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## Combined Radiation and Thermal Injury After Nuclear Attack

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### Introduction

The explosion of nuclear weapons over the Japanese cities of Hiroshima and Nagasaki in 1945 dramatically changed the potential for thermally injured casualties as a result of warfare. Except for isolated radiation accidents over the ensuing years, little practical experience has been gained in the treatment of thermal injuries associated with radiation or nuclear warfare. In this chapter, we discuss the current status of burn care, review experimental animal data regarding combined injury of burns and radiation, and correlate the findings with the need to triage thermal injuries under the conditions of nuclear warfare.

### Current Status of Burn Care

Thermal injuries are a common medical problem affecting more than 2 million individuals in the United States annually. Most of these injuries are minor and are treated on an outpatient basis. Between 60,000 and 70,000 patients per year are burned severely enough to require hospital treatment.<sup>1</sup> Major burn injury results in a systemic response characterized by an early period of shock with hypovolemia, gastrointestinal ileus, and oliguria. After adequate resuscitation, the burn patient converts to a hyperdynamic state characterized by increased cardiac output, diuresis, and peripheral catabolism.<sup>2</sup>

When nuclear weapons were used in 1945, there was little if any treatment available. Since that time, there have been a number of advances in the treatment of thermally injured patients, especially in the areas of fluid resuscitation, burn wound care, and surgical management of the burn wound. Investigators, including Harkins, Cope and Moore, Evans, and the group at the U.S. Army Institute of Surgical Research, defined plasma volume deficit

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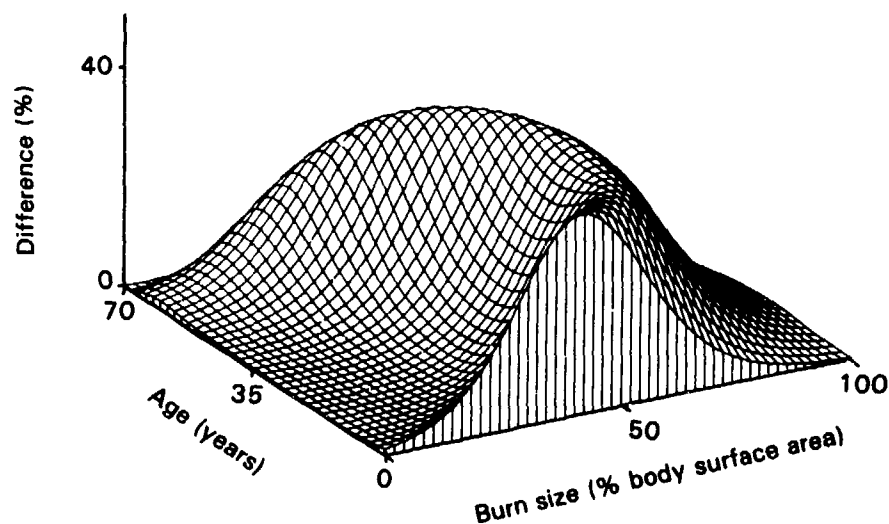
as the cause of early burn shock and developed resuscitation formulas that have essentially eliminated early death from burn shock and early acute renal failure.<sup>3,4</sup> As patients were successfully resuscitated from burn shock, sepsis became the major cause of death in thermally injured patients.<sup>5</sup> The introduction of penicillin and other systemic antibiotics changed the bacteriology of burn-wound infection from streptococcal organisms to other organisms, such as the *Staphylococcus* and *Pseudomonas aeruginosa*.<sup>6</sup> The development of topical chemotherapeutic agents, such as mafenide acetate and 0.5 percent silver nitrate, has resulted in a marked decrease in invasive burn wound infection by effectively controlling proliferation of bacteria.<sup>7</sup>

In addition to the development of effective resuscitation and topical chemotherapy, there have been other changes in the management of burn wounds. The trend recently has been to perform early excision of the burn wound, either tangentially or to the level of the investing fascia, and to close the wound early with the use of meshed autografts.<sup>8</sup> When donor sites are limited, the use of cadaver allograft or other biologic or synthetic skin substitutes has allowed the burn wound to be removed early and the wound to be covered temporarily, pending final closure with autograft.<sup>9</sup> During this time, there have also been changes in nutritional support, mechanical ventilation, invasive hemodynamic monitoring, and other aspects of general supportive care of critically ill patients.

Associated with these advances in burn care has been an improvement in patient survival, with the predominant improvement in young adults and middle-aged individuals with major burns. Figures from the early 1980's compared to those of the middle 1940's show an increase in LA<sub>50</sub> (extent of burn that has been associated with death in 50 percent of patients) for young adults from 43 percent of the body surface to 59.6 percent (table 1). An improvement was also seen for individuals over 40 years of age. Figure 1 shows these changes in mortality, and illustrates the age, burn size, and percentage decrease in death rate at the U.S. Army Institute of Surgical Research from 1950-63 to 1980-86. In this three-dimensional representation, the major gains are noted in the young and middle-aged groups with burn size varying from 40 percent to 60 percent in the region of the LA<sub>50</sub>.

**Table 1.** Survival Rate of Patients With Burns  
From 1945-47 to 1980-84 (LA<sub>50</sub>)

| Age of patient | Survival rate (percent) |         |
|----------------|-------------------------|---------|
|                | 1945-47                 | 1980-84 |
| 15-40          | 43                      | 59.6    |
| Over 40        | 23                      | 35.7    |



**Figure 1.** Decrease in number of deaths per 100 patients from 1950-1963 to 1980-1986 at the U.S. Army Institute of Surgical Research.

### Logistics of Burn Care

In the United States, major burns (involving more than 20 percent of body surface area for adults) are best cared for at specialized burn centers. In 1987, 182 hospitals in the United States either had burn care units or specialized burn care programs. There were about 1,800 dedicated burn care beds. In 1985, of the approximately 70,000 patients requiring hospitalization for burns, 25-30 percent (about 21,000) were admitted to burn care facilities. Patients with major burns generally require 1 day of hospitalization for each percentage of the body surface area with second- or third-degree thermal injury. While in the intensive care unit, patients with thermal injuries require approximately 28 hours of nursing care per day, in addition to specialized care from respiratory therapists, occupational and physical therapists, dieticians, and pharmacists. Because patients require up to 9 percent of the blood volume for each 1 percent of the body surface area excised by the tangential technique, major burns can strain blood-banking services. It is clear from these statistics that only a limited number of patients can receive the quality and quantity of care required to achieve the survival rates previously described. However, most patients with minor thermal injuries do well with simple outpatient care, and do not require a substantial investment of resources.

### Combined Injuries

The airburst detonation of a nuclear weapon over a population center will result in many thermal injuries. In addition to the thermal injuries, a significant

number of survivors will also suffer some degree of radiation injury, either immediately or over the ensuing several weeks as a result of fallout. At Hiroshima and Nagasaki, from one-fourth to one-half of the survivors had some degree of thermal injury.<sup>10</sup> Most of these injuries resulted from the flash of radiant heat from the detonation of the bomb. A small number resulted from flame burns caused by secondary fires. Only a small area of the body surface (up to 10 percent) was involved in most patients, because clothing or other objects in the path of the radiation provided significant protection. Because of the small size of the nuclear devices used in Hiroshima and Nagasaki, it is difficult to extrapolate these data to the larger weapons stored in military arsenals today. These larger devices are more likely to cause major fires, so-called superfires, when detonated over large population centers.<sup>11</sup> Thus, the possibility exists for a significant increase in the number and size of burns resulting from direct flame, and burns often will be complicated by inhalation injury.<sup>12</sup>

The expected mortality from thermal injuries complicated by radiation injury in humans is unknown. In major burns, mortality rates similar to those described earlier could be expected if comprehensive care were available to the injured. If comprehensive care were unavailable, as is likely after a nuclear attack, mortality rates approaching 100 percent for patients with thermal injuries involving more than 30 percent of the body surface area could be expected. In all likelihood, individuals with burns on less than 20 percent of the body surface area would survive, although they would not receive specific treatment for a period of time.<sup>13</sup> Many who have only partial thickness burns or minor full-thickness burns involving less than 10 percent of the body surface area could be expected to survive even without treatment. As the area involved with full-thickness injury exceeds 10 percent, increased mortality can be expected if treatment is unavailable. Mortality depends on the age of the patient and the presence or absence of other associated mechanical injuries.

Because the majority of burns in survivors of the Hiroshima attack were minor, little additional effect on mortality seemed to be caused by thermal injuries in those patients who suffered radiation injuries. However, based on results of experiments in animals, the combination of radiation and thermal injuries appears to cause a synergistic effect. Brooks et al.<sup>14</sup> found that the addition of 1 Gy of radiation increased the mortality in dogs with a 20-percent body surface area burn from 12 percent to 73 percent. Similar experiments in swine by Baxter et al.<sup>15</sup> demonstrated that 4 Gy of total-body radiation (which by itself causes 20-percent mortality) resulted in 90-percent mortality in animals with a 10-15-percent surface area burn that was otherwise nonlethal. In a rat study, Alpen and Sheline<sup>16</sup> found that the  $LA_{50}$  at 48 hours after thermal injury decreased from 32.8 percent to 23.9 percent when 5 Gy of radiation were added to the injury. Radiation doses of 1 Gy and 2.5 Gy, which by themselves were not lethal, markedly increased the mortality in a 30-percent burn model at 30 days. Based on these data, it is reasonable to assume that the combination of a radiation injury and a thermal burn (other than the most minor burn)

will result in a mortality rate significantly higher than that expected from either injury alone. However, some levels of radiation injury and thermal injury will result in essentially 100-percent mortality by themselves, regardless of the presence or absence of any other injury.

### **Triage During Nuclear Warfare**

After a nuclear attack, it is almost certain that sophisticated medical care of any type will be either severely limited or nonexistent. Triage, or sorting of casualties, is a system of evaluating or classifying casualties for the purpose of treatment. It is based on the principle of accomplishing the greatest good for the greatest number of wounded or injured individuals under the special circumstances present at a given time. Limits on available resources following a nuclear attack will clearly change the treatment recommendations for patients with thermal injuries and combined thermal-radiation injuries from those in a time of unlimited resources. During conventional warfare with limited resources, approximately 50 percent of young and middle-aged soldiers whose burns involve 60-70 percent of the total body surface area are saved.<sup>17</sup> Results are worse for those at the extremes of age. In this setting, expectant care should be applied to those patients with burns over more than 70 percent of their body surface area. Individuals with burns over less than 20 percent of their body surface area can usually have treatment delayed, and available resources can be applied to individuals with burns over 20-70 percent of their body surface area. As resources become more limited, the upper limit of the maximum size burn to be treated is decreased in 10-percent decrements until the patient load equals the resources available.

In the setting of nuclear attack, further restrictions in triage are inevitable. Individuals with thermal injury over less than 10 percent of the body surface area and no associated radiation or mechanical injury would be expected to survive without any significant treatment. Individuals with burns over more than 30 percent of the body surface area are unlikely to survive unless adequate treatment is available. Thus, when resources are limited it will be necessary to apply available resources to individuals who have thermal injury involving 10-30 percent of the body surface area. Because the exact effect of the combination of radiation and thermal injury on mortality in humans is unknown, it is impossible to give a definitive recommendation on treatment. Extremely minor thermal injury is unlikely to influence the mortality of radiation injury, and will not affect triage in this specific group. The presence of any identifiable symptoms of radiation injury in patients suffering a thermal injury over more than 30 percent of the body surface area will almost surely result in 100-percent mortality, unless extremely sophisticated resources are available. In an intermediate group, with thermal injury of 10-30 percent of the body surface area, one would expect a significant increase in mortality from a combination of thermal and radiation injury. In this group, the expenditure of health care

resources should be decreased as the extent of burn and the dose of radiation increase.

## Conclusions

Since the introduction of nuclear warfare in 1945, there have been significant improvements in burn care and corresponding decreases in mortality from burn injury. The large number of burn casualties following a nuclear attack on a population center will overwhelm available medical resources and make survival unlikely for anyone with a major burn injury. The exact effects of combined radiation and thermal injury in humans are undefined. At the extremes of injury, little effect will likely be noted. In the middle range of injury severity, a synergistic effect on mortality can be expected, based on experimental data.

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