mild and severe injury groups there was an outcome improvement.

Dr Heimbach asked about the impact of ventilation

mode in the current period, and that was one of the findings in the study, that is, that there was a significant improvement in outcome related to mode of ventilation, and that was most evident in the patients with severe inhalation injury. There has been a change, and this addresses one of Dr Flint's questions and of Dr Hartford's questions in the frequency of causative organisms of infection, ie, *Pseudomonas* is an organism of historic interest and the most common organism causing infection in burn patients today is *Staphylococcus aureus*. There is a significantly lesser comorbid effect of the gram-positive organisms than that of the gram-negative organisms. That change is accounted for in the statistical comparison in the recent study period.

There is a difference in the pathogenesis of the disease being addressed in this study, ie, inhalation injury isn't ARDS. Dr Heimbach asked why high-frequency ventilation would be effective in inhalation injury when it is not for many of the other causes of ARDS. The difference reflects the fact that inhalation injury is an endobronchial injury and that it is in this form of pulmonary disease that the high-frequency ventilator prevents progressive atelectasis and progressive increase in the volume of lung involved. The fact that there is no difference in the mortality of the patients with mild inhalation injury and patients without inhalation injury is another indication of the effectiveness of high-frequency ventilation. I can't predict what will happen when the current staff leaves the ISR, but these data support continued use of high-frequency ventilation. The nature of the disease hasn't changed in the past decade, but Dr Flint asked if there is a difference in the gases that are inhaled. That is certainly possible in view of the wider use of plastics and the markedly irritant gases produced when they are burned. However, aldehydes are significant irritants produced by the combustion of wood products, and they may elicit a comparable pulmonary response.

We have not changed our antibiotic use, and our liberal use of bronchoscopy hasn't changed during the years of the study. We also had as many respiratory therapists at the beginning of the study period as at the end and use the same indications for tracheostomy. Dr Hartford, I have addressed the change in predominant organisms, and our indications for antibiotic therapy are just the same today as in the past.

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