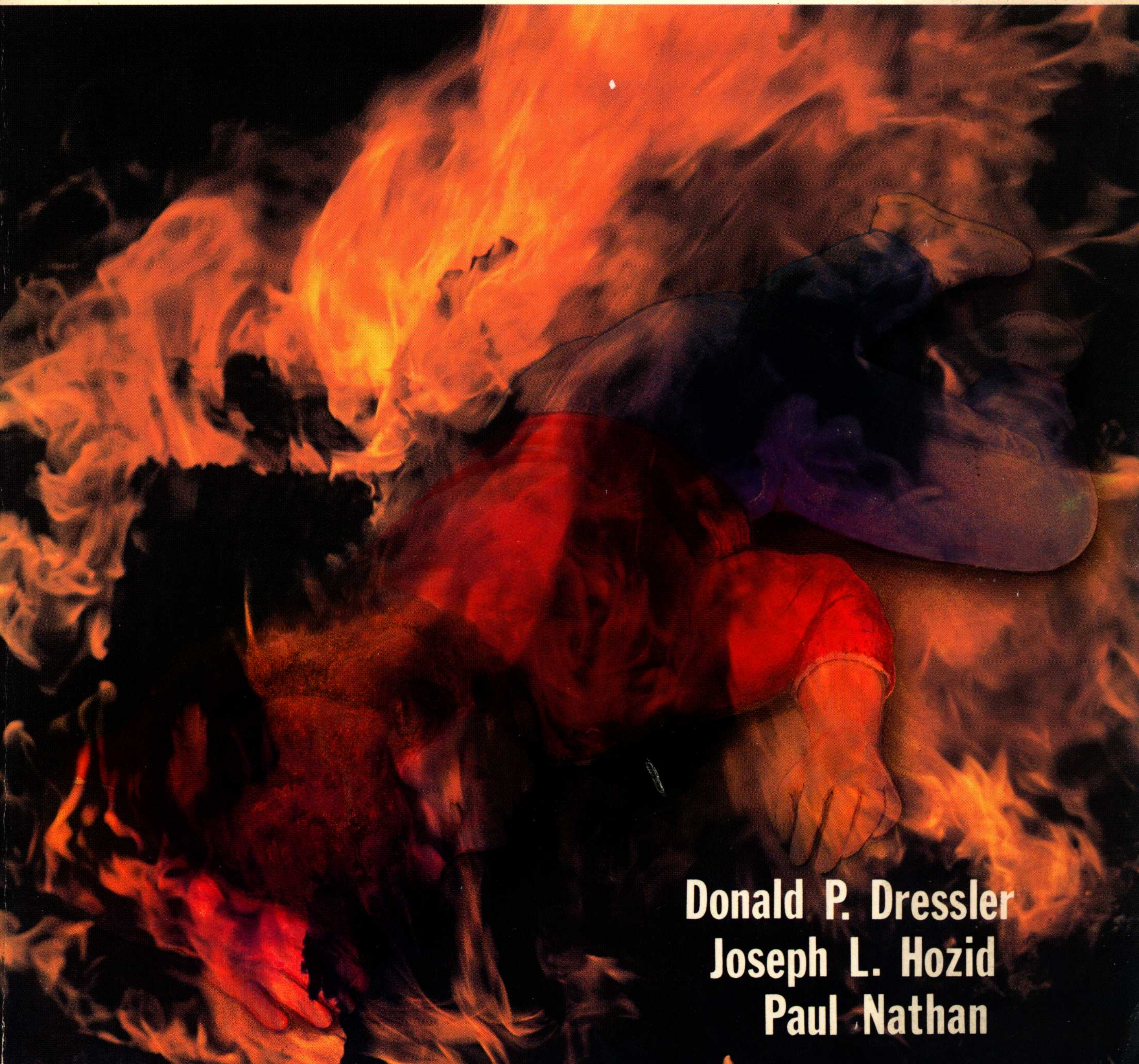
THERMAL INJURY



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Preface

No affliction of mankind challenges both the patient and the health care professionals as much as that of thermal injury. Although both the overall injury and death rates from fire are decreasing, if there is to be a further reduction in mortality, the health care provider must more systematically address the total care from site of the injury through the initial evaluation and resuscitation phase through all the aspects of wound healing.

The reduction of morbidity is not a new concern; however, when mortality was the main challenge, considerations of morbidity and all of its components were viewed somewhat as a luxury. Fortunately this is no longer the case, and the lessons learned from the care of life-threatening thermal injuries can now be applied to the pervasive lesser injuries. It is readily evident to health care providers that prevention is the most practical solution; e.g., injury from hot liquids can be prevented by design, use, and type of products.

This monograph has been designed to meet the present and emerging needs of health care professionals in the treatment of thermal injury. Given the multiplicity of factors involved, interdisciplinary efforts are required for the development of practical methods for predicting the hazard, preventing the occurrence, rescuing the victims, and treating the patients.

Consistent with the need for providers to extend their knowledge to the fire scene, the first three chapters are concerned with the patterns of fire injury, fire dynamics, fire fighting, and rescue. Chapters 4 through 10 cover the practical, day-to-day clinical applications; and Chapters 11 and 12 address the causes and complications unique to the burn victim and the body areas particularly sensitive to thermal injury.

Chapter 13, Disaster Burn Care, presents a number of new concepts. Catastrophic situations involving thermal injuries were previously viewed as a logistic nightmare; this chapter identifies guidelines for realistic planning for such disasters.

The references have been selected as representative and as a beginning source of information retrieval. It should be noted that, since thermal injury in its many aspects is multidisciplinary, the usual surgical or trauma sources need to be augmented by the behavioral and physical sciences.

In keeping with this multidisciplinary format, we recognize the following contributors: Frederick Clarke, Ph.D., and Lt. Walter P. Long, representing the fire science and fire fighting professions. We would also like to express appreciation to a number of individuals who contributed generously of their time: Eileen Bonner, Col NC USAR (disaster burn care), Costa Chitouras, B.S. (electrical engineering), Dwight G. Geha, M.D. (critical medicine), Varant Hagopian, M.D. (ophthalmology), M. Cherie Haitz, M.S. (library science), John R. Hall, Jr., M.D. (National Fire Protection Association/fire statistics), Merrill C. Johnson, M.D. (nuclear medicine), Lucinda E. O'Loughlin, B.A. (medical records and billing), Ward R. Maier, M.D. (anesthesiology), and Joel Umlas, M.D. (blood banking).

Donald P. Dressler

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CHAPTER

1 Patterns of Fire Injury

MILESTONES

During this century a number of disastrous fires have had a direct impact on social awareness, code enforcement, and medical care. Application of the lessons learned from these catastrophes has significantly lowered the mortality and the morbidity resulting from burns and has had a profound effect on all aspects of prevention.[7,9,15,24]

The 602 deaths that resulted from the Iroquois theater fire in Chicago in 1903 dramatically documented the urgent need for rigorous and enforceable fire codes for public assembly buildings.

Similarly, the deaths of 145 workers in the Triangle Shirtwaist Co. fire in New York City in 1911 highlighted not only grossly inadequate fire codes but also the abysmal plight of the workers, mostly immigrants, in sweatshops where conditions could lead to further large-scale fires and an escalation of thermal injury and mortality.

The 1929 Cleveland Clinic fire, which caused 125 deaths, brought to the attention of the public and the medical profession the hazards of the rapidly emerging synthetic materials. In this case, nitrocellulose in the x-ray film ignited easily and emitted toxic gases.

Unfortunately, the fire in the Ohio State penitentiary in Columbus, Ohio, in 1930, killing 320 inmates, seems to have had little impact on prison fire safety. This problem remains unsolved because of neglect and lack of funding. With the dramatic increase in incarceration sentences, correctional institutions are grossly overcrowded. Given the scale of arson in these institutions, mass casualty care incidents would not be unexpected.

In marked contrast, the Cocoanut Grove fire in Boston in 1942, which killed 492, resulted in the alteration of medical care given burn cases and in the development of new fire codes. These new methods for burn care were immediately implemented in the armed forces in World War II.

In 1944 the Ringling Brothers and Barnum and Bailey Circus fire in Hartford, Conn., in which 168 people died, resulted in new codes, as well as the demise of the circus tents; and the munition depot explosion and fire in Port Chicago, Calif., which killed 300, resulted in new policies for fire control in handling hazardous materials.

Regrettably, fire disasters still occur, especially when fire codes are not uniformly and wisely enforced. Examples can be found in the National Fire Protection Association (NFPA) investigative reports of the Beverly Hills Supper Club fire in Covington, Ky., in 1977, in which 165 people died, and at the Las Vegas MGM Grand Hotel in 1980, in which 65 died.

FIRE LOSS AND INJURY IN THE UNITED STATES

Vital statistics

As reported by the National Safety Council (NSC) of the National Center for Health Statistics, in 1983 the overall burn death rate was 1.8 per 100,000 population.

According to the NFPA, the death rate for urban residential dwellings has remained almost constant for the past 50 years: two deaths per 100,000 population or about 5000 per year.

Fire deaths and injuries by property use

Table 1-1 lists the number of fire deaths and injuries for selected property use in the United States in 1979. Although there has been some reduction during the more recent years, the ratios have remained constant.

Since the fire incidence is higher in the northeast region of the country, which contains many older structures, it will be of interest to note in the coming years whether, with urban renewal and with updated building/fire codes, the deaths and injuries in one- and two-family dwellings will decline and whether commercial buildings such as hotels and industrial properties will be similarly affected by new fire codes.

Table 1-1. Estimate of United States fire deaths and injuries for selected property use categories in 1979 (FEMA)

Property Use	Deaths (%)	Injuries (%)
Residential (total)	5,446 (83.7)	21,100 (69.9)
One- and two-family*	4,175 (64.2)	16,100 (53.3)
Apartments	1,025 (15.7)	3,600 (11.9)
Hotels	165 (2.5)	1,075 (3.6)
Other residential	81 (1.3)	325 (1.1)
Nonresidential	229 (3.5)	3,625 (12.0)
Highway vehicles	650 (10.0)	2,850 (9.4)
Other vehicles	90 (1.4)	1,225 (4.1)
All other categories	90 (1.4)	1,400 (4.6)

From the Federal Emergency Management Agency (FEMA).
*Includes mobile homes.

House fires

Although the largest number of fires result from heating and cooking, followed by arson, and then cigarettes, three fourths of the fire-related deaths result from house fires. There is a variance in incidence between the socioeconomic levels. For example, in fires ignited by heating or electrical equipment in 1984, the number of fires in the lowest-value census tract was nine times higher than in the highest.

Cigarette fires

It is noteworthy that in 1984 the NFPA reported that more than half of the house fires were cigarette ignited. In the United States, cigarette tobacco, unlike pipe and cigar tobacco, is treated with oxidizing chemicals that permit the tobacco to burn hotter, faster, and more evenly. These additives also support combustion; e.g., unlike a pipe or cigar, the cigarette will continue to burn without puffing when enmeshed in upholstery or bedding.

Single fatalities caused by smoking in bed are almost impossible to prevent. However, with the present attitudes toward the health hazards of smoking and the increasing regulations restricting smoking, a substantial decrease in smoking can be expected.

Vehicle fires

Although vehicle fires have been dramatically addressed by Ralph Nader in his book, *Unsafe at Any Speed*, and by the subsequent litigation involving the Ford Pinto fires, the scope, cause, and remedy have yet to be fully elucidated.

In the sunbelt regions, the mobile home has tended to replace the lower socioeconomic residences available in the older cities. The problem of vehicle fires has been compounded by the increase in arson cases and the pervasive problems of highway safety.

Arson

Arson is the fastest growing crime in the country and should be suspected when a building is unexpectedly heavily engulfed in a fire within a relatively short period of time or when multiple ignition sources are suspected. Under these circumstances, the use of an accelerant may result in an unexpected increase in the number of injuries to the firefighters, rescuers, and victims. It is also not infrequent that the arsonist also becomes a victim.

All findings should be accurately recorded for later investigation or prosecution. Any unusual findings should be reported to the authorities. In the event an injury or death occurs as a result of the fire, the arsonist could be charged with assault, intent to murder, or homicide.

Institutional fires

A number of special problem areas relating to institutional fires need to be addressed in more depth. These include fires in hospitals and nursing homes, halfway houses, and correctional institutions. The facilities involved are subject to numerous regulations, and, where enforced through inspection and training, a commendable improvement in the reduction of fire deaths has resulted. Only in facilities that have not been fully sprinkled do deaths occur.

Halfway houses and rooming and lodging houses frequently seem to fall between the cracks of fire code enforcement. Used in many cases by the indigent, homeless, or the recently released mentally retarded or handicapped, they are frequently sites of multiple fire deaths.

Fires in correctional facilities represent a whole different challenge. Not only are the facilities underfunded and overcrowded, but the inmates use fire for attention, revenge, or self-destruction. A review of recent prison fires in Florida, Tennessee, and Nova Scotia gives ample documentation of the problem.

Hot liquid injuries

In a New York study of 156 hot liquid injuries, 50% of patients were under the age of 4, and 27% were over 60 years of age. Of these injuries, 85.2% occurred in the bathtub, 10.7% in the shower, and 4.1% had other causes.[2,6]

Most gas heaters are preset for 140° F (60° C). As noted in Table 1-2, only a 1.5-second exposure at this temperature will result in a second-degree burn, and a 6-second duration will cause a full-thickness injury in adults. For electric heaters the standard is set at 150° F (66° C), which can cause a full-thickness burn in 2 seconds.[22]

Table 1-2. Water temperature vs. time for second-degree burn[24]

Degrees Fahrenheit	Seconds
150	0
140	1.5
130	12
125	42
120	300

The federal standard of 120° F (50° C) in elderly housing and nursing homes can still cause a full-thickness injury to adults in 2 minutes, and in less time to children and the elderly.[7,24] This 2-minute time period is adequate if a person is able to extricate himself promptly; the severely physically or mentally handicapped, however, have difficulty in getting up and over the side of a tub or even out of a shower in 2 minutes.

It is unequivocally distressing to note that parental or guardian abuse, or neglect, is not uncommon in scald burns of children. Guidelines for identifying suspicious cases are detailed in Chapter 11.

TRENDS IN FIRE PREVENTION

Factors affecting life safety

A number of factors must be considered in determining the overall fire hazard and, concomitantly, in developing cost-effective fire protection/prevention measures: structure design; facility use; location; materials; construction; furnishings; adherence to fire codes; and number, physical, and mental condition of occupants. Given its presence in the living space environment, a product's flammability, including ease of ignition and flame spread, and its toxicity are critical considerations in the selection process.[10,11,12]

The box on p. 6 lists the physiological factors affecting survival during a fire. The actual escape response will also depend on the degree of vision, which can be adversely affected by obscuration of the exit signs caused by smoke density and opacity, as well as by physiologic factors such as loss of color and fine vision when the oxygen in the atmosphere falls below 17%.

Training and familiarity are important considerations in ensuring escape and/or survival. It is not uncommon to find victims completely confused in the fire situation. The presence of physically or mentally handicapped people within the structure poses special problems that only forethought, design, and training can overcome. The need for bilingual instructions, exit signs, and even rescue personnel, has often been neglected in the past and should be part of all fire safety programs. Given the prevalence of pets in our society, including their involvement in pet-facilitated therapy for the disabled and elderly, their rescue also requires attention.

Physiological factors affecting survival

Increased carbon monoxide concentration	Direct consumption by fire
High temperatures	Fear
Noxious or toxic gases	Preexisting disease
Smoke	Duration of exposure
Decreased oxygen concentration*	Associated injury

*Actually, life depends on the partial pressure of oxygen, i.e., 160 torr, whereas combustion depends on the percent of oxygen in the atmosphere.

Table 1-3. Trends in fire causes*

Cause	1959 (%)	1972 (%)	1981 (%)
Heating and cooking	22.9	16	42
Smoking and matches	18	12	8
Electrical and appliances	13.9	16	13
Flammable liquids and explosions	6.5	7	1
Open flames and sparks	6	7	4
Lightning	3.3	2	1
Children and matches	3.9	7	5
Incendiary or suspicious	2.3	7	12
Spontaneous ignition	2.6	2	1.2
Miscellaneous, known	14.1	2	5.8
Miscellaneous, unknown	6.5	20	7

*From the Federal Emergency Management Agency (FEMA).

Trends in fire etiology

There have been important trends in fire etiology (Table 1-3), including a reduction in burn injury. Some reductions, such as those from smoking and matches, may reflect increasing public awareness and education, including the use of prevention measures such as flame-retardant materials in children's sleepwear and the selection of approved interior decorator and construction materials.[17,24,28,29]

On the other hand, some of the reduction in burn injury may simply reflect a better reporting system, although improved reporting usually shows an increase.

Building and housing factors

Building/fire codes. It should be noted that present building/fire codes have been highly effective in reducing fire deaths from flame and, concomitantly, from smoke inhalation. When a gross violation occurs, the results are tragic. Examples are readily found when recent hotel fires (e.g., the Beverly Hills Supper Club fire) and various prison fires are reviewed. If the codes had been rigorously enforced, it is doubtful that a large loss of life, or even the fire itself, would have occurred.

Moreover, the devastating recent fires outside the United States such as in the Philippines, South America, and Japan can also be attributed to lack of enforcement of building codes and thus gross deficiencies in them.

Safety construction. Although there have been a number of hotel fires since the MGM Grand catastrophe, including the Dupont Plaza Hotel fire in San Juan, Puerto Rico, in 1987, in which 95 people died, increased code enforcement coupled with the public awareness of the problem have resulted in major improvements in building construction, emphasizing fire prevention and/or capability. For example, the following measures have become standard features of any new building/housing construction: the installation of properly rated smoke alarm detection systems, pressurized stairwells, more extensive use of fire-rated construction materials (e.g., dry wall), and the widespread use of sprinklers. According to the NFPA, there have never been multiple fire deaths in a properly sprinkled building. However, deaths can occur in the room of origin even with sprinklers.[4,24,28]

Smoke detectors

The rapid development in the past decade of inexpensive smoke detectors has supplanted heat detectors, both in cost and early warning, in residential dwellings. In commercial buildings, both smoke and heat detectors are used in a system of early detection.[8]

There are two types of smoke detectors: ionization and photoelectric. The ionization type responds slightly faster than the photoelectric to an open, flaming fire; the photoelectric has a quicker response to a smouldering fire. Either one is acceptable, although the ionization type is now more common.

There are also two types of connections: a single-station battery mode, which has the advantages of ease of installation, low cost, and nondependency on the house power system; and the installation system connected directly to the house power, with switches that are not easily accessible and thus cannot be accidentally turned off. The installation system does not rely on battery replacement, and, more important, it can be installed in series, so that if one detector sounds, all the detectors in the dwelling will also signal. Even if a battery-operated system is the first choice, a dual system is recommended and often required in all new installations.

The recommended locations for smoke detectors are in the hallways outside the bedroom doors; hallways by the living room and dining room, but far enough away from the kitchen so that usual cooking does not set off the alarm; and at the top of the basement stairs. Additional alarms can be added to each bedroom and near the heating system. They should always be placed on the ceiling, or within 4 to 12 inches of the ceiling on a side wall. In ranch and split-level homes, detectors should also be placed within each major section and at each level.

In addition to smoke detectors, training in and planning for emergency procedures such as responding to alarms, feeling the doors for heat before opening, identifying escape and alternate escape routes, establishing a meeting place outside the dwelling, and reviewing procedures for calling the fire department are essential. Each occupant should know the location of other occupants and have emergency lighting. Almost needless to state, smoking in bed is to be condemned.

Special attention should be paid to the sleeping quarters of children and any disabled people in a dwelling unit. These areas should be identified and suitable attention given to escape plans.

Smoke detectors save lives: in the United States and in England, according to NFPA statistics, the risk of death is reduced 50%.

ANALYSIS OF FIRE DEATHS

Overview

What actually causes death or injury during fire? The data are far from complete; but during the past 50 years, according to NFPA information, the number of deaths in this country has decreased from approximately 20,000 in 1933 to 5000 in 1985. And at the same time the population has increased from 110 million to almost 240 million.[7,19,24,32]

To account for this decrease in mortality, several changes should be considered: smoke inhalation has often been stated to be the major cause of death in fires. This statement is misleading. In 50% of fire deaths, the victims arrive at the hospital alive; those that suffer only from smoke inhalation will survive if associated cardiovascular disease, traumatic injuries, drug overdosage, or cutaneous burns are not present. In contrast to previously reported high death rates from shock and burn wound sepsis, the most common cause of pulmonary death in victims of smoke inhalation is pulmonary sepsis. The cause of this high susceptibility to pulmonary infection and death may be related to the inhalation of toxic products, but there are many other reasons such as the presence of cutaneous burns, malnutrition, and dysfunction of the pulmonary host defense mechanisms.

It is important to be aware that a burn injury is not limited either in its deleterious effects to the skin or in inhalation effects to the bronchopulmonary surfaces.

Comparative analysis

Table 1-4 compares the cause of death in burn patients at three different time periods during the past 30 years. Although the data are from my files at two different facilities, the patient groups are similar in age and socioeconomic status. The causes of the injuries were different in that the latter group in California represented fewer

Table 1-4. Comparison of cause of death in three groups of burn patients

Cause of death	1956-1964* (284 patients)	1965-1968* (201 patients)	1980-1981† (286 patients)
Shock	17	7	6
Burn wound sepsis	12	4	5
Respiratory complications	6	20	(13)‡
Myocardial infarction	3	0	3
Carcinoma	1	0	(1)‡
Pulmonary embolus	(9)‡	2	0
Gastrointestinal hemorrhage	(1)*	0	0
Suicide	0	1	(4)‡
Cardiovascular accident	0	2	2
Multiple trauma—homicide	0	0	1
Total deaths	39	36	17
% Mortality	13.7	17.9	5.9

*Boston City Hospital, Boston, Mass.
†San Bernardino County Medical Center, San Bernardino, Calif.
‡Secondary cause of death.

building fires and a slightly greater number of substance abuse situations than in the Boston groups.[35] However, this is representative of the trends throughout the country.

Shock is no longer the major cause of death, but does occur in the massively burned patient. In these patients vigorous resuscitation results in cardiac failure, whereas reduction of fluids contributes to hypovolemia, oliguria, hypotension, and death.

Burn wound sepsis is still the major cause of death in those patients with massive burns in whom the body defense mechanisms are depleted and who then fall prey to any opportunistic bacteria or fungus infections. Death from respiratory complications increased precipitously during the second reported period, 1965 to 1968, after the introduction of effective topical antimicrobial therapy, but before the wide introduction of newly available methods of ventilatory support.

At present, respiratory deaths occasionally occur as a result of adult respiratory distress syndrome (ARDS), but more commonly in those that survive the initial resuscitation period, death is caused by pulmonary sepsis.

Myocardial infarction continues to be a problem and is understandable in view of the stress of the initial injury and the subsequent treatment. Just as with cerebrovascular accidents, death from myocardial infarction will probably increase with the aging population.

Consistent with the generalized trends initiated even before the major improvement in burn care made in the early 1960s, deaths caused by pulmonary embolus and stress ulcers have decreased during the past 30 years.

Although there has always been an awareness that a number of burn victims had psychological problems before their injury, only recently is this being fully appreci-

Table 1-5. Comparison of three groups of burn patients with second- and third-degree burns in relation to mortality and area of burn

	Deaths/total no. of patients		
Burn area (%)	**1956-1964***	**1965-1968***	**1980-1981†**
0-29	15/257	9/166	0/218
30-39	6/9	3/8	3/23
40 and over	18/18	24/27	12/39
	LD_{50} = 26%‡	LD_{50} = 38%‡	LD_{50} = 65%‡

*Boston City Hospital, Boston, Mass.
†San Bernardino County Medical Center, San Bernardino, Calif.
‡Percent of total BSA burn at which there is a 50% probability of survival.

ated. In view of this, suicide as a cause of death is being recognized. Similarly, homicide related to the increasing crime of arson is also being noted.[13,14,25,30]

Probit analysis

The mortality rate tabulated in Table 1-4 can be highly misleading, since this simple method does not account for many important variables, most particularly, the varied percentage of total body surface area (BSA) burn within each group.

Table 1-5 uses the probit analysis method introduced by Bull and Fisher in 1954,[4] Pruitt and associates in 1964,[27] and Rittenbury and co-workers in 1965.[31] To analyze burn data, this method factors not only the numbers in each category, but also the percent of TBSA burn. Generally, at least 100 patients with burns severe enough to require hospital admission or with major burn injury are necessary to provide any conclusions concerning treatment trends. These results are similar to those reported from other burn centers during the same time periods with adjustments for type of facility (i.e., community hospital, burn center, tertiary facility) and patient age.

This type of data cannot be used to predict the outcome of an individual patient or that of small numbers of patients, except in general terms. But it is evident that the LD_{50} per percent of TBSA burn has increased considerably during the past 20 years.

Furthermore, it is of more than passing interest to note that in most burn centers a plateau has been reached, with only slight inroads being made into the survival of the more massive burns involving over 65% TBSA, the elderly, or those with other complicating injury or diseases. These data reveal that there is an urgent need to improve early care at the fire site of those persons with major injuries and to make a concentrated effort to reduce the morbidity of the vast number of less seriously burned persons.