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Respiratory Burns:

A Correlation of Clinical and Laboratory Results

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CONSEQUENT to the better control of wound sepsis, respiratory tract damage has become a more prominent cause of death in thermal burns.[4, 6, 7, 9] At present, treatment of pulmonary burns is based solely on clinical impressions.[5, 7, 8] There have been almost no laboratory investigations into this problem, primarily because of failure to develop an acceptable experimental model.[1, 3, 10]

During the past 2 years, various difficulties were encountered in the management of 27 patients with pulmonary burns (Table 1). Routine therapy, at least as is generally recommended, did not seem to be of appreciable benefit. Mortality was 89% in this group of patients.

A review of the cases revealed that certain errors in management were made, yet at the time these measures seemed to be the only possible way of salvaging the patient. There were no experimental results upon which to base a rational course of therapy. This dilemma led to a series of experiments in the laboratory, first to develop a pulmonary burn model and, secondly, to evaluate the methods of therapy available at present.

Clinical Experience

Patient Material. During the 24-month period ending December 31, 1965, 27 patients were admitted to the Surgical Service of Grady Memorial Hospital for treatment of pulmonary burns. The diagnosis was made if three criteria were satisfied: 1) flame burns involving the face (particularly the mouth and nose); 2) singed nasal vibrissae; and 3) burns sustained in a closed space. There were 11 additional patients who undoubtedly had received pulmonary burns, but were not included because of failure to meet all three criteria.

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TABLE 1. *Lethal Complications of the Pulmonary Burn. Experience in 27 Patients*

Type	No.	Died	Mortality (%)
Pulmonary insufficiency	5	5	100.0
Pulmonary edema	10	6	60.0
Pneumonia	14	7	50.0
Unrelated to pulmonary burn		6	
Totals (patients)	27	24	88.9

Ages ranged from 5 months to 88 years and there were 11 men and 16 women. Associated body surface burns varied from a minimum of 15% to a maximum of 98%.

As previously mentioned, all patients had physical signs which included burns of the face and nasal hairs. Additional findings on admission to the hospital were dysphagia in 22, cough in 17, dyspnea in 13, cyanosis in 8, soot-flecked sputum in 6, and some combination of pulmonary rales, rhonchi, or wheezes in 3. Chest roentgenograms on admission consistently failed to demonstrate any acute pulmonary changes. In general, radiologic evidence of pulmonary damage did not appear until at least 36 hours postburn.

Dyspnea was so severe in 8 patients that oxygen therapy was required immediately upon admission to the emergency clinic. Five of these had labored respirations and sternal retraction, similar to croup. However, in none did there seem to be any improvement following tracheostomy.

Positive findings on auscultations of the chest were always ominous if present at the time of admission. All three patients with such changes died in the first 24 hours. An additional 22 developed some combination of rales, rhonchi, and wheezes once fluid resuscitation had been instituted for body surface burns; yet it was usually 2 or 3 days postburn before these findings could be detected. Clinical evidence of pneumonia or pulmonary edema always preceded the roentgenographic confirmation of complications.

Treatment. The administration of humidified oxygen was routine. It was accomplished through a nasal catheter, via an oxygen tent, by means of a cuff or collar fitted around the tracheostomy, or by delivery from a positive pressure machine directly into the tracheostomy tube. A wetting agent was usually added to the solution in the humidifier bottle. Prophylactic antibiotic drugs were administered to 26 of 27 patients. In addition, an anti-inflammatory adrenal steroid was given to 10 in an effort to overcome bronchospasm, and three others received at least a single dose of aldosterone.

Bronchoscopy was seldom required. When any difficulty with pulmonary secretion developed, a tracheostomy was performed to permit more frequent aspiration of the tracheobronchial tree. On occasions, small amounts of saline or a saline-detergent mixture were injected into the tracheostomy cannula just prior to suctioning to facilitate more thorough removal of secretions.

Sixteen of the 27 patients underwent tracheostomy at some time during their hospital course. Delayed tracheostomy was usually performed as a semi-elective procedure in order that adequate lighting, equipment, and personnel might be available. Despite these precautions, it often proved a most difficult operation because of massive cervical edema and lack of cooperation by the hypoxic patient.

Results. Twenty-four of the 27 patients died, 18 as a direct consequence of the respiratory burn (Table 1). Ventilatory insufficiency resulted in five deaths within 36 hours of the time of burn. Despite tracheostomy, positive pressure ventilation with 100% oxygen, and steroid administration on a maintenance schedule, all patients who developed severe respiratory distress in the absence of pulmonary edema or secretory problems failed to survive beyond the first 3 hospital days.

Significant pulmonary edema developed in 10 patients and accounted for six deaths

(Table 1). Tracheostomy appeared to initiate the complications in six patients and four died within a few minutes of insertion of the tracheostomy cannula despite prompt institution of specific measures. Pulmonary edema was reversed in the other two patients by the immediate administration of oxygen by a positive pressure ventilator. Four patients developed pulmonary edema as a consequence of circulatory overload. This complication resulted from over-zealous administration of intravenous fluids to patients with pre-existing cardiac disease. Two of the four died.

Some degree of pulmonary sepsis was present in all patients who lived 2 or more days (Table 1). Seven developed septicemia originating from the lung, and six of these died. Positive blood cultures were *Pseudomonas aeruginosa* in five, hemolytic *staphylococcus aureus* in one, and a proteus species in one. Another death resulted from pulmonary sepsis in the absence of positive blood culture. In this case, autopsy revealed innumerable parenchymal abscesses from which *Ps. aeruginosa* was cultured. The remaining patients with pulmonary sepsis had sputum cultures of some combination of Pseudomonas, hemolytic staphylococcus aureus, a proteus species, or Klebsiella-Aerobacter. Measures directed toward good pulmonary toilet and appropriate antibiotics as determined by sputum cultures appeared to be of definite benefit, although not always life-saving.

The final six deaths were a consequence of complications unrelated to the pulmonary burn (Table 1). In two, however, pulmonary sepsis significantly contributed to death.

Comment. In the absence of profuse pulmonary edema or upper respiratory obstruction, pulmonary insufficiency has been uniformly fatal. Tracheostomy, oxygen therapy and other measures consistently failed to improve the situation. Autopsy usually demonstrates parenchymal hemorrhage and edema, vascular congestion, alveolar edema with a protein-rich fluid, and, probably most important, a disruption of the alveolo-capillary membrane. It is generally believed that these pathological changes are produced either by inhalation of noxious products or completion of gaseous combustion within finer radicles of the pulmonary tree. If structural alterations are sufficiently severe, fatal hypoxia results. Otherwise, fatal edema develops and becomes the more prominent feature several hours later. Adrenal steroids were used in an attempt to reverse the situation. However, aldosterone seemed only to make the progression from respiratory insufficiency to pulmonary edema more rapid and to make the pulmonary edema resistant to any form of therapy. On the other hand, the only definite benefit obtained with anti-inflammatory steroids was the interruption of severe bronchospasm. Mild pulmonary edema frequently became fulminating as soon as a tracheostomy had been performed. Only positive pressure ventilation was successful in reversing the process. Apparently, removal of the glottic barrier significantly decreased intra-alveolar pressure and thereby led to the development or progression of pulmonary edema. Thus there is some question as to the true value of early tracheostomy. In any event, the cuffed tracheostomy tube connected to a positive pressure respirator often proved life-saving, presumably through the restoration of more normal intra-alveolar pressure.

Pulmonary sepsis was another major problem. Antibiotics appeared helpful in the control of an already established pneumonia, but seemed uncertain as prophylaxis. The most important therapeutic measure was maintenance of good pulmonary toilet. Tracheostomy provided the most practical means of removing excessive secretions. Nebulizers also were of benefit, although at times they seemed to delay eschar maturation of the facial burn and thereby led to earlier burn wound sepsis.

Positive pressure respirators appeared to be a mixed blessing. For patients in refractory pulmonary edema, one of these machines often proved life-saving. However, during the first five days postburn, patients usually developed fulminating bacterial pneumonia from which they usually died. Cultures of the ventilator and patients' sputum consistently showed identical organisms, usually *Ps. aeruginosa*. Such evidence incriminates these machines as a source of massive innoculation of lung parenchyma through forceful insufflation of virulent bacteria. Certainly, damaged pulmonary parenchyma provides an ideal culture medium.

Several methods of sterilizing the machines were tried. Rinsing with solutions of acetic acid and mechanical cleansing reduced the number of organisms in the bacterial flora, but sterile cultures were never obtained. Only a few hours in the patient's room were required for the machines to become heavily contaminated with either *Ps. aeruginosa* or hemolytic *S. aureus*. Both organisms are abundant on any burn ward, and both have become refractory to routine hospital cleansing methods. Sterilization of the machine with ethylene oxide offered the only sure means of temporarily eradicating these bacteria.

Laboratory Investigations

This review of 27 patients provided an insight into certain aspects of pulmonary burns, yet no problem was actually solved. What influence do the various etiologic factors (such as heat, smoke, and humidity) have in determining the severity of a given pulmonary burn? Is it possible to develop an experimental model of the pulmonary burn in the laboratory animal? Finally, using such a burn model, what are the advantages and disadvantages of the various therapeutic measures commonly employed?

To answer these questions, several methods of producing pulmonary burns were tested.[1, 3, 10] The rat was the experimental animal, since it had previously provided a reliable preparation for evaluation of fluid therapy and burn wound sepsis.

Etiologic Factors

Temperature. Fifty-five anesthetized Sprague-Dawley rats (weighing 200 Gm.) were placed in a drying oven which had been preset to 70° C. Humidity was 10%. After 5 minutes, 5 animals were removed from the oven. After each additional minute, 5 more were removed until all animals had been retrieved. The rats were then observed in a survival study for 10 days. Autopsies were performed on animals that died. Two additional groups of 55 animals each were subjected to the same conditions, except that the temperature was 85° and 100° C., respectively. A similar survival study was carried out and again autopsies were performed on those that died.

At 70° C., there were no deaths after exposure for 12 minutes or less (Table 2). The mortality rate became 100% following exposure for 15 minutes. At 85° C., 12 minutes of exposure was the maximum that any animal survived; while at 100° C. all animals died after 9 or more minutes of exposure. Thus, the expected relationship

TABLE 2. *Influence of Temperature on Respiratory Burns. Timed Exposure to Various Temperatures (5 rats in each group; 10% humidity)*

Exposure Time (min.)	Mortality (%) at 10 Days Postburn		
	70° C.	85° C.	100° C.
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	40
9	0	0	100
10	0	20	100
11	0	80	100
12	0	100	100
13	20	100	100
14	40	100	100
15	100	100	100

of temperature to severity of pulmonary burn was confirmed.

Although animals were observed for a period of 10 days following burn, only six of 95 deaths occurred 4 hours or longer after removal from the oven. The majority were found dead in the oven at the scheduled time for removal, while others died immediately after being placed in their cages. Death usually was preceded by cyanosis, agitation and finally generalized convulsions. Autopsy uniformly revealed interstitial pulmonary edema and hemorrhage. Intra-alveolar edema was minimal although there was evidence of an alteration in the alveolo-capillary membrane.

Humidity. A similar study was performed on an additional 165 anesthetized rats. The oven was maintained at 95° C., but the humidity was established at 10, 70, and 100%, respectively, for each of the three groups of 55 animals. Five animals were removed from the oven every minute after the first 5 minutes. This gave an identical spread of 5 to 15 minutes for each of the three groups. Deaths were noted during a 10-day observation period, and autopsies were performed on animals that died. Terminal behavior and autopsy findings were similar to those in the temperature study.

No animal survived an exposure of 11 minutes or longer at 10% humidity (Table 3). At 70% humidity, 10 minutes was uniformly lethal, although four of five died when exposed for 9 minutes. No animal survived 7 minutes or longer when the humidity was 100%.

Increasing the humidity augmented the environmental temperature in producing a pulmonary burn. Part of this effect was a reflection of water vapor being a more rapid conductor of heat. Possibly more important, however, was the fact that a given volume of steam contains considerably more energy (expressed in calories of heat per ml.) than an equal volume of dry air. Thus the amount of thermal trauma inflicted on the lung becomes greater as the humidity of the inspired gas increases.

TABLE 3. *Influence of Humidity on Respiratory Burns. Timed Exposure to Various Humidities (5 rats in each group; 95° C. temperature)*

Exposure Time (min.)	Mortality (%) at 10 Days Postburn — Humidity		
	10%	70%	100%
5	0	0	0
6	0	0	60
7	0	0	100
8	0	20	100
9	0	80	100
10	60	100	100
11	100	100	100
12	100	100	100
13	100	100	100
14	100	100	100
15	100	100	100

Smoke. Pulmonary burns were inflicted on 220 rats by placing them in an oven preset to 95° C. There were four groups of 55 animals each. In one, the humidity was 100%; and, in another group, steam was used to obtain a humidity of 100%. The remaining two groups had humidities of 10 and 100%, respectively, with the addition of smoldering cotton to produce a thick haze of smoke. After 3 minutes of exposure to the environment, five animals were removed from the oven and five more were removed with each additional minute that elapsed. The animals were then observed for 10 days, with autopsy of those that died. Again, there appeared to be no difference from the other studies in the terminal behavior of the animals that died. No deaths occurred later than 2 hours following removal from the oven.

Those groups subjected to the combination of heat and humidity alone had mortality rates similar to those in the preceding study on humidity (Table 4). However, the addition of smoke significantly increased the lethal nature of the environment. No animal in either group survived more than 5 minutes of exposure to the

TABLE 4. *Influence of Smoke on Respiratory Burns. Timed Exposure to Smoldering Cotton Smoke. (5 rats in each group; 95° C. temperature)*

Exposure Time (min.)	Mortality (%) at 10 Days Postburn			
	10% Humidity		100% Humidity	
	Without smoke	With smoke	Without smoke	With smoke
3	0	0	0	0
4	0	0	0	60
5	0	80	0	100
6	0	100	20	100
7	0	100	100	100
8	0	100	100	100
9	0	100	100	100
10	20	100	100	100
11	80	100	100	100
12	100	100	100	100
13	100	100	100	100

combination of heat, humidity and smoke. When humidity was increased from 10 to 100%, fatal exposure time decreased to 4 minutes.

The importance of smoke in producing pulmonary burns has been debated. However, it appears that a heavy concentration of smoke is more damaging than 100% humidity and that it is almost as important as the temperature.

Experimental Model

Despite the reproducible mortalities obtained in the animals exposed to a heated environment, death occurred too rapidly to permit evaluation of a particular mode of therapy. Since steam insufflation of the lung had previously been used to create a pulmonary burn in other animals,[1, 3, 10] this method was investigated as a means of obtaining the desired experimental model.

Steam (at 10 mm. Hg pressure) was insufflated into the lungs of anesthetized Sprague-Dawley rats (200–300 Gm.) through a metal cannula that had been passed as an oral endotracheal tube. There were 10 animals in each of five groups. Durations of steam insufflation were 1, 2, 3, 4 and 5 seconds, respectively. A survival study was conducted for 10 days and all rats that died were autopsied.

No animal survived an exposure of 4 seconds or longer, and mortality was high except for the one second group (Table 5). There were only a few delayed deaths as most animals died within an hour following burn.

Autopsy consistently revealed considerable laryngeal edema, so severe as to completely obstruct the larynx. Pathologic changes in the lung consisted primarily of hemorrhage and edema, both of which were mild for shorter exposures. However, steam insufflation for 3 or 4 seconds produced extensive hemorrhage into the parenchyma. Nevertheless, it appeared that laryngeal obstruction was the immediate cause of death. In a few animals, tracheostomy was performed, and improvement in the animal's condition was dramatic. Because of the small caliber of the rat trachea and the necessity of a tracheostomy tube, this method of prolonging survival seemed too impractical.

It appeared that the metal cannula conducted a significant amount of heat and that the major damage had occurred in the larynx rather than in the lung. Other types of endotracheal tubes were tried and it was discovered that a plastic cannula, previously chilled in iced water, would permit passage of steam for 5 seconds without significantly damaging the larynx.

TABLE 5. *Respiratory Burns Produced by Steam. Times Exposure to Endotracheal Steam Insufflation (10 rats in each group)*

Exposure Time (sec.)	Mortality (%)			
	Metal Endotracheal Tube		Polyethylene Endotracheal Tube	
	At 4 hr. Postburn	At 10 da. Postburn	At 4 hr. Postburn	At 10 da. Postburn
1	10	10	0	10
2	50	60	10	30
3	80	90	20	80
4	100	100	80	100
5	100	100	100	100

An additional 50 rats were studied using this adaptation of the steam insufflation procedure (Table 5). With a 3-second exposure, the immediate mortality (at 4 hours) was only 20%, yet, at 10 days postburn, there was a final mortality of 80%. This preparation, therefore, seemed to offer an adequate period of time for the evaluation of treatment programs and it was accordingly designated as the pulmonary burn model for additional experiments.

Environmental Therapy

Using anesthetized Holtzman rats (200–250 Gm.), 384 pulmonary burns were produced by the steam insufflation method as described for the experimental model The animals were placed in groups of 48 each to evaluate methods of environmental therapy. These were: oxygen at 20, 30 and 40% concentration, humidity at 30, 80 and 100%, and the addition of a wetting agent (Alevaire) to the water vaporizer.

Special cages were constructed for housing the animals so that a desired environmental condition could be maintained. Accordingly, a large *oxygen tent* arrangement was placed around the individual cages. This permitted a constant concentration of the desired components. Oxygen and air flowed into the tents through tubes at a fixed rate and fixed humidity. Frequent samplings of the environmental atmosphere demonstrated that gas concentrations were not always constant, although they did remain within 5% of the prescribed figure.

Immediately after receiving a standard pulmonary burn, rats were placed in their cages and the selected environment established. Environmental conditions were maintained for 7 days, and the animals were observed for an additional 3 days. Parameters measured were: the number of survivors at 10 days postburn, average length of survival for those that died in each group, gross and microscopic autopsy findings of those that died and several of each group that were sacrificed, lung and blood cultures at the time of death or sacrifice, and lung specific gravity as a reflection of the degree of pulmonary congestion and edema.

TABLE 6. *Influence of Oxygen Content in Inspired Air on Mortality*
(Mortality 10 Days Postburn)

Oxygen Content	No.	Died	Mortality (%)
20%	96	67	69.8
30%	96	58	60.4
40%	96	44	45.8

Oxygen Concentration. There was no difference in any parameter between animals given oxygen at 20% and those that received oxygen at 30% (Table 6). However, there was a significant reduction in mortality from 69.8% in the control group to 45.8% in animals receiving oxygen at 40%. Otherwise, all groups were identical.

Humidity. Increasing the humidity definitely decreased mortality (Table 7). At a 30% humidity, the mortality rate was 83.4%. With 80% humidification, the mortality rate fell to 58.3%, while at 100% humidity, it was only 37.5%.

Another striking difference was reduction in the number of positive blood cultures (Table 8). These were reduced from 81.3% at 30% humidity to 25.0% when the environment had 100% water saturation. Although other parameters did not seem to be altered to any significant degree, there was a tendency for the animals that died to survive longer with increases in humidity.

It appears that humidification of inspired

TABLE 7. *Influence of Humidity of Inspired Air on Mortality*
(Mortality at 10 Days Postburn)

Humidity	No.	Died	Mortality (%)
30%	48	40	83.4
80%	144	84	58.3
100%	96	36	37.5

TABLE 8. *Influence of Humidity on Development of Septicemia (Positive Blood Culture by 10 Days Postburn)*

Humidity	No.	Positive Blood Culture	%
30%	48	39	81.3
80%	96	29	30.2
100%	96	24	25.0

air is of significant benefit to rats with pulmonary burns. Not only is mortality rate improved but, in addition, the incidence of fatal pulmonary sepsis is reduced. Humidification of inspired air dilutes pulmonary secretions and thereby facilitates pulmonary drainage.

Wetting Agents. A surface-active detergent (Alevaire) was added to the vaporizer in 2 groups exposed to an environment of 100% humidity. These were compared to controls treated with 100% humidity alone. There was no significant reduction in mortality rate (Table 9) or in incidence of positive blood cultures (Table 10) by the addition of Alevaire, although there was a trend toward improvement in both of these measures. Other parameters were not affected.

Comment. A reduction in mortality and incidence of septicemia was achieved by any increase in humidity or by a doubling of the oxygen content of inspired air. Wetting agents in the vaporizer seemed helpful, although improvement was not statistically significant. The lowest mortality rate of any group (25%) was obtained when a combination of 40% oxygen, 100% water saturation, and Alevaire mist were provided in the environment.

TABLE 9. *Influence of Wetting Agent in Vaporizer on Mortality: (Mortality at 10 Days Postburn)*

Wetting Agent in Vaporizer	No.	Died	Mortality (%)
Present	96	32	33.3
Absent	96	36	37.5

TABLE 10. *Influence of Wetting Agent on Development of Septicemia (Positive Blood Culture by 10 Days Postburn)*

Wetting Agent	No.	Positive Blood Culture	%
Present	96	20	20.8
Absent	96	24	25.0

Drug Therapy

Standard pulmonary burns were inflicted on 384 anesthetized Holtzman rats (200–250 Gm.). The animals were divided into multiple groups of 12 or 16 each and then immediately placed in special cages where an environment could be maintained at a fixed oxygen concentration and humidity. Drug therapy was instituted within 5 minutes postburn and daily intraperitoneal administration continued for 10 days, at which time the experiment was terminated. Daily dosages of the following drugs were evaluated: aldosterone (0.005 mg./Kg.), an anti-inflammatory adrenal steroid (Celestone, 0.1 mg./Kg.), aqueous penicillin (100,000 units/Kg.), and Gentamicin sulfate (Garamycin, 4 mg./Kg.). Several groups were given both penicillin and Gentamicin. Approximately half of the animals received one of the steroids (aldosterone or Celestone) as well as one or both of the antibiotics (penicillin and Gentamicin). Data were collected on the total number of rats that survived 10 days, average length of survival of those animals that died, gross and microscopic findings at death or sacrifice, lung and blood cultures, and lung specific gravity.

TABLE 11. *Drug Therapy in Pulmonary Burns. Influence of Adrenal Steroids on Mortality (Mortality at 10 Days Postburn)*

Steroid	No.	Died	Mortality (%)
Aldosterone	128	77	60.2
Celestone	128	104	81.3
None	128	67	52.3

TABLE 12. *Steam Insufflation Pulmonary Burn. Lung Specific Gravity After Burn (Averages for 80 Rats)*

Time	Specific Gravity
Normal	0.6676
1 Day postburn	0.8384
2 Days postburn	0.8850
3 Days postburn	0.8673
4 Days postburn	0.8650
5 Days postburn	0.8409
6 Days postburn	0.8400
10 Days postburn	0.7895

Aldosterone. The administration of aldosterone increased the mortality rate, but not to a degree of statistical significance (Table 11). More striking was the increase in lung specific gravity. At 2 to 3 days postburn, the average specific gravities for lungs of controls were 0.8850 and 0.8673, respectively (Table 12). However, rats treated with aldosterone had an average lung specific gravity of 0.9790 during the same 2-day period (Table 13). This was a reflection of increased pulmonary congestion and edema. Microscopic sections of lung confirmed the greater severity of these pathologic changes.

Other data were not significantly altered by administration of aldosterone. It was apparent that the marked retention of sodium and water as effected by aldosterone were detrimental, for at least part of the retained fluid and electrolyte was sequestrated into the pulmonary parenchyma. This phenomenon undoubtedly accounted for the small, though definite, increase in mortality.

TABLE 13. *Drug Therapy in Pulmonary Burns. Influence of Steroids on Specific Gravity (Average of 10 Rats in Each Group at 2 and 3 Days Postburn)*

Drug	Specific Gravity
Aldosterone	0.9790
Celestone	0.9075
None	0.8832

TABLE 14. *Influence of Adrenal Steroids on Development of Septicemia (Positive Blood Culture by 10 Days Postburn)*

Steroid	No.	Positive Blood Culture	%
Aldosterone	96	30	31.3
Celestone	96	62	64.6
None	96	27	28.1

Celestone. The administration of an anti-inflammatory adrenal steroid markedly increased mortality (Table 11). In controls, 52.3% died, while mortality increased to 81.3% in animals receiving Celestone. The average time of survival of animals that died was 1.7 days longer than that of controls. Delayed deaths appeared to be the result of sepsis. There was a twofold increase in the incidence of positive blood cultures in animals receiving Celestone (Table 14). Microscopic sections of the lungs consistently revealed a more extensive bronchopneumonia with more parenchymal abscesses than in animals not receiving steroids. Other measurements were not significantly altered.

Although the anti-inflammatory steroids may reduce the amount of pulmonary edema and congestion, associated reduction in resistance to bacterial infection more than offsets the advantage gained. Administration of antibiotic drugs did not improve mortality in this group.

Antibiotics. Antibiotics, whether single or in combination, consistently failed to alter the mortality rate (Table 15) or incidence of a positive blood culture (Table

TABLE 15. *Influence of Antibiotics on Mortality (Mortality at 10 Days Postburn)*

Antibiotic	No.	Died	Mortality (%)
Penicillin	96	50	52.1
Gentamicin	96	54	56.3
Penicillin & Gentamicin	96	48	50.0
None	96	56	58.3

TABLE 16. *Influence of Antibiotics on Development of Septicemia (Positive Blood Culture by 10 Days Postburn)*

Antibiotic	No.	Positive Blood Culture	%
Penicillin	72	26	36.1
Gentamicin	72	28	38.9
Penicillin & Gentamicin	72	23	32.0
None	72	27	37.5

16) in any one of the groups. There were no significant changes in other parameters.

Comment. Increased mortality resulted from administration of steroids. That from aldosterone was minor, although the drug led to more severe pulmonary edema and congestion through increased sequestration of fluid into the lung parenchyma. On the other hand, Celestone (an anti-inflammatory steroid) seemed to diminish the intensity of the pulmonary reaction to burning, but at the expense of a significant increase in lung sepsis. The result was a much higher mortality rate. Antibiotics appeared to play no role in the prevention of bacterial pneumonia, although in established bacterial infection they undoubtedly offered some benefit.

Discussion

There are three clinically recognizable stages through which a pulmonary burn progresses. Each phase is associated with a specific pathologic change in the lung. Early death represents the most severe form of pulmonary trauma. In milder degrees of pulmonary burns, the first two stages may not be obvious clinically, although all patients who survive at least 24 hours will develop some component of bacterial pneumonia at a later date.

Respiratory Insufficiency. The first pathologic phase lasts approximately 24 to 36 hours postburn. It is characterized by ventilatory insufficiency in the absence of airway obstruction or clinical evidence of pulmonary edema. There is cyanosis, diminished to absent breath sounds, and agitation which may progress to convulsions, coma, and finally death. Pulmonary secretions are minimal. Sternal retraction is probably the most striking finding and appears typical of upper respiratory obstruction. The volume of respiratory gas exchange is significantly diminished, although tracheostomy consistently fails to alleviate the situation.

The clinical course is similar to that seen in rats when pulmonary burns were inflicted in the drying oven. Terminal events and autopsy findings are identical. Hemorrhage into pulmonary parenchyma, interstitial edema, and disruption of the alveolo-capillary membrane are the major pathologic changes. Intra-alveolar edema is minimal if death occurs within the first few hours following burn, yet, if death does not occur for 24 to 36 hours, classical pulmonary edema becomes the most prominent feature.

At present therapy has consisted of tracheostomy, positive pressure ventilation with oxygen, and administration of one of the adrenal steroids in an effort to block the severe bronchospasm and to diminish the inflammatory response of pulmonary parenchyma. Despite these measures, mortality has not been improved. Tracheostomy has in no way increased the volume of respiratory exchange and has, on occasion, led to fatal pulmonary edema. Nevertheless, there have been several reports of proximal airway obstruction as a result of pulmonary burn, so that tracheostomy probably should be considered if other measures fail.

Ventilation with one of the positive pressure machines has not appeared to overcome hypoxia. In addition, massive inoculation of the pulmonary parenchyma occurs when contaminated equipment is used. Oxygen administered into a tent or through a catheter does not seem to carry this hazard. A tracheostomy humidification collar, and the head tent as developed by Bradley and collaborators[2] provide adequate oxy-

gen flows with 100% water saturation. By isolation of the respiratory tree, areas of surface burn are not moistened and thereby are permitted to develop a mature eschar at an early date. The head tent is especially suited for these situations and, with minor adjustment, may be easily fitted over the tracheostomy cannula.

Adrenal steroids are of questionable value. The administration of aldosterone definitely accelerates the development of pulmonary edema and, therefore, is contraindicated. This complication was seen both clinically and in experimental animals.

Anti-inflammatory steroids should be reserved for those patients who fail to respond to all other measures. Bronchospasm can be eliminated by the rapid intravenous injection of a large dose of one of the anti-inflammatory steroids, but maintenance doses of the drug are of little benefit and seem to predispose to the development of fatal bacterial pneumonia. However, if therapy with one of the positive pressure respirators is included, fatal pneumonia is assured. Forceful transbronchial inoculation of pathogenic bacteria into the *burned* lung becomes insurmountable if resistance against infection has been significantly diminished. Therefore, anti-inflammatory steroids should be recognized as a *one-shot* means of alleviating bronchospasm. A maintenance or withdrawal dose is contraindicated. Massive amounts of appropriate antibiotics may later be required for those patients who have received such steroid therapy.

Pulmonary Edema. Transudation of fluid into the bronchial tree seldom occurs prior to the eighth hour postburn. It usually develops after fluid resuscitation re-expands the extracellular fluid compartment and, therefore, at the time that adequate urine flow is established. All efforts at reversal of the process have proven fruitless with the exception of positive pressure ventilation. By increasing intrabronchial pressure, fluid transudation is decreased and edema gradually subsides.

A fulminating type of pulmonary edema occurs in one of two situations. The first is when intrabronchial and intra-alveolar pressures have been significantly reduced through elimination of intermittent glottic obstruction to expiration. This usually develops within a few hours following tracheostomy.

The other situation is when over-hydration in a patient with a pre-existing cardiac lesion produces circulatory overload. Fluid restriction and specific medications may prove helpful, although recourse must often be made to the positive pressure respirator. Therefore, in the patient with some degree of cardiac decompensation, it is wise to proceed with hydration at a slower pace, to give more colloid and less electrolyte solution than normally and to administer a digitalis preparation as a prophylactic measure.

Positive pressure ventilation may be accomplished through a cuffed tracheostomy tube, by means of a mouthpiece in the cooperative patient, or through an orally passed endotracheal tube in the comatose patient. All tubes and connectors should be as sterile as possible. Sterilization with ethylene oxide is preferred, although mechanical cleansing will suffice provided the apparatus has been thoroughly cleaned and dried prior to use. If positive pressure therapy is continued for longer than 1 to 2 hours, antibiotic prophylaxis should be considered.

Bacterial Pneumonia. Bacterial pneumonia is the third and final stage through which all pulmonary burns must pass. It is a more lethal complication in patients who have previously been treated with the positive pressure ventilator or steroids or both. Administration of antibiotic drugs, even in massive doses, has consistently failed to prevent the development of this complication.

Autopsy has shown the condition to be

more than a simple bronchopneumonia. Multiple abscesses are seen in the pulmonary parenchyma, which do not appear to communicate with the bronchial tree. As a result, septicemia is more likely to occur. Bacteriologic cultures consistently demonstrate that the most virulent organisms on the burn ward are responsible for the pneumonia. In the first few days, the majority are produced by a penicillin-resistant *S. aureus*. However, antibiotic therapy changes the flora to gram-negative organisms within 3 or 4 days. *Ps. aeruginosa* becomes the dominant flora once secondary invasion has developed.

Maintenance of a good bronchial toilet is the most important therapeutic measure. This can be achieved through humidification of inspired air or oxygen, tracheostomy with frequent suctioning, and an occasional therapeutic bronchoscopy. Daily cultures of pulmonary secretions should be obtained to assure appropriate antibiotic therapy. When the flora of the pulmonary parenchyma changes from gram-positive to gram-negative, the antibiotic program should be altered accordingly. Small doses of antibiotic drugs will only lead to the evolution of resistant strains. Therefore, near maximal doses should always be used.

If there is a large surface component to the burn, every effort should be made to delay administration of antibiotics. Systemic administration of these agents has been shown to alter wound flora and to lead to an earlier development of lethal burn wound sepsis. Consequently, antimicrobial agents should be reserved for patients who have not responded to all other measures of treating the pneumonia.

Summary

A review was made of 27 patients who had sustained pulmonary burns; 24 deaths produced an 89% mortality rate.

Etiologic factors in the production of pulmonary burns were investigated in the laboratory animal. These studies indicated that smoke and humidity were as important in the production of pulmonary burns as was temperature.

An experimental model of the pulmonary burn was produced by steam insufflation of the tracheobronchial tree in the rat. Several methods of treatment were evaluated. Humidity and oxygen were of definite benefit. Adrenal steroid therapy appeared to be contraindicated, and antibiotic drugs were of questionable value.

Pulmonary burns pass through three stages (respiratory insufficiency, pulmonary edema, and bacterial pneumonia). These clinical phases could be correlated with definite pathologic changes. Successful management of pulmonary burns depends upon the clinical stage to which the patient has progressed and upon the timely institution of appropriate therapeutic measures.

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