Hypoxemia in the Burned Patient: *

A Clinical-Pathologic Study

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ALTHOUGH physicians have been highly successful in treating the initial shock phase of an acute burn, the mortality rate in patients with extensive burns has not improved significantly over that reported by Sneve in 1905.[22] Pulmonary abnormalities in the burned patient have been described in a number of reports.[15-17, 25] It has even been suggested by one group that following thermal injury respiratory tract damage is the prime cause of death.[16]

Three investigators have measured oxygen and carbon dioxide in the arterial blood of acutely burned patients to determine if a deficiency in blood-gas exchange occurs. In 1943, Richards[18] noted that in 12 of 19 patients studied, arterial oxygen saturation varied from 81 to 88 per cent. Desaturation persisted for three to seven days after injury and frequently occurred in the absence of pneumonia or recognizable pulmonary pathologic change. Baxter,[3] in 1957, found that arterial oxygen saturation and oxygen tension diminished as the total body surface burn increased. The latter investigator also found that in a few patients with extremely low oxygen saturation and tension, administration of 100 per cent oxygen did not improve oxygenation as much as was anticipated. Baxter was unable to determine the cause of the hypoxemia. Birke *et al.*,[4] in 1959, found low oxygen saturation in seven of eight patients studied. Only in the study by Birke was complete clinical and postmortem data presented in conjunction with blood-gas analyses. Many of these patients were in the older age group (average age—49).

It is the purpose of the study here reported to attempt to determine the magnitude of ventilation and oxygenation defects in the burn patient population at the Surgical Research Unit (S.R.U.), Brooke Army Medical Center. Since the S.R.U. functions as the burn referral center for the United States Army, many young, healthy adults are admitted with no preexisting respiratory, or cardiac problems. It is believed that this is an aid to the study of the effect of the burn injury itself.

In a preliminary investigation by the authors it was found that in 21 previously healthy burned adults, oxygen saturation of hemoglobin was diminished in seven.[10]

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Better definition of the nature of problems in oxygenation was attempted in the present investigation by a correlated study of blood gases and pH, clinical signs and characteristics, and postmortem pathologic changes.

Methods

Fifty-six arterial punctures were performed on 28 acutely burned, young, adult patients admitted to the Surgical Research Unit during the period of January to August 1962. All patients studied had no history of previous cardiopulmonary disease. They were selected especially if a face burn was present, or the burn index† was greater than 20, and only if admission to the S.R.U. was within five days of the burn injury. Specimens were collected on more than one occasion whenever possible if a low oxygen tension was found at any time, or if a patient with a previously normal oxygen tension developed a pulmonary problem.

Following local infiltration of 1.0 per cent lidocaine, femoral artery puncture was performed in all but one instance (brachial). Duplicate specimens were collected anaerobically in heparinized syringes, immediately iced, and analyzed separately within 20 minutes. If the patient was receiving oxygen, it was discontinued 25 minutes prior to puncture.

The specimens were analyzed for oxygen tension, oxygen saturation, carbon dioxide tension, and pH. All results were compared to those determined in a group of ten healthy adults.

Oxygen tension (P_{O_2}) was measured using an Instrumentation Laboratory (I.L.) micro-electrode of the Clark design,[5] employing a polyethylene membrane. The electrode was calibrated with previously analyzed tanks of different oxygen concentration. Gas calibration was compared to blood calibration and the former reading was found to be 2.0 per cent less than the latter after air equilibration. Due to this small difference, and the greater speed and convenience of gas calibration, this was used throughout. All results using this technic were compared to the values obtained by the same method from a control group. Oxygen saturation was measured spectrophotometrically according to the method of Nahas.[14] This method had previously been compared to the standard manometric Van Slyke in this laboratory and results agreed within ± 0.8 per cent.[10]

pH was measured with a Cambridge Research Model R pH meter or with an Instrumentation Laboratory Sanz electrode. Carbon dioxide tension (P_{CO_2}) was determined directly with an I.L. P_{CO_2} electrode of the Severinghaus design,[20] or indirectly. In the latter case plasma carbon dioxide content was determined using the manometric method of Van Slyke and Neill.[24] This value was corrected to 37° C. Plasma bicarbonate was calculated by subtracting the gaseous, dissolved carbon dioxide from total carbon dioxide content.[9] P_{CO_2} was derived from the plasma bicarbonate and pH values using the Henderson-Hasselbalch Equation.[9] Readings with the P_{CO_2} electrode were generally 1.0 mm. Hg higher than when the indirect method was used. No effort was made to correct for this small difference.

After an initial control measurement was made with the patient breathing air, 95 per cent * oxygen was administered to seven patients with diminished oxygen tension. Oxygen was given to six through a cuffed endotracheal tube inserted through the tracheostomy stoma, and to one by

† The sum of the percentage of third degree plus half of the percentage of second degree burn.[19] Burn index was utilized throughout this study in an attempt to weight the relative severity of problems arising from the third degree burn more heavily than the second.

* It was intended that 100% oxygen be given. However, upon completion of the study, the wall oxygen source was checked and noted to be supplying only 95% oxygen.

TABLE 1. *Arterial Blood Gas and pH Measurements in Patients Breathing Air*

Groups	No. Patients	No. Observations	P_{O_2} (mm. Hg)	O_2 Sat. %	P_{CO_2} (mm. Hg)	pH
Burned-low tension*	17	36	61 ± 2***	92 ± 0.5	31 ± 1	7.48 ± 0.01
Burned-normal tension**	11	14	83 ± 2	96 ± 0.2	31 ± 1	7.44 ± 0.01
Unburned normals	10	10	83 ± 2	95 ± 0.2	33 ± 1	7.44 ± 0.01

* Less than 75 mm. Hg. P_{O_2} (See Text).
** Greater than 75 mm. Hg. P_{O_2}.
*** Standard Error.

face mask. A demand system employing a nonrebreathing valve was used. Arterial blood specimens were collected after 25 minutes and analyzed for P_{O_2}, P_{CO_2}, and O_2 saturation. Results were compared to six adults in the control group who breathed oxygen by mask through a nonrebreathing valve for 15 minutes while in the supine position. Although 15 minutes is more than sufficient for nitrogen washout and oxygen replacement in the control group, the patients breathed oxygen for 25 minutes to allow for abnormal distribution and delayed excretion of nitrogen.

Oxygen uptake was determined in six patients with diminished oxygen tension and results compared to burned patients with normal oxygen tension and to standard tables based on surface area. All values are reported standard temperature and pressure (dry). The measurements were made with a Benedict-Roth spirometer and all patients were at least four hours post prandial.

The clinical status of the patient was recorded at the time of each puncture by two of us (B. S. E., D. L. H.). Pertinent data such as results of chest x-ray, method of burning, nasal or pharyngeal injury, extent of burn, age, sex, therapy, and postmortem findings were also noted. Postmortem examination was performed by one pathologist thoroughly familiar with burn pathology (C. T.).

Statistical correlations and standard errors were calculated by the usual methods.[2, 21]

Results

The lowest oxygen tension (75 mm. Hg) was found in the unburned control group. This value was used to separate the 28

TABLE 2. *Arterial Blood Gas and pH Measurements in Seven Hypoxic Patients* and Five Unburned Controls While Breathing Air and 95% Oxygen*

	No. Observations	P_{O_2}		O_2 Saturation	
		Air	95% O_2	Air	95% O_2
Burned**-low tension	9	59 ± 1	469 ± 17	92 ± 0.1	99 ± 0.1
Unburned control	5	83 ± 2	430 ± 25	95 ± 0.2	100 ± 0.1
		P_{CO_2}		pH	
		Air	95% O_2	Air	95% O_2
Burned-low tension		30 ± 2	30 ± 1	7.51 ± 0.001	7.50 ± 0.001
Unburned control		33 ± 1	32 ± 1	7.44 ± 0.001	7.45 ± 0.001

* Patients No. 1, 2, 4, 6, 12, 13, 14 in appendix.
** Burn index ranged from 18–90; mean 48.

TABLE 3. *General Characteristics of Burned Patients—Low Oxygen Tension Group vs. Normal Oxygen Tension Group*

P_{O_2} Group	No. patients	P_{O_2} (mm. Hg)	Age	Burn Index	No. Patients: Burn of Mouth–Nose Area	No. Patients: Pulmonary Problems Clinical or x-ray	No. Patients: Deaths
Low	17	61*	29 (19–49)**	44 (14–90)	15	11	11
Normal	11	83	23 (19–27)	24 (4–82)	9	1	2

* Mean
** Range.

burned patients into low tension and normal tension groups.

I. Blood-Gas Measurements. The arterial blood gas and pH data for the patients breathing air are presented in Table 1. The mean P_{O_2} values for the burned group with low oxygen tension were 22 mm. Hg less than the burned, normal tension group and the unburned controls. This lowered oxygen tension was also reflected as a decreased percentage of hemoglobin saturation (92 vs. 96, 95). The P_{CO_2} for the three groups was essentially the same (31 vs. 31, 33 mm. Hg) and was lower than the generally accepted mean value of 40.[11] In the low P_{O_2} group the pH values were slightly elevated compared to the controls and were above values reported in the literature as the upper level of normal.[11]

The results of administering 95 per cent oxygen to seven of the hypoxemic patients and to five normal volunteers are reported in Table 2. Both the hypoxemic patients and the unburned control group reached a similar maximum P_{O_2} (469 and 430 mm. Hg) and percentage saturation of hemoglobin (99 and 100). The effect on carbon dioxide tension and pH was negligible. The measurements were made from four to 15 days post-injury. There was no observable relationship between the time post-injury and the response to breathing oxygen.

In nine of the 17 patients with a diminished P_{O_2} (Patients 1, 4, 6, 11, 14, 15, 16, 17 in appendix *), oxygen saturation was above 94 per cent. This was usually associated with a high blood pH. In six cases this value exceeded 7.48 and in the others it was on the extreme high side of normal (see discussion).

Oxygen utilization was elevated in the hypoxemic burned patients as compared to resting basal values in health adults [1] (228 $\pm$ 15 vs. 105–186 ml./m.^{2}/min.). This slight increase in oxygen uptake was also noted in the burned patients with normal arterial oxygen tensions (222 $\pm$ 25).

II. Characteristics of Patients and their Relationship to Measured Data. The burned group with low oxygen tension was compared to the burned group with normal oxygen tension as follows (Table. 3):

Age. Three patients in the low oxygen tension group were older than 40 years of age but less than 50; however, there was no appreciable age difference between the two groups.

Burn Index. The burn index in the low tension group was considerably greater than in the group with a normal tension.

* See footnote, page 1 of paper.

TABLE 4. *Specific Characteristics of Burned Patients—Low Oxygen Tension Group vs. Normal Oxygen Tension Group*

Po_2 Group	Area of Mouth & Nose: 2° and/or 3° Burns: Yes	Area of Mouth & Nose: 2° and/or 3° Burns: No	Depth of Burns: 2°	Depth of Burns: Deep 2° or 3°	Singed Nasal Hairs	Injection, Burn or Edema of Pharynx	Method of Burning: Flash	Method of Burning: Flame	Place of Burning: Outdoors	Place of Burning: Indoors of Enclosed Space
Low (17)	15	2	5	10	3	5	1	16	6	11
Normal (11)	9	2	7	2	2	1	0	11	4	7

Relationship of Oxygenation to Burn Index. The initial P_{O_2} readings in the patient were correlated with the logarithm of the burn index. As burn index increased, P_{O_2} decreased ($r = -0.52$; $p < 0.01$—Fig. 1). This relationship did not hold for oxygen saturation and burn index ($r = -0.29$; $p > 0.10$). When the P_{O_2} values were plotted against burn index separately in three postburn time periods (1–4 days, 5–8 days, 9–21 days), the relationship between P_{O_2} and burn index was statistically significant in all periods ($r = -0.56$, -0.55, -0.73, respectively).

Pulmonary Findings—Clinical or Chest X-ray. Eleven patients with low oxygen tension had evidence of pulmonary problems clinically or by x-ray. In nine, the diagnosis was evident on auscultation of the chest. Rales occurred in eight patients; wheezing, in four. In only five patients was an x-ray helpful. In only one patient with a normal P_{O_2} was there clinical or x-ray evidence of pulmonary disease.

Deaths. Eleven patients died in the hypoxemic group compared to two in the group with a normal tension.

Burns of the Face. The presence of a burn of the face was included only if the areas around the mouth and nose were involved—the so-called respiratory area.[15] Two of the patients in the low oxygen tension group as well as two in the group with a normal tension were free of burns in this area. Burns of the face were further classified into second degree vs. deep second, or third degree (Table 4). Patients in the low tension group had more severe burns of the face than those in the group with a normal tension.

Irritation of the Nasopharynx. Singed nasal hairs were noted upon admission in three instances in the low tension group; two, in those with a normal tension. Five patients in the former group had signs of injection, burn, or edema of the pharynx; one, in the latter. These findings were listed only if mentioned in the physical examination performed by the attending physician. Occasionally, this information was not noted. In addition, the pharynx of several patients was not examined due to severe edema of the face and inability to open the mouth.

Method and Location of Burning. In the 28 patients studied, all but one received a flame burn. An equal percentage of patients in the low tension group and normal tension group were burned indoors or in an enclosed space.

III. Autopsy Findings Relevant to the Problem of Blood-Gas Exchange. Postmortem examinations were performed on 11 patients in this series. The most frequent cause of death at autopsy was septicemia secondary to burn wound infection (seven patients). The causes of death in the remaining four were gastrointestinal bleeding secondary to Curling's ulcer;[1] uremia;[*1] and circulatory failure.[2]

A variety of respiratory tract abnormalities were present at autopsy. Aside from the presence of edema and congestion, only

* In this patient, the initial fluid therapy was inadequate in the three days prior to admission to the S.R.U.

a minority of the cases had pulmonary pathology of sufficient severity to cause a serious disturbance in blood-gas exchange. The pulmonary alterations will be discussed below. The appendix should be consulted for alterations in the individual patients.

Upper Respiratory Tract and Tracheobronchial Tree. Despite the presence of severe burns of the face, upper respiratory tract pathology above the level of the tracheostomy site was found in only one case (focal, slight, nonobstructive laryngitis). In four patients, there was no alteration in the upper respiratory tract; however, there was an erosion of the anterior tracheal wall at the point of contact of the distal portion of the tracheostomy cannula. An associated secondary bacterial infection at the site of the erosion was noted in three of the four cases—one, a severe, focal, necrotizing tracheitis. Lesions of the bronchi were either a focal erosion secondary to trauma from a suction catheter, or an extension of a necrotizing tracheitis which orginated at the site of erosion by the cannula (one case).

Lung. *Thrombo-emboli.* Rare, septic, microarterial emboli occurred in three cases, but were not widespread and were, therefore, considered significant only as a manifestation of generalized sepsis.

Intra-alveolar changes. In seven patients, scattered intra-alveolar red cells and macrophages were present, but the changes were minimal; in two others, they were severe. One case showed intra-alveolar macrophages, hemorrhage, and protein deposition (severe) and another, extensive intra-alveolar hemorrhage.

Atelectasis. Although atelectasis was present in six patients, five had only slight, focal incomplete atelectasis. In two of these, this was evident only on microscopic examination. In one patient, a diffuse, but patchy atelectatic pattern involving approximately 40 per cent of the total pulmonary parenchyma was noted. Careful

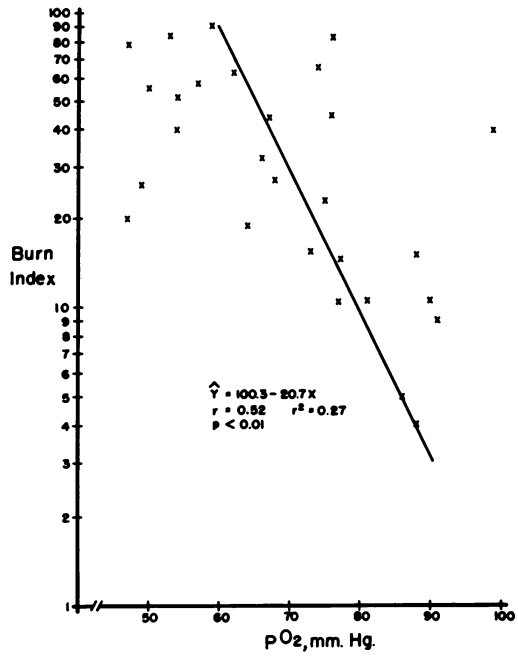

FIG. 1. Relationship of burn index to oxygen tension.

examination of the bronchial and bronchiolar radicals distributed to foci of atelectasis usually failed to demonstrate plugs or secretions. This raised the question of limited pulmonary excursion as a basis for inadequate expansion of the alveoli. All instances of focal atelectasis without discernible airway plugs were associated with the presence of a firm, circumferential eschar of the chest and abdomen.

Bronchopneumonia. Minimal, focal (terminal) bronchopneumonia was present in three cases. A more extensive involvement was noted in one case.

Emphysema. In two patients, slight, focal emphysema was present. Both of these patients had bronchospasm during life.

Hematogenous Pneumonia. The majority of autopsied cases showed blood-borne bacterial pulmonary lesions with and without scattered microarterial septic emboli. The percentage of pulmonary parenchyma involved was small.

Pulmonary Edema and Congestion. All eleven autopsies revealed varying degrees

of pulmonary edema and congestion which was graded as moderate to severe in most instances.

Heart. Cardiac abnormalities and/or dilatation were absent with the exception of small microscopic, myocardial lesions of bacterial origin (one case).

Discussion

Arterial oxygen tension is theoretically a more sensitive index of impairment in oxygenation than is hemoglobin saturation.[6] In many patients in this investigation, the oxygen tension was reduced while the oxygen saturation was normal, or only slightly low. This is primarily because the oxygen dissociation curve contains a flat portion, beginning at about 85 per cent saturation, where a small change in oxygen saturation may be associated with a large change in oxygen tension. Saturations of this magnitude were frequently found in this study.

Alkalosis was present in many of the patients who had a subnormal oxygen tension but a normal saturation. A normal saturation in this case is probably due to a greater binding of oxygen at the alkalotic pH. Oxygen tension, however, is less influenced by changes such as pH and P_{CO_2}. The inverse correlation between severity of burning (burn index), and P_{O_2} that was demonstrated in this study, was not apparent in a previous experiment which relied upon the less sensitive criterion of hemoglobin saturation.[10]

Low oxygen tension was frequently associated with a diminished P_{CO_2} and elevated pH; that is, a respiratory alkalosis. This is presumably due to reflex stimulation of the carotid body by the low oxygen tension in the arterial blood. In a few patients no alkalosis occurred in association with low P_{O_2}. In some of these, P_{O_2} was reduced minimally. In others, studies were performed within the first few days postburn when metabolic acidosis, or other electrolyte disturbances could have overshadowed the respiratory effects.

Hyperventilation was not reduced after oxygen administration. This is not surprising since hyperventilation might also have been produced by apprehension, pain, sepsis, hyperthermia, and metabolic acidosis.

There are many causes of hypoxemia. These include: 1) hypoventilation; 2) venous-to-arterial shunting; 3) impairment of diffusion; and 4) uneven distribution of alveolar gas and blood.[7] Hypoventilation did not occur in this study since P_{CO_2} was not elevated; indeed, the opposite was true. Although no direct measurements of intrapulmonary or intracardiac shunting were made, administration of oxygen to hypoxemic patients raised oxygen saturation and tension values to the same extent as in the unburned controls.* This suggests that shunting was not a major problem. Therefore, uneven distribution of alveolar gas and blood and/or an impairment in diffusion are the most likely causes of hypoxemia.

The oxygen utilization data supplement the blood-gas measurements. They indicate that overall oxygen utilization and hence the metabolism of the burned patients was slightly increased. This is in agreement with earlier work.[4, 8, 13] Birke *et al.*[4] observed a high positive correlation (+ 0.92) between changes in oxygen uptake and cardiac output in severely burned patients. These observations, if applicable to the present study, would indicate that cardiac output was normal or slightly elevated.

Clinically, many patients appeared to be

* After administration of oxygen, oxygen tension did not increase to as high a level as is sometimes reported as normal.[7] Our results compare more closely to those of Heller and Watson.[12] An evaluation of our method showed that the oxygen source was 95% and not 100%, and that the gas standardization of the P_{O_2} electrode gave a 5% lower value than blood equilibrated by tonometry. These factors combined with the effect of a moderate shunt leave only a small unexplained difference between the observed and theoretical values.

ventilating adequately or overventilating. Copious tracheobronchial secretions, bronchospasm, rales and less commonly, edema of the lungs, were observed. These factors could have produced uneven ventilation or abnormalities in diffusion. Generalized visceral congestion with pulmonary edema were frequently found at autopsy. This suggests that they may have been present at the time of blood-gas measurements although not diagnosed. This diagnosis is difficult to make in the burned patient for several reasons: 1) the presence of a chest eschar may limit the reliability of auscultation of the lungs; 2) peripheral edema may be secondary to causes other than circulatory failure; and 3) measurements of venous pressure are seldom feasible due to the frequent presence of extensive arm burns.

It was hoped that a correlation could be made between postmortem pathology in the lung and blood-gas abnormalities. This was not possible. In six of 11 deaths, the intervals between the last blood-gas measurements and death were too long to allow direct pathophysiologic correlations. Measurements were within one to two days of death in the remaining five cases, yet in only two were there sufficient morphologic changes in the lung to account for a decrease in oxygenation. This emphasizes the fact that blood-gas exchange can be altered by factors during life which are not demonstrable at autopsy.

Damage to the upper respiratory tract secondary to thermal injury is possible; however, it was not found in this group of patients at autopsy. Tracheal lesions were all caused by tracheostomy cannulae. Similar erosions in association with these cannulae have been identified frequently in 70 consecutive postmortem examinations at this unit.[23] This abnormality is not found in patients who have no tracheostomy.

Even though the study included only young adults, all eleven autopsies revealed pulmonary congestion and edema. Generalized visceral congestion and venous distention were common. This suggests the possibility of a general circulatory basis for the pulmonary findings. However, in the absence of cardiac lesions and dilatation, this circulatory problem cannot be strictly defined as "congestive *heart* failure." Other factors such as fluid administration, hypoalbuminemia, peripheral vascular collapse, septicemia, and terminal oliguria must all be considered in the circulatory failure of the burn death.

This study has demonstrated that hypoxemia should be suspected in the early post burn period. If possible, the cause of the hypoxemia should be determined and eliminated. In the general care of the burned patient, it is recommended that oxygen be administered to a patient 1) with a large total body surface burn; 2) with clinical signs of pulmonary involvement; or 3) in whom a deep flame burn of the "respiratory area" of the face is present. Although this study is limited to previously healthy adults, clinical experience at the Surgical Research Unit indicates that problems in oxygenation are exaggerated in children and the aged.

Summary

Oxygen tension (P_{O_2}) of arterial blood was reduced in 17 of 28 previously healthy, young adult burned patients in the early post-burn period.

Hypoxemia, as evidenced by low P_{O_2}, was discovered frequently even though auscultation of the chest and chest x-ray revealed no abnormalities.

Low oxygen tension was thought due to an impairment in diffusion, or uneven distribution of alveolar gas and blood. A correlation with clinical and postmortem findings is included.

Results of this investigation indicate that oxygen should be administered to a patient 1) with a large total body surface burn; 2) with clinical signs of pulmonary

involvement; or 3) in whom there is a deep flame burn of the mouth and nose.

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References

1. Baldwin, E. de F., A. Cournand and D. W. Richards, Jr.: Pulmonary Insufficiency; Physiological Classification, Clinical Methods of Analysis, Standard Values in Normal Subjects. Medicine, 27:243, 1948.
2. Batson, H. C.: An Introduction to Statistics in The Medical Sciences. Minneapolis, Burgess Publishing Co., 1956.
3. Baxter, C. R., J. J. DeCosse, N. L. Green and C. R. Kennedy: Pulmonary Function Following Thermal Trauma-Hypoxia. U.S.A. Surgical Research Unit Annual Report, p. 3, June 1958.
4. Birke, G., S. O. Liljedahl, and H. Linderholm: Studies on Burns. V. Clinical and Patho-Physiological Aspects on Circulation and Respiration. Acta Chir. Scand., **116**: 370, 1958–59.
5. Clark, L. C., Jr.: Monitor and Control of Blood and Tissue Oxygen Tensions. Trans. Amer. Soc. Art. Int. Organs, 2:41, 1956.
6. Comroe, J. H., Jr.: Interpretation of Commonly Used Pulmonary Function Tests. Am. J. Med.,10:356, 1951.
7. Comroe, J. H., Jr., R. E. Forster II, A. B. Dubois, W. A. Briscoe and E. Carlsen: The Lung. Clinical Physiology and Pulmonary Function Tests. 2nd Edition. Chicago, Year Book Medical Publishers Inc., 1962.
8. Cope, O., G. L. Nardi, M. Quijano, R. L. Rovit, J. B. Stanbury and A. Wight: Metabolic Rate and Thyroid Function Following Acute Thermal Trauma in Man. Ann. Surg., 137:165, 1953.
9. Davenport, H. W.: A.B.C. of Acid Base Chemistry. 4th Ed. Chicago, Univ. Chicago Press, 1958.
10. Epstein, B. S., D. L. Hardy, H. N. Harrison, Y. Villarreal and A. D. Mason, Jr.: Ventilation and Blood Gas Measurements in the Acutely Burned Patient. U.S.A. Surgical Research Unit, Brooke Army Medical Center, Annual Research Progress Report, MEDDH-288, p. 10, 30 June 1962.
11. Handbook of Respiration. Edited by D. S. Dittmer and R. M. Grebe. Philadelphia and London, W. B. Saunders Co., p. 57, 1958.
12. Heller, M. L., and T. R. Watson, Jr.: Arterial Oxygenation During Transition From 100 Per Cent Oxygen To Air Breathing: Polarographic Pa O_2 Study. Anesthesiology, 22: 385, 1961.
13. Moyer, C. A.: The Metabolism of Burned Mammals and its Relationship to Vaporizational Heat Loss and Other Parameters. Research in Burns. Edited by C. P. Artz, Washington, D. C. and Philadelphia, American Institute of Biologic Sciences and F. A. Davis Co., p. 113, 1962.
14. Nahas, G. G.: Spectrophotometric Determination of Hemoglobin and Oxyhemoglobin in Whole Hemolyzed Blood. Science, 113:723, 1951.
15. Phillips, A. W. and O. Cope: An Analysis of the Effect of Burn Therapy on Burn Mortality. Research in Burns. Edited by C. P. Artz. Washington, D. C. and Philadelphia, American Institute of Biologic Sciences and F. A. Davis Co., p. 1, 1962.
16. Phillips, A. W. and O. Cope: Burn Therapy II. The Revelation of Respiratory Tract Damage as a Principal Killer of the Burned Patient. Ann. Surg., 155:1, 1962.
17. Report of an *ad hoc* Panel of the Committee on Pathology of the National Research Council on 41 Fatal Burn Injuries (1950–1953) from Brooke Army Medical Center.
18. Richards, D. W., Jr.: The Circulation in Traumatic Shock in Man. The Harvey Lectures, Science Press Printing Co., 1943–44.
19. Schwartz, M. S., H. S. Soroff, E. Reiss and C. P. Artz: An Evaluation of the Mortality and the Relative Severity of Second and Third Degree Injury in Burn. USA Surgical Research Unit Report 6-56, August 1956.
20. Severinghaus, J. W. and A. F. Bradley: Electrodes for Blood P_{O_2} and P_{CO_2} Determination, J. Appl. Physiol., 13:515, 1958.
21. Snedecor, G. W.: Statistical Methods. 5th Ed. Ames, Iowa, Iowa State College Press, 1956.
22. Sneve, H.: The Treatment of Burns and Skin Grafting. J.A.M.A., 45:1, 1905.
23. Teplitz, Carl: To be published.
24. Van Slyke, D. D. and J. M. Neill: The Determination of Gases in Blood and Other Solutions by Vacuum Extraction and Manometric Measurement. J. Biol. Chem., 61:523, 1924.
25. Wilson, B. J. and J. A. Stirman: Initial Treatment of Burns. J.A.M.A., 173:509, 1960.