

Chapter 3

TRIAGE AND TREATMENT OF RADIATION-INJURED MASS CASUALTIES

ROBERT F. DONS, M.D.,* and T. JAN CERVENY, Ph.D.**

INTRODUCTION

PRINCIPLES OF TRIAGE

Operational Considerations for Triage

Peacetime Triage

Military Triage

Signs and Symptoms of Radiation Injury

Cutaneous Phenomena

Gastrointestinal Phenomena

Cardiovascular, Respiratory, Metabolic, and Neurological Phenomena

Hematological Phenomena

Triage of the Combined-Injury Patient

Burn Injury

Blast Injury

Eye Injury

MEDICAL MANAGEMENT OF THE COMBINED-INJURY CASUALTY

Concerns in the Treatment of the Combined-Injury Patient

Specific Treatment Concerns

Surgery

Anesthesia and Pain Control

Control of Infections

Antiemetics and Antidiarrheals

Fluids and Electrolytes

Blood Component Therapy

Chelation Therapy

Nutritional Support

SUMMARY

* Lieutenant Colonel, United States Air Force; Department of Experimental Hematology, Armed Forces Radiobiology Research Institute, Bethesda, Maryland 20874-5145

** Major, United States Air Force; Program Manager, Bioenvironmental Hazards, Air Force Office of Scientific Research, Bolling Air Force Base, Washington, D.C. 20332-6448

INTRODUCTION

The effective medical sorting of mass casualties (triage) and their subsequent treatment after a nuclear event have been considered extremely difficult or even impossible.¹ In the case of a major exchange of strategic nuclear weapons (500-5,000 MT), the triage of casualties using the remaining resources would certainly be futile and frustrating. Without transportation and tertiary medical-care facilities, the only benefit would be to identify persons who are capable of combat. Even the minimally injured casualty may receive little (if any) meaningful attention in such a situation.

However, if a nuclear event occurs, it is more likely to take place on a limited scale rather than as a strategic weapons exchange.¹ After a smaller-scale tactical detonation (0.1-2.0 kt) or a nuclear detonation by terrorists, hundreds or a few thousand casualties are more probable than millions² or billions.³ Considerable medical resources may be intact and available for treating many of them. This chapter presents plans for the management of large numbers of casualties suffering either radiation injury alone or conventional trauma combined with radiation injury.

PRINCIPLES OF TRIAGE

In conventional triage, patients are assigned to one of the following priority categories, depending on the nature and extent of their injuries: (a) The *immediate treatment* group includes patients who have a high chance of survival if they are given immediate life-saving treatment or surgery that is relatively quick and uncomplicated. (b) The *delayed treatment* group includes patients who may need major surgery, but who can be sustained on supportive treatments until surgery is possible. (c) The *minimal treatment* group includes patients with relatively minor injuries who can care for themselves or who can be helped by untrained personnel. (d) The *expectant* category includes patients with serious or multiple injuries requiring extensive treatment, as well as patients with a poor chance of survival. This group should receive supportive treatments that are compatible with resources, including large doses of analgesics.

The speed of assessing and categorizing the status of patients is the key to effective triage. Any method is useful that gives the triage officer a quick, accurate idea of the extent of injury. When making the assessment rapidly based on anatomical findings, the probability of injury is related to the degree of estimated force on the body part. For example, a patient close enough to a nuclear explosion to be caught in the blast wind is assumed to have internal and possibly occult traumatic injury. Such a patient will most likely be in the expectant category (Table 3-1). A slower but more accurate method of assessment is to expose the injured area directly and perform an abdominal examination. Even

with a relatively small number of casualties, this exam might be prohibitively time consuming in the critical moments shortly after a nuclear event.

Rapid assessment based on physiological status will permit the gathering of useful information on respiratory rate and systolic blood pressure in a large number of patients. In contrast, a determination of the Glasgow coma scale score⁴ (although fairly rapid in experienced hands) is less useful than a brief neurological evaluation of the patient's degree of alertness, responsiveness to verbal and painful stimuli, and state of consciousness. Attention to other relatively obvious factors, such as extremes of age (under 5 years or over 55 years) and preexisting or recently induced cardiovascular or respiratory illness, will aid in establishing a patient's status as expectant.

Operational Considerations for Triage

Regardless of the findings from an anatomical or physiological assessment of the patient, the first priority of the military triage officer is to conserve the fighting force. Combatants in the expectant category, however, should not receive aid or resources that might be of greater benefit to less severely injured noncombatants, even if these resources seem to be in adequate supply. In rare circumstances, a terminally injured unit commander might receive resources to permit continued functioning in a crucial command role.

This chapter pertains primarily to the management of acutely irradiated casualties following the detonation of a nuclear weapon. The military physician should recognize two essential facts in dealing with mass casualties during military triage in a declared war: (a) all medical resources fall under the jurisdiction of the military, and (b) peacetime triage practices are of limited use. However, in more limited events (such as a major nuclear reactor accident), the military may be asked to assist with the management of mass casualties under the constraints of peacetime disaster triage.

Peacetime Triage. In peacetime, a two-tiered system of care for the critically ill is assumed. Based on the triage decision, the patient goes either to the emergency room of the nearest community hospital or to the regional trauma center. This system depends on rapid, reliable transportation in which trained attendants monitor the patient with radio guidance from trauma staff at the hospital or center.⁵

In this scheme, the sorting of patients is based on a physiological trauma score in which the less-injured patient, with a score of 15-16, is in the delayed category, a third priority. Patients with a trauma score of 3 or less are considered expectant (the fourth, or last, priority). Third- and fourth-priority patients would probably be sent to the local hospital emergency room. All patients with trauma scores of 4-10 (first priority) and some with scores of 11-12 (second priority) would go to the trauma center.⁵

Military Triage. Military triage contrasts starkly with that used in peacetime, but the two do have some elements in common. For example, military triage decisions would most likely be made at the level of the battalion aid or clearing station. The local community hospital might be equivalent to the second-echelon radiation decontamination center and field hospital. Only fixed medical-care facilities or existing tertiary-care facilities that are able to perform surgery would suffice as trauma centers for handling combined-injury casualties.

In wartime, it cannot be assumed that rapid and reliable transportation of wounded persons is possible, as it is in peacetime or might be in smaller, low-yield nuclear events. In the confusion of armed conflict, casualties with a wide variety of injuries might be expected to arrive at the nearest medical-care facility regardless of its capability. Extra effort will be needed to keep the patient moving forward in the system to an appropriate level of care. The greatest number of lives will be saved only by ensuring that time and materials are not allocated to hopeless cases or to those whose injuries are so minor or uncomplicated that definitive care can be postponed.

In a nuclear disaster, triage decisions cannot be made on the evidence or probability of conventional injury alone. When significant radiation exposure is combined with conventional injuries, there may be a dramatic shift of patients to the expectant category (Table 3-1). In order to make an appropriate decision, the triage officer must recognize the symptoms of ARS and understand the difficulties in estimating radiation exposure from clinical findings.

Signs and Symptoms of Radiation Injury

It will be difficult to assess the radiation doses of persons who have been injured in a mass-casualty disaster. Thus, a system has been devised to identify radiation exposure based on the symptoms of “unlikely,” “probable,” or “severe” radiation injury (Table 3-2).⁶ These symptoms are nonspecific, and permit only the cursory screening of a large number of cases.

Cutaneous Phenomena. Information about the cutaneous changes after ionizing radiation exposure comes mainly from accidental or therapeutic high-dose local radiation exposures and, to a lesser extent, from studies of the victims of the 1986 nuclear reactor accident in Chernobyl, USSR, and the 1987 cesium-137 accident in Goiânia, Brazil. Skin injury in those events resulted from very intense local irradiation or direct contact of the skin with radioactive material. Burns among casualties at Hiroshima and Nagasaki in 1945 were caused by heat rather than radiation exposure.³

When extremely high doses of whole-body radiation (100 Gy) are delivered acutely, skin may have the sensation of tingling or being on fire even though no lesion immediately appears. Within the first 24 hours, there is the appearance of a characteristic transient erythema secondary to capillary dilation and the release of

histamine-like substances. The initial erythema usually peaks within 24 hours, and then disappears for 1-3 weeks. Thereafter, it may reappear with pain and edema. Severe pain may occur if more radio-resistant nerve tissue is surrounded by necrotizing tissues. Melanotic pigmentation (Figure 3-1) or ulceration may develop.⁷ Pain from nerve compression may occur as healing and atrophy take place. Hair loss over the affected area occurs at the end of the second or third week. In contrast to erythema induced by high-dose beta radiation, skin injury from gamma radiation occurs only at doses that damage the bone marrow. Thus, if sufficient marrow is exposed, thrombocytopenia with cutaneous petechiae, purpura, and hemorrhage can be expected. In granulocytopenic patients, otherwise-noninvasive surface bacteria may colonize areas of wet desquamation and lead to suppurative lesions.

The threshold dose for gamma-radiation-induced erythema is about 3-5 Gy; for desquamation, it is about 10 Gy. Ulceration develops at doses of 20 Gy. At doses of more than 40 Gy, gangrenous radionecrosis can be confidently predicted, if the dose is well documented and can be confirmed on review of the evidence.⁸ Different body areas may have different radiation sensitivities; a gradient from greater to lower resistance is observed for scalp, face and neck, trunk, ears, groin, and extremities. Exposure of the skin to temperatures greater than 42°C may enhance cutaneous radiosensitivity and increase the probability of a more severe injury.⁷

Beta-emitting isotopes from smoke and fallout can cause desquamation from high-dose local radiation delivered to exposed skin surfaces, but only if these isotopes are in contact with the skin for longer than 1 hour. Since beta radiation is not as penetrating as gamma radiation, dry desquamating skin lesions secondary to beta burns may not be as serious as wet desquamating lesions, which occur as the result of high-dose exposure and suggest that underlying structures are involved. The wet lesions may be complicated by secondary infection, and usually indicate a poor prognosis.

Gastrointestinal Phenomena. A sense of fatigue and malaise associated with nausea and loss of appetite is characteristic even of relatively low-dose radiation exposure (1-2 Gy). The abrupt onset of nausea and vomiting occurs with acute high-dose radiation in the range of 5-10 Gy. These initial symptoms may be followed by a short latent period of 1-2 days. The severity of initial symptoms, including diarrhea, serves as a useful index of probable outcome, as does the rapidity of onset or a delay in the appearance of symptoms. Following the latent period, an increase in vomiting, diarrhea, and anorexia, as well as dehydration and signs of infection, can be expected.⁹

An abrupt onset of bloody diarrhea after acute high-dose radiation indicates lethal exposure. If less-acute doses are received, diarrhea may not appear for several days or a week after exposure. The onset of diarrhea within a week of exposure is usually associated with death. However, patients have survived when the onset of

radiation-related diarrhea was delayed for more than 1 week after protracted radiation exposure.¹⁰ Nausea and vomiting occur after exposure to doses greater than 2.5 Gy. Identification of the onset of these symptoms may be useful in the initial triage of a radiation-only casualty. However, in combined chemical-nuclear warfare environments, chemical agents may account for much of the nausea and vomiting.

Cardiovascular, Respiratory, Metabolic, and Neurological Phenomena. If a casualty has no conventional injuries or psychosomatic complaints, then cardiovascular, respiratory, metabolic, and neurological symptoms usually indicate terminal high-dose radiation exposure. Radiation-related hypotension, radiation pneumonitis, or ETI identify persons who may be expected to die within 2-3 days. This prognosis is certain, despite a variable period of transient improvement that occurs shortly after the event.

Initial symptoms of high-dose exposure may not be distinct from those of lower-dose exposures. Nausea and vomiting may occur even without direct exposure to the gut in patients who received high-dose local radiation to the head or chest.

Metabolic abnormalities can be expected after radiation of moderate to high doses, and include the consistent finding of non-bacteria-mediated hyperthermia with marked fever and shaking chills. A 25% drop in plasma glucose may occur within the first day, but a neuroglycopenic state of confusion has not been observed. Hemorrhagic coagulopathies, associated with disseminated intra-vascular coagulation and a reduction in noncellular clotting factors, are possible. Liver injury probably accounts for hypoglycemia and the coagulation factor deficiencies.^{11,12} Cardiac arrhythmias associated with electrolyte imbalance (hyper- or hypokalemia) may occur.

In the later stages after lung exposure, the loud crepitus of radiation pneumonitis, which has been likened to the “thundering of a rain storm on an iron roof,”¹⁰ is associated with tachypnea and severe hypoxemia.

ETI in primates (and its locomotor equivalent in rodents) is characterized by the complete but temporary cessation of motor function, and does not occur unless high-dose radiation is delivered acutely.¹³ Transient loss of consciousness is not typical of ETI. Unconsciousness is more suggestive of conventional head injury.

Hematological Phenomena. The most useful and rapid method of assessing the degree of radiation exposure is to obtain serial total lymphocyte counts. Optimally, this should be done every 6 hours during the first 48 hours, or at least once every 24 hours after exposure. This estimate and its interpretation need to be standardized for the available laboratory methodology. To that end, a chart of blood cell morphology (Figure 3-2) and a nomogram of the acute radiation-induced change in lymphocytes/mm³ (Figure 3-3) may be useful. A laminated copy of this nomogram should be included in the field kit of every medical

officer. Changes in peripheral blood granulocytes do not give as clear a picture of the severity of radiation injury because their numbers are affected by stress and infection, fall more slowly, and vary widely.

Sophisticated methodology has become available that permits the rapid and quantitative determination of the total and differential leukocyte counts at DEPMEDS (Deployable Medical Systems) field hospitals. Using the QBC II assay methodology,¹⁴ a total lymphocyte count requires only a fingerstick blood sample (rather than a phlebotomy) and can be performed by relatively inexperienced personnel. Effective suppression of electrical power surges and adequate supplies of special sample tubes would be needed to permit this option on the nuclear battlefield at a field hospital.

A drawback of this method is that monocytes cannot be differentiated from lymphocytes unless a separate Wright-stained slide is prepared and interpreted. Such a determination done by hand would become prohibitively time consuming and labor intensive in a mass-casualty situation. However, with the QBC II methodology, the determination of the total granulocyte percentage and the mononuclear cell percentage is automated (although it still requires data transcription by hand).

Triage of the Combined-Injury Patient

Priorities in handling patients of conventional trauma are modified in cases of concurrent radiation injury. Triage priority is based on the conventional injury as well as the degree of radiation suffered by the combined-injury victim (Table 3-1).

All patients exposed to more than 4.5 Gy are in the expectant category, as are those with exposure of 1.5-4.5 Gy who cannot be given care immediately. If exposure was less than 1.5 Gy, the nature of the conventional injury will dictate the treatment priority. Casualties who receive radiation exposure alone over a wide range of doses will need little if any treatment initially.¹⁵

Since an estimate of the exposure dose in the early phases of radiation-casualty triage will be almost impossible, a more practical triage scheme, based on symptoms of unlikely, probable, or severe radiation exposure, will be useful (Table 3-2). In the event of combined injuries, symptoms of probable or severe exposure may be confused with symptoms associated with conventional injury. In giving the benefit of the doubt to such patients, those with injuries treatable on an immediate basis should receive prompt attention. However, if radiation exposure does account for the observed symptoms, the patient in the conventional categories of immediate (Table 3-3) or delayed (Table 3-1) may actually be expectant. Even with severe symptoms of radiation exposure, patients with minimal traumatic injury may be capable of survival if evacuated for observation and advanced medical management. However, if transportation resources are

limited, disposition of the minimally injured but heavily exposed patient should coincide with that of the casualty in the expectant category. Patients in the delayed category with probable radiation symptoms are expectant, unless adequate tertiary-care facilities are readily available. Regardless of the triage scheme used, it is probable that a number of combined-injury patients in the expectant category will receive treatment for more immediate and delayed conventional injuries.

Conventional injuries that are particularly relevant following a nuclear detonation include burn, blast, and eye trauma.

Burn Injury. The extent of a thermal burn may be rapidly estimated according to the “rule of nines.”⁴ Conventional thermal burns are predicted to be among the most frequent injuries to troops on the nuclear battlefield.¹⁵ A more severe hematopoietic subsyndrome is likely if partial-thickness burns involve more than 10% of the body surface.¹⁰

Blast Injury. Dynamic overpressure from the explosion of a nuclear weapon will induce overt crush injuries and occult internal bleeding.¹⁶ The triage officer should suspect occult traumatic injuries, which will likely place the irradiated patient in the expectant category.

Eye Injury. Eye injuries from a thermonuclear flash may be as minor as transient blind-ness (for a few seconds to minutes) or a permanent retinal scar in which peripheral vision is spared.^{3,16} These are minimal injuries. However, permanent foveal damage with 20/200 visual acuity may occur if the victim focuses directly on the nuclear fireball. A variety of eye injuries resulting primarily from protracted high-dose radiation exposure was observed among firefighters at the Chernobyl reactor accident. These injuries will most likely lead to permanently impaired vision.¹⁰ Clearly, if the corrected visual acuity of a patient is 20/200 or less after more than 1 hour from time of injury, the usefulness of that person as a combatant will be limited, and assignment to a category of delayed treatment is appropriate. Gross eye injuries, most likely from flying objects after a nuclear blast, may have a dramatic appearance, but they are frequently minimal and should not divert attention from more significant injuries.

MEDICAL MANAGEMENT OF THE COMBINED-INJURY CASUALTY

Patient management will focus on three issues. First, basic life-support concerns need to be quickly addressed for casualties in the immediate category; an airway, adequate ventilation, and circulatory function should be assured for patients whose injuries will permit them to survive. Concerns about internal or external contamination with radioactivity should be second priority. Finally, an effort should be made to retrieve data from any dosimeters carried by the military com-

bat unit. Currently, radiation dosimeters cannot be relied on to accurately estimate the severity of an individual's radiation injury. Dosimeters do not account for partial shielding and do not reflect the delivery rate of a radiation dose, and so make only a small contribution to the diagnostic picture. Any data from physical dosimeters must be interpreted by the medical attendant in light of the observed physiological changes.

Because most of the radiation exposure likely to be encountered on the battlefield has no immediate life-threatening consequences, the medical attendant should first focus on conventional injuries. Needless risks, such as prolonged contact with contaminated clothing or wash water, must be avoided, but in emergency medical treatment, direct contact with a contaminated patient is usually not hazardous. No conclusive evidence exists that any attendant has ever been adversely affected by brief contact with a radiation casualty. On the other hand, in a nuclear attack that is combined with chemical or biological weapons (which may be more likely than a nuclear attack alone), the attendant will need to wear protective gloves, as well as a mask outfitted with an entire chemical ensemble, to manage these casualties safely.

Wearing this chemical ensemble will pose special problems in primary medical management. Even if the mask is equipped with a voice emitter, verbal communication over more than a few yards will be hampered. In the early phases of identification and triage, familiarity with a brief dictionary of sign language will be useful. The signs for “radiation casualty” and “chemical casualty” are illustrated in [Figure 3-4](#).

Concerns in the Treatment of the Combined-Injury Patient

Once an airway, proper ventilation, and circulatory stability have been established, definitive care should be planned for the casualty who can survive. Treatment planning is based on the competent handling of conventional injury and the anticipation of predictable sequelae of radiation injury. In the following discussion, early placement of a peripheral intravenous catheter for infusion of adequate quantities of fluids and blood components is assumed. The use of central venous lines in protected sites for long-term infusions is also discussed.

The decision to apply any of these measures to the combined-injury patient will be a difficult one, and will have to be based on the availability of resources and the projected number of casualties. The prognosis for combined injury is markedly worse than for either traumatic or radiation injury alone. Patients with moderate or severe conventional injuries who arrive at tertiary centers that are capable of handling combined injuries will probably receive the maximum available care, unless they have received obviously massive doses of radiation (over 8 or 9 Gy). It will be hard to justify the decision to continue therapeutic interventions in a trauma patient whose dose of radiation is eventually determined to exceed 4 Gy. Continuing advanced life-support measures will not be in the best

interests of a patient who will most likely suffer a protracted, terminal illness. Nor will less-injured patients benefit if their access to hospital resources is limited because of the excessive allocation to hopeless cases. On the other hand, the military organization should attempt to assure that the psychological support of casualties in the expectant category are augmented as much as possible by nonmedical personnel.

Specific Treatment Concerns

Surgery. Since exposure to doses of less than 5 Gy is of no immediate threat to health, conventional injury that is surgically remediable deserves priority treatment. Ideally, surgery should be initiated as soon as possible, or within 36 hours of radiation exposure,³ and be completed before 48 hours.¹⁷ Surgery after this time is contraindicated for at least 6 weeks, or until there is evidence that immunocompetence has returned and that incised tissue is able to revascularize. Clearly, the best candidate for surgery is the patient who requires only one procedure with no surgical revision. Patients who have been exposed to more than 1.5 Gy, who have extensive injuries, and who need multiple procedures and reconstructive surgery are classified as expectant. However, patients who have suffered severe conventional injury, who have had successful wound closure, and who then received radiation may actually be more radioresistant and better able to survive.¹⁷ Decontamination of the radiation casualty should include prompt surgical debridement, if needed, and washing of the surgical area with mild antiseptic soaps. The skin should be cleansed before surgery to adequately reduce any radioactivity in the area of the incision. An important secondary concern is to cleanse crevice areas (nails, ears, and skinfolds) and orifices (particularly mouth and anogenital regions). To avoid abrading the skin, washing should be done gently with mild soaps and hair should be clipper-cut instead of shaved. These procedures will eliminate at least 95% of a patient's surface contamination with isotopes.

Anesthesia and Pain Control. In controlled trials with animals, the induction and recovery from anesthesia for irradiated subjects do not differ from those for nonirradiated subjects.¹⁸ However, anecdotal experience in humans has suggested that the times of induction and recovery from anesthesia may be prolonged.¹⁹ In irradiated animals and humans, there is a clear resistance to the effects of analgesics. However, care should be exercised to avoid overtreatment with sedative narcotics and anesthetics.⁹

In a local high-dose radiation injury (over 40 Gy) to an extremity, prompt amputation gives the patient the greatest pain relief and makes the most efficient use of resources. The use of nonsteroidal anti-inflammatory drugs and thrombolytic agents, as well as topical corticosteroids, has been claimed to delay the appearance of dermal necrosis and to lessen the pain of local skin damage.²⁰ However, topical corticosteroids are contraindicated in thermal burn injuries.

Control of Infections. A variety of measures has been advocated to reduce infections in the irradiated patient. These measures include meticulous hygiene of skin and orifices, aseptic skin punctures, reverse isolation, and prophylactic administration of immunoglobulin G. Difficulties associated with the strict maintenance of reverse isolation procedures are obvious. Laminar airflow rooms are in limited supply, constant surveillance is required for nosocomial infectious agents in plumbing fixtures and ice machines, and food must be free of gram-negative bacteria (no raw fruit, vegetables, or salad). The best result that might be achieved by these methods is a reduction in the appearance of new infections. Meanwhile, endogenous reinfection would be little affected unless antibiotics to eliminate opportunistic pathogens from the gut are effectively used. Although measures to control infection are prudent, their efficacy has not been clearly shown. Life-threatening infections remain a complication in the management of radiation casualties.

Maximum doses of two or three antibiotics of different classes should be infused empirically when specific signs of bacterial infection occur. These signs include the appearance of a sudden fever spike, usually in the presence of a depressed leukocyte count (that is, granulocytes fewer than $500/\text{mm}^3$). Prophylactic antibiotic treatment has given good results when used perioperatively in patients who have penetrating abdominal wounds.²¹ The use of poorly absorbed oral antibiotics that selectively decontaminate the gut may be indicated as a preventive measure in patients known to have been exposed to moderate or high radiation doses. Even commonly used and widely available antibiotics (penicillins, streptomycins, and sulfas) may be useful with mass casualties, because sensitive and otherwise-noninvasive organisms usually become prominent pathogens in immunosuppressed radiation casualties.¹⁰ Antifungal and antiviral agents are indicated when specific signs of these infections occur.

Antibiotics may rapidly become scarce in a mass-casualty radiation disaster and should be allocated to the victims most likely to survive. Such patients include (a) those with minimal injuries and evidence of localized infection, (b) those who require only one surgical procedure, and (c) those with contaminated wounds who have received lower doses of radiation.

Antiemetics and Antidiarrheals. The phenothiazine class of antiemetics, when used in the high doses needed to relieve a radiation victim's nausea and vomiting, has an unacceptably high incidence of extrapyramidal neurological side effects. Since the currently available antiemetic agents are of limited use, intense research efforts have been directed to finding new agents. Promising results have been obtained with the use of serotonin (5-HT₃) blocking agents. This class of drugs significantly reduces radiation-induced emesis in the ferret, nonhuman primate, and human. However, some of the drugs may result in nausea.²² Results of clinical trials of these relatively nontoxic agents are pending, as is their approval as agents potentially useful in the field by NATO forces. The goal in the use of any effective antiemetic is threefold: (a) to enhance patient comfort without

drug side effects, (b) to reduce the risk of aspiration pneumonia, and (c) to conserve body fluid and electrolytes. It may be possible to prevent emesis by administering serotonin antagonists prophylactically or immediately after exposure. Diarrhea from radiation damage to the gut may be controlled in part by a restricted-fiber diet and in part by medication. Drugs such as diphenoxylate HCl, codeine, or atropine have been advocated. If these are ineffective and the damage is localized to the large bowel, hydrocortisone enemas may help. The late complication of bowel stricture from local radiation damage is managed surgically.²³

Fluids and Electrolytes. While adequate supplies of intravenous fluids are not likely to be available in a situation involving mass radiation casualties, the survival of patients with milder cases of fluid and electrolyte loss may be enhanced by replacement therapy. Careful measurement of the volume of losses will serve two purposes: (a) patients with severe degrees of fluid loss can be categorized as expectant, and (b) the proper volume of replacement can be given to patients who are capable of surviving. Measurement of the relative volumes of vomitus and diarrhea will help guide the fluid replacement. Those with more vomiting than diarrhea will suffer the greater loss of chlorides and may develop alkalosis, while those with secretory, cholera-like diarrhea may develop hypokalemia and hyponatremia with total-body salt depletion. The collection and measurement of excretions, including urine, serve another purpose: with the proper collection of serial specimens and access to radioanalysis equipment, estimates of internal radionuclide contamination can be made by measuring the radioactivity of the samples. In the event of combined-burn injury involving more than 10% of the body surface, crystalloid infusions are just as satisfactory as colloid, but a higher volume of infusate may be necessary.²⁴

Placement of central venous catheters made of silicone elastomer (such as the Hickman or Broviac type)²⁵ should be considered a minor surgical procedure and be accomplished within the first 36 hours, if needed. Vascular obstructions and exotic infections increasingly complicate the use of these lines in immunocompromised patients,²⁶⁻²⁸ and so they should be limited to the critically injured patients who need them most. However, a long-term illness following serious radiation injury will dictate that long-term venous access be maintained. The probability of wound-healing disturbances and the chronicity of phlebotoxic intravenous therapy involved in the care and treatment of any critically ill patient make central venous access preferable to peripheral intravenous access.

Using peripheral lines in the radiation casualty has further disadvantages: (a) placement is difficult if hemostasis is compromised and local hemorrhage develops, (b) placement is restricted to percutaneous insertion after 36 hours, even if a venous cutdown is otherwise desirable, (c) the lines are unsuitable for infusion of hyperosmolar solutions, and (d) the lines are at greater risk of becoming infected at the catheter tip if used longer than 72 hours. Long-term use of the percutaneous subclavian cannula made of polyethylene or polyvinyl chloride is

contraindicated because of the high rates of infection, vascular occlusion, and thrombogenicity associated with these materials.

Blood Component Therapy. Impaired hemostasis after radiation injury is best related to the decline in platelet numbers that occurs several weeks after exposure. After protracted lower-dose irradiation, the decline in platelets may take more than 2 weeks. In the interim, autologous platelets can be harvested, cryopreserved, and stored for later reinfusion. This procedure was used successfully to aid the victims of the Chernobyl reactor accident. If bleeding develops, patients with reduced numbers of platelets secondary to marrow suppression benefit from platelet transfusion even if the count is greater than 20,000/mm³. However, prophylactic platelet transfusions are indicated on a regular basis if the count falls below 20,000/mm³, even in the absence of bleeding.

Platelets can be collected either by harvesting the platelet-enriched plasma obtained by centrifugation of fresh units of whole blood, or by using plateletpheresis. Although pheresis technology is complicated and expensive, each pheresis platelet concentrate provides the equivalent of platelets from five to eight whole-blood donations. Thus, a single pheresis unit is the usual transfusion dose and can be obtained in a single cost-effective procedure.²⁹

Anemia develops rapidly in the critically injured radiation casualty. Maintenance of perfusion pressure and oxygen delivery to injured areas, better wound healing, and an enhanced sense of well-being will depend on preventing anemia through red-cell transfusions. As with patients suffering thermal burns alone, patients with radiation skin burns and those with combined injuries require more red-cell transfusions.¹⁰ A recall system is essential for the large number of healthy blood donors needed to keep up with the demand for red cells for mass casualties.

Erythrocytes may be stored for up to 10 years using modern cryopreservation techniques. Critical government and military leaders should stockpile autologous blood for use in case of wartime emergency.

In the fight against infections, fresh heterologous granulocyte infusions, bone-marrow transplants, and even the use of recombinant leukocyte stimulatory factors, such as granulocytemacrophage colony-stimulating factor (GM-CSF), have been advocated. Adequately controlled clinical investigations are needed to demonstrate the effectiveness and safety of these three therapies. Unfortunately, such a study was not performed during the clinical use of GM-CSF in the 1987 radiation disaster in Brazil.^{30,31} Further research is needed if the preservation of granulocytes for autologous transfusion is to be made practical. A protocol has yet to be developed for the rational and balanced use of the many humoral hemopoietic stimulatory factors and the timing of their administration. The disappointing results from attempts to use conventional bone-marrow transplants in radiation victims have obviated the use of this procedure in the treatment of mass radiation casualties.¹⁰

Chelation Therapy. Chelator treatment of internal contamination is most effective when initiated within the first 2 hours, before the radionuclide leaves the vascular space and enters the cell. Currently available chelating agents are not lipophilic and will not cross the cell membrane. Ethylenediaminetetraacetic acid (EDTA) is widely available, but it is toxic regardless of the route of administration. The calcium disodium salt of EDTA is used to avoid hypocalcemic tetany. To avoid nephrotoxicity, the maximal total dose of intravenous EDTA should not exceed 550 mg/kg given as a dilute solution in divided doses over at least 4 days. Intramuscular EDTA (75 mg/kg three times daily) is very painful and should only be given with a local anesthetic. EDTA is contraindicated in renal and hepatic disease. EDTA is used to chelate lead, zinc, copper, cadmium, chromium, manganese, and nickel; none of these metals is related to nuclear weapons or reactor accidents. Its use in radiation accidents is largely confined to the treatment of contamination with the transuranic elements, plutonium and americium.

Diethylenetriaminepentaacetic acid (DTPA) is more effective than EDTA for the treatment of transuranic element contamination. This agent is particularly useful for plutonium, curium, californium, berkelium, and americium, which are commonly involved in nuclear weapons accidents. DTPA is administered intravenously or by external lavage as a dilute solution of the calcium or zinc trisodium salt in physiological saline or glucose. The recommended intravenous dose is 1,000 mg/day infused over 1 hour in 250 ml of solution for 4-5 days. Used as a solution for the irrigation of radionuclide-contaminated wounds, it will cause pain unless a local anesthetic (such as 2% lidocaine) is added.³²

Nutritional Support. In combined-injury patients and in nonirradiated critically ill patients, heightened catabolic stress and impaired nutritional status may play pivotal roles in morbidity and mortality. The incidence of wound infections and sepsis has been reduced by correcting the indices of malnutrition in postoperative patients.³³ Malnutrition may also contribute to impaired wound healing, depressed immune response, prolonged postoperative ileus, bowel atrophy, increased respiratory infections and insufficiency, impaired ventilatory responses to hypoxia and hypercarbia, delayed weaning time for patients on ventilators, and prolonged hospitalization. Since many of the above phenomena or characteristics can be linked to radiation exposure alone, their accentuation in the malnourished radiation victim is highly probable.

Simple and reliable methods of nutritional assessment are not available, particularly in the irradiated patient, whose lymphocytes will be affected independent of nutritional status. However, parameters that can be used to assess nutritional status in critically ill patients are serum albumin, transferrin, body weight, allergic skin reactions, thickness of triceps skin fold, and direct assay or clinical evidence of micronutrient deficiencies.

In selecting the route of administration of nutrients in the radiation victim, the following considerations are important. The oral route is the safest, most econom-

ical, and most natural way to provide nutrients. However, some patients will be unable to consume sufficient quantities of nutrients because anorexia occurs over a wide range of radiation doses. If the alimentary tract has not been injured by radiation, and if inanition supervenes and persists, then nutrients can be infused by nasogastric, gastric, or intestinal feeding tubes. Fluid loss associated with the cholera-like diarrhea of the gastrointestinal subsyndrome may require that nutrients and fluids be administered by both the enteral and parenteral routes. With appropriate placement of an enteral feeding tube, the use of intravenous fluids can be reduced, and transition to enteral therapy alone will be facilitated.

The catabolic critically ill radiation casualty will require no less than 2,500-2,800 kcal/day. This requirement can be met by the infusion of a balanced mixture of glucose, amino acids or protein, and lipids. Based on ideal body weight, total protein or amino acid infusion should approach (but not exceed) 2 g/kg/day. Simple carbohydrates (3.5-6.0 g/kg/day) adequately supply most of the 30-40 kcal/kg of nonprotein nutrients needed. Usually, a maximum of 30% of the total caloric requirement can be supplied as lipids. However, short-term peripheral infusion of up to 80% of total calories as lipids is acceptable if central venous access is unavailable.

The infusion of micronutrients, including vitamins, minerals, and trace elements, may need to be adjusted with long-term parenteral therapy. The usual daily replacement dosages of essential water-and fat-soluble vitamins, with the exception of vitamin K, are commercially supplied in a single vial. In thermal-burn-injury patients, the requirements for B-complex vitamins and vitamin C are increased. Vitamin K is given as a 10-mg intramuscular injection once a week. If renal impairment supervenes, the normal requirement for potassium (60-100 meq/day), magnesium (8-12 meq/day), and phosphorus (30-60 meq/day) may need to be reduced. Since sodium depletion may occur with diarrhea in the gastrointestinal subsyndrome, sodium infusion of over 150 meq/day may be needed. If chelation therapy with EDTA is undertaken, supplements of zinc (>4 mg/day), copper (>1.5 mg/day), chromium (>15 µg/day), manganese (>0.8 mg/day), and iron (>2 mg/day) may be needed. The patient who receives multiple blood transfusions will not need iron supplements until after the blood count has stabilized. Trace element supplements, including iodine and selenium, should be considered if prolonged parenteral feeding becomes necessary.

SUMMARY

Triage

The degree of injury of a radiation casualty can be categorized by the symptoms of exposure. Casualties can be rapidly sorted on the basis of unlikely, probable, or severe radiation symptoms. This rapid sorting of victims allows the conventional traumatic injuries to receive appropriate attention. Lymphocyte counts are the

most necessary laboratory procedure in the first hours and days after exposure. Information from currently available physical dosimeters is of limited value and cannot be relied on entirely in making triage decisions.

Triage is greatly complicated if the patient has suffered combined injuries. A shift in priority to the expectant category is likely for a radiation casualty who requires more than one surgical procedure or who has received a surface burn of more than 10%.

Medical Management

In the first hours after radiation injury, the priority will be to treat the injuries that require immediate attention. Candidates for surgery must be carefully chosen. Only radiation victims who can be attended to within 36 hours and whose condition does not call for multiple procedures should go to surgery.

Decontamination of surface radionuclides is nearly always a second priority after the initial resuscitative support, and can be effectively done with lavage before surgery. Chelation therapy for internal radionuclide contamination can be safely accomplished with the experimental agent DTPA, but the effectiveness of this therapy with mass casualties remains uncertain.

The use of antiemetics and antidiarrheals may contribute significantly to patient comfort. Unfortunately, in effective doses, the currently available agents have major side effects that impair the patient's performance.

The prevention of infection and the appropriate use of antibiotics are important in the first few weeks after exposure. Within the first 7-10 days, selective gut decontamination should be used before leukopenia and sepsis occur. Two to 3 weeks later, if infection is indicated by fever and leukopenia, parenteral antibiotics should be initiated. To help prevent infection with new organisms, environmental control measures should be instituted as soon as possible.

Supportive therapy with blood components has been shown to be extremely effective in combating hemorrhage and anemia following combined injury. However, granulocyte transfusions and bone-marrow transplants as currently used appear to be of little help. A combination of simple supportive measures, including fluids, electrolytes, antibiotics, adequate nutrition, and platelet transfusions, can significantly reduce mortality, as shown by studies of animal research models.

Effective triage will permit the use of limited resources to improve the greatest number of radiation casualties. Survival after either radiation injury alone or combined injury can be greatly enhanced by the application of currently available treatments. Research into new and experimental therapeutic agents for the

treatment of radiation injury may be expected not only to benefit the civilian population, but also to enhance the survival of the fighting force.

REFERENCES

1. Walker, R. I., and Conklin, J. J. 1987. Military radiobiology: A perspective. In *Military Radiobiology*, edited by J. J. Conklin and R. I. Walker, 1-8. Orlando, FL: Academic Press.
2. Leaning, J. 1986. Burn and blast casualties: Triage in nuclear war. In *The Medical Implications of Nuclear War*, edited by F. Solomon and R. Q. Marston, 251-281. Washington, DC: National Academy Press.
3. Wiener, S. L., and Barret, J. 1986. Thermonuclear weapons. In *Trauma Management for Civilian and Military Physicians*, 497-506. Philadelphia: W. B. Saunders.
4. American College of Surgeons Committee on Trauma (D. D. Trunkey, chairperson). 1984. *Advanced trauma life support course for physicians*. Chicago: American College of Surgeons.
5. Champion, H. R., and Sacco, W. J. 1986. Triage of trauma victims. In vol. 2, *Current Therapy of Trauma*, edited by D. D. Trunkey, 5-12. Toronto: B. C. Decker.
6. Conklin, J. J., and Walker, R. I. 1986. Diagnosis, triage, and treatment of casualties. *Medical Bulletin of the U.S. Army, Europe* 43(7): 11-15.
7. Dutreix, J. 1986. Human skin: Early and late reactions in relation to dose and its time distribution. *Br. J. Radiol. (Suppl.)* 19: 22-28.
8. Lushbaugh, C. C.; Fry, S. A.; Ricks, R. C.; Hubner, K. F.; and Burr, W. W. 1986. Historical update of past and recent skin damage radiation accidents. *Br. J. Radiol. (Suppl.)* 19: 12-17.
9. Milroy, W. C. 1984. Management of irradiated and contaminated casualty victims. *Emerg. Med. Clin. North Am.* 2: 667-686.
10. Gus'kovaya, A. K., ed. 1987. *Early acute effects among the victims of the accident at the Chernobyl Nuclear Power Plant* [USSR Ministry of Health Order No. 4851]. Translated by U.S. Defense Intelligence Agency [LN 818-871. Moscow: USSR Ministry of Health.
11. Murano, G.; MacVittie, T. J.; Conklin, J. J.; Casey L. C.; and Walker, R. I. 1985. Hemostatic changes in a canine model of combined injury. In *The*

Pathophysiology of Combined Injury and Trauma, edited by R. I. Walker, D. F. Gruber, T. J. MacVittie, and J. J. Conklin, 105-110. Baltimore: University Park Press.

12. Cockerham, L. G.; Simpson, S. A.; Doyle, T. F.; and Gossett-Hagerman, C. J. 1984. Canine post-irradiation plasma glucose variations. *Life Sci.* 34: 2641-2646.

13. Landauer, M. R.; Ledney, G. D.; and Davis, H. D. 1987. Locomotor behavior in mice following exposure to fission neutron irradiation and trauma. *Aviat. Space Environ. Med.* 58:1205-1210.

14. Wardlaw, S. C., and Levine, R. A. 1983. Buffycoat analysis. *JAMA* 249: 617-620.

15. North Atlantic Treaty Organization. 1978. *NATO handbook on the concept of medical support in NBC environments* [AMed P-7 (A)]. Brussels: North Atlantic Treaty Organization.

16. Giambarresi, L. 1986. Nuclear weapons: Medical effects and operational considerations. *Medical Bulletin of the U.S. Army, Europe* 43(7): 7-10.

17. Streffer, C., and Messerschmidt, O. 1966. Untersuchungen über Kombinationschaden. Die Ausscheidung von Taurin and Harnstoff im Ur in wei er Mause bei einer Kombination von Strahlenbelastung and Hautwunde. *Strahlentherapie* 130: 285.

18. Hunt, W. Personal communication.

19. Conklin, J. J.; Walker, R. L; and Hirsch, E. F. 1983. Current concepts in the management of radiation injuries and associated trauma. *Surg. Gynecol. Obstet.* 156: 809-829.

20. Messerschmidt, O. 1986. Treatment of subcutaneous radiation lesions. *Br. J. Radiol. (Suppl.)* 19: 122-137.

21. Fabian, T. C.; Hoefling, S. J.; and Strom, P. R. 1982. Use of antibiotic prophylaxis in penetrating abdominal trauma. *Clin. Ther.* 5: 38-47.

22. King, G. Personal communication.

23. Spiro, H. M. 1970. Inflammatory disorders other than ulcerative colitis. In *Clinical Gastroenterology*, 570-574. Toronto: Macmillan Co.

24. Kaplan, J. Z. Care of thermally injured victims of a thermonuclear explosion. In reference 11, 41-45.

25. Cormed, Inc. is located in Medina, NY.
26. Venezia, F. R., and O'Keefe, P. 1986. Infections of intravascular devices. *J. Nosocom. Infect.* 4: 10-26.
27. Kaufman, J. L. 1987. Venous catheter-related thrombosis and infection. *JAMA* 257: 2594.
28. Allo, M. D.; Miller, J.; Townsend, T.; and Tan, C. 1987. Primary cutaneous aspergillosis associated with Hickman intravenous catheters. *N. Engl. J. Med.* 317: 1105-1108.
29. Warkentin, P. I. 1987. Plateletapheresis: An invaluable blood resource. *Cleve. Clin. J. Med.* 54: 381-383.
30. Roberts, L. 1987. Radiation accident grips Goiania. *Science* 238: 1028-1031.
31. Butturini, A.; Gale, R. P.; Lopes, D. M.; Cunha, C. B.; Ho, W. G.; Sanpai, J. M.; De Souza, P. C.; Cordiero, J. M.; Neto, C.; De Souza, C. E.; Tabek, D. G.; Burla, A.; and the Navy Hospital Radiation Team. 1988. Use of recombinant granulocyte-macrophage colony-stimulating-factor in the Brazil radiation accident. *Lancet* 2 (August 27): 471-475.
32. Durakovic, A. Internal contamination with medically significant radionuclides. In reference 1, 241-264.
33. Schmitz, J.-E.; Ahnefeld, F. W.; and Burri, C. 1983. Nutritional support of the multiple trauma patient. *World J. Surg.* 7: 132-142.