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Radiological and Nuclear Emergencies: Medical Management of Radiation Injuries

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ABSTRACT

Nuclear radiation which could be in the form of alpha, beta, gamma rays, etc, could cause radioactive contamination, radiation burns, acute radiation syndrome or a combination of any of these above-mentioned disasters. Effects of radiation and the subsequent treatment depend on the severity of exposure and the organs directly involved. Radiation levels up to 200 rads lead to nausea and vomiting whilst radiation levels between 200 rads and 400 rads lead to diarrhea, vomiting and pneumonitis. Whilst 450 rads is lethal in 50 per cent population, doses above this cause increased fatality and organ involvement with the Central Nervous System being affected with 2000 rads radiation. Nuclear disaster management lies most importantly in identifying that patient who would recover if treated immediately. Whereas decontamination of skin and wounds is done first, immediate first aid may take priority in a seriously injured patient. In the event of internal contamination, effective decorporation maybe required. This is followed by prevention and treatment of infections in sterile conditions. Radiation burn injuries will require effective long-term management. Finally, what would be most important is the necessity to have suitable hospital care where bone marrow, stem cell transfusion and restitution of the immune system would take place.

Keywords: Nuclear disaster, medical management, RDD, radiation, radiation injuries, nuclear emergency

1. INTRODUCTION

One of the potential hazards of the application of nuclear energy towards industrial growth or nuclear weapons testing is the release of radioactivity to the environment. Nuclear energy is one of the most powerful energies known, and, it produces heat and light which are more powerful than the sun. In 1896, French physicist Antoine Becquerel discovered natural radioactivity when he found uranium gives off energy in the form of invisible rays. Subsequently, British physicist Ernest Rutherford and James Chadwick, German Radiochemist Otto Hahn and Fritz Strassman, Austrian physicist Lise Meitner and Otto Frisch, and German physicist Albert Einstein made a series of contributions in the development and utilisation of nuclear energy.

The first atom bomb, code named 'Little Boy', containing 0.7 kg of uranium 235 as fission fuel with an explosive yield equivalent to 12.5 kilo ton of TNT was hurled on Hiroshima on 6th August 1945. This was followed by explosion in Nagasaki, on 9th August 1945 of the 'Fat Man', which contained 1 kg of plutonium 239 as fission fuel with explosive yield equal to 22 kilo ton of TNT. While in Hiroshima, 27 per cent people died and 30 per cent were injured; 21 per cent died and 12 per cent were injured in Nagasaki. In both cities, 90 per cent of those within half km of the hypocentre died on the day of the explosion whilst 50 per cent of those within 1.2 km died.

Amongst the survivors, leukemia and thyroid cancer increased in the 1950s, breast and lung cancer in the 1960s, stomach and colon in end 1960s, multiple myeloma in the 1970s.

Apart from the minor nuclear accidents which took place subsequently, some of the major ones include the accidental exposure of people to fallout of isotopes of radioiodine at Marshall islands in 1954, Windscale accident in the United Kingdom in 1957, Three Mile Island accident in United States in 1986, Chernobyl accident in USSR on 26 April 1986, and the disaster in Delhi in 2010[1].

2. THE CHERNOBYL ACCIDENT

The Chernobyl accident took place on 26 April 1986. Activity released was 200 times the combined release of Hiroshima and Nagasaki. 29 persons died and 237 had radiation sickness. Cs^{137}, Te^{132}, I^{131} (46 million Curies) were the important radionuclides.

On 26th April 1986 night, Pripyat, the closest monitoring zone to Chernobyl, showed radiation level of 10mSv/hr. By the next day, more than 135,000 people in a 30 km range were evacuated.

Increased air radioactivity was detected in Poland on 27th April 1986 night. A government commission was set up on 28th April 1986morning to assess the situation. After studying the reports, they recommended the following intervention levels[2]

(i) Whole body committed dose should not exceed 5 mSv/year
(ii) Thyroid committed dose should not exceed 50 mSv/

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year in children and 500 mSv/yr in adults.

(iii) Thyroid content in children 16 years and below should not exceed 5700 Bq at any moment.

The ability and uniqueness of the thyroid to trap iodine has been found to be the most useful method of blocking the uptake of radioiodine. It was decided to treat the population in 11 most affected provinces in the following manner:

(i) 15 mg of potassium iodide for newborn, 50 mg for children 5 years and under, 70 mg for all others.
(ii) Milk with radioactivity above 1000Bq/l banned for consumption.
(iii) All children below 4 years given powdered milk.

Increase in thyroid cancer increased dramatically from 6 in 1989 to 29 in 1990, 55 in 1991, and 30 within the first-half of 1992[3]. Radioiodine exposure, being the cause, is substantiated by the fact that the 8 youngest victims were *in utero* in April 1986 and developed thyroid cancer within 5 years after birth[4].

3. EFFECTS OF NUCLEAR EXPLOSION

Unlike conventional bombs, which release most of its energy in the form of blast, atomic bombs release 50 per cent energy as blast, 35 per cent as heat, and, 15 per cent as nuclear radiation. Although only 15 per cent is released as nuclear radiation, this is potentially the most dangerous of the three. In contrast to this, when there is a reactor accident, as the one took place at Chernobyl, radiation is the only cause of destruction. In the blast of a radiological dispersal device (RDD), the source of radioactivity is so small, the effect is practically equivalent to that of a conventional bomb, other than the psychological havoc created by the emanation of a little bit of radioactivity which has more theoretical nuisance value than practical harmful effects.

The detonation of nuclear weapons gives rise to the following:

- Blast wave,
- Thermal wave,
- Massive fires,
- Initial radiation (neutrons and gamma rays),
- Radioactive fallout,
- Electromagnetic pulse,
- Climatic changes,
- Other environmental disturbances

3.1 Blast Wave and Blast Injuries

Blast wave constitutes about half of the total energy released in a nuclear explosion. Principal injuries include crush injuries beneath collapsing buildings or mutilation from flying shrapnel's, multiple lacerations, compound fractures, crush and head injuries, damaged lungs, ruptured internal organs, penetrating wounds of the abdomen and thorax.

3.2 Thermal Wave and Thermal Injuries

A blinding flash of light is the first indication of a nuclear attack and can be 30 times as bright as the sun with temperature rising up to a million degree. The flash lasts for up to 10 s and causes temporary blindness and retinal damage. Thermal injuries depend on the yield of the bomb, distance from the epicenter, and shielding. There maybe immediate charring of the body, direct flash burns, and indirect burns from explosion.

3.2.1 Massive Fires

The nuclear weapon explosion will start fires, leading to rising hot air so that fresh air is sucked into that area leading to a firestorm.

3.2.2 Radio-active wind

Radioactivity can be carried thousands of kilometer due to the wind effect as a air movement moving away from the zone carrying the environmental radioactivity far and wide.

4. RADIATION INJURIES

4.1 Initial Radiation

It is produced up to one minute after detonation and comprises of gamma rays and neutrons. The neutron pulse is more up to a distance of 1.5 km and beyond this, gamma rays predominate. The initial radiation comprises primary radiation from the bomb explosion and secondary radiation due to interaction of primary radiation with the materials, predominantly metals.

4.2 Residual Radiation

This occurs one minute after explosion and comprises beta and gamma radiation. It predominantly includes the radioactive fallout. Beta particles have range of 2-3 m in air and are attenuated by thick clothing, while being completely stopped by walls. Residual radioactivity can affect the body in various ways as follows :

(i) Direct irradiation of wholebody
(ii) Localised beta burns of skin
(iii) Ingestion of radioactivity
(iv) Inhalation of radioactive particles.

4.3 Radioactive Fallout

(i) *Local:* It is the radioactivity deposited on the ground within first 24 h after explosion and occurs mostly in ground burst.
(ii) *Intermediate Fallout:* It is due to air burst and the radioactivity is deposited in the troposphere.
(iii) *Global Fallout:* This is the radioactivity from airburst of high yield (mega tons) weapons. This fallout reaches stratosphere and spreads all over the globe.

4.4 Symptoms/Signs of Radiation Injuries

Degree of severity of radiation injury

Up to 200 rads: Adults have nausea and vomiting. Babies and young children maybe seriously affected

200-400 rads: General malaise, diahorrhoea, vomitting, radiation pneumonitis.

450 Rads: 50 per cent death.

Above 2000 rads: Severe damage to cardiovascular system (CVS) and central nervous system (CNS).

(i) *Central Nervous System Syndrome:* Acute doses of over 2000 rads, leading to headache, Drowsiness, muscle tremor, coma, convulsions and shock leading to death.

(ii) *Gastrointestinal Syndrome:*Dose of 500-2000 rads. Nasuea, vomiting and bloody diarrhea, leading to death in 1-2 weeks disturbances in body fluid.

(iii) *Haemopoeitic Syndrome:* Caused by acute exposure in lower doses of 200-500 rads, reduction in white blood cells Anaemia due to bone marrow suppression and bleeding Death may occur from immunosuppression, sepsis or haemorrhage.

(iv) *Radiation Sickness (less than 200 rads):* Anorexia, nausea and vomiting may be seen, blood counts may be decreased.

(v) *Radiation Skin Burns (subacute period):* Radiation burns may present as erythema, epilation, transepidermal injury or full thickness burn, blistering occurs about 3 weeks.

(vi) *Psychological Effects:*Entire population may have physical and mental weakness, broken spirits, lost initiative, aggressiveness, irritability, nightmares and irrational behaviour.

5. PRINCIPLES OF MEDICAL MANAGEMENT

5.1 Casualty Management

5.1.1 Evacuation

Evacuation will be done by trained quick reaction teams who have NBC protective suit, gloves, overboots and face mask, personal RPL dosimeter, disposable PVC sheets along with stretcher.

Radiation worker SOP: If the rescue operators are exposed to 5 rads /day, then they can work daily for 2-3 weeks, if 25 rads, then they can work daily for 3-4 days, and if 50 rads, then they can work for 1 day.

Protection and Decontamination of Equipment, Men, Stores, and Vehicles: Equipments, like ambulances, need to be thoroughly decontaminated every time they enter a radiation-free zone. Clothing, boots, caps, etc. being worn by the rescue workers, should also be changed every time they enter a radiation-free zone.

Radiation dose is reduced by reducing time spent in the radiation area, increasing distance from a radiation source, or using metal or concrete shielding.

Respiratory and Skin Protection: Respiratory protection that is designed to protect responders against chemical or biological agents, is likely to offer benefits in an RDD event. Ordinary surgical facemasks provide good protection against inhaling particulates, and allow excellent air transfer for working at high breathing rates. Normal barrier clothing and gloves give excellent personal protection against airborne particles. First responders, who work closest to the point of detonation of an RDD or the hypocenter of a nuclear explosion, will require radiation detector and quantifying equipment.

Medical Triage for Evacuation

Categorise the patient's into the following groups:

Gp I Poor chance of survival
Gp II Reasonable chance, if treated immeadietly
Gp III Treatment required, but not an emergency
Gp IV Treatment can be postponed

(i) Patients in Gp II should be shifted to the hospitals at the earliest. Any delay in this will cause the patients to shift from 'Survival possible' to 'Survival improbable'. Those with a poor chance of survival should be given pain killers and palliative treatment.

(ii) As the number of patients may be large, need may far exceed the resources. Planning and faithful execution is therefore crucial.

(iii) Ambulance services should be geared up for evacuation of a large number of casualties to different hospitals, which may be as far away as 100 km.

(iv) Individual dose assessment is usually not possible in the early phases. Accurate individual dose estimates may take up to a month or more and are retrospectively performed based upon physical dosimetry, accident reconstruction or biological markers and clinical examination.

(v) Patients who experience radiation-induced emesis within one hour after a radiation incident require extensive and prolonged medical intervention, and an ultimately fatal outcome is expected in many cases.

(vi) Initial complete blood count are taken and repeated every 4-6 h to evaluate lymphocyte depletion kinetics

5.1.2 Evaluation of Radiation Exposure

Though a number of methods exist to assist in the evaluation of radiation received, the best two indicators remain the history (location and time spent by the individual in the zone) and the clinical symptoms seen at the presentation and during a second follow up visit, preferably after 1 week. Patients who vomit later than 4 h post-accident are likely to have, at worst, a mild acute radiation syndrome. From these data, the time to vomiting would appear to be a useful triage instrument.

The instrument used to perform the survey should be sensitive to both penetrating and non-penetrating radiation (e.g. a Geiger-Mueller tube with a thin wall or entrance window). Care should be taken not to contaminate the probe by contact with the patient or any other potentially contaminated surface. Collect urine and feces specimens to help determine whether internal contamination has occurred.

Cytogenetic methods are adopted to conduct dosimetry in persons exposed to < 100 rads. Chromosome exchanges resulting in unstable aberrations such as dicentrics, rings, acentric fragments and other asymmetrical rearrangements may by measured using the technique of fluorescence *in situ* hybridisation (FISH), which is currently the assay of choice for definitive biodosimetry ultimately prove to be the most sensitive, reproducible biodosimeter. Counting the frequency or number of micronuclei in the cytoplasm of irradiated cells, electron spin resonance detection of free radical formation in tooth enamel, and measurement of serum biochemical markers such as amylase, IL-6, iron, cholesterol and apolipoprotein levels have also been investigated as potential techniques for determining radiation dose.

For 100 rads and above, hematology is the best method for practical implementation. Fall in cell count start 1st day onwards and continues upto 3-4 days, then recovery start. If the nature of the event is such that it is difficult to obtain serial lymphocyte determinations, a conservative rule of thumb is that a lymphocyte count < 1 x $10^3 \mu L^{-1}$ within 24-48 hours in a patient without known prior lymphocytopenia suggests that the patient has received at least a moderate (> 2 Gy) absorbed dose of radiation.

After 4 days however, blood counts alone may not give a true picture, particularly in marginal cases, and cytogenetic studies or whole body counting may supplement clinical symptomatology in assessing the dose received and the need for subsequent follow-up. Other specialised radiation monitoring equipments like the thyroid probe can be used. Automatic blood cell counter is the best modality to conduct on an average differential blood cell count of 250 cases per day.

Analysis of urine and blood samples for radioactivity is also a means to estimate the radioactivity exposure that needs to be made available to the trained medical personnel for individualising the treatment and for treatment follow-up. Gamma camera and other such imaging equipment can also be used in the time of emergency to estimate the radionuclide content of individuals. Calibration of the equipment at site is an important feature in giving the correct dose estimate of the exposed individuals.

5.1.3 Decontamination of Persons

(i) Removal of the persons' clothing usually reduces most of the contamination (90 per cent). Washing exposed body surfaces with soap-water will further reduce this problem
(ii) Skin or wound contamination is almost never immediately life threatening to the patient or to medical personnel. Therefore, treating conventional trauma injuries is the first priority. Decontaminate the patient only after medical stabilisation in a hospital / shelter
(iii) Gentle brushing with non-abrasive material dislodges some contamination physically held by skin protein and removes a portion of the horny layer of the skin. The stratum corneum of the epithelium is replaced every 12-15 days, so contamination that is not removed and is not absorbed by the body will be sloughed within a few days. Decontaminating to two times the normal background radiation level should suffice.
(iv) Procedure for specialised skin / wound decontamination

Health personnel should wear proper surgical attire before attempting decontamination according to the following procedure:

- Cut open the clothing of the injured / contaminated person.
- Put all the clothing / swabs in a plastic bag.
- Wash the open wounds.
- Metallic shrapnel should be handled with forceps and, if found to be radioactive, placed in a lead container.
- Clean the skin and decontaminate by progressive cleansing agents.
- Gargle with 3 per cent hydrogen peroxide for pharyngeal contamination.
- Rinse eyes and nose with saline.

Caution should be taken not to disrupt the integrity of the skin. Contaminated wounds should be treated first, since they will rapidly incorporate the contaminant. Washing, gentle scrubbing, or even debridement may be necessary to reduce the level of contaminants.

5.1.4 Treatment of Blast Injuries

Treatment of life-threatening injuries should take precedence over measures to address radioactive contamination or exposure. The treatment of blast injuries, whether combined with other injuries or not is best managed by a team of orthopedic, neurosurgeons and cardiothoracic surgeons.

Treatment is divided into four basic phases

(i) First-aid and Resuscitative phase
(ii) Surgical phase
(iii) *Recovery phase:* In the immediate post-operative period, patients require minimal movement, Transportation to other facilities should be delayed until the patient's condition has stabilised.
(iv) *Convalescent phase:* In the scenario, probably the best convalescent place is the patients' home away from the contaminated zone.

5.1.5 Treatment of Burn Injuries

(i) Calculation of area of burn
(ii) ABCD: airway, breathing, circulation, drug management
(iii) Aggressive fluid replacement therapy as early as possible. The basic principle in these formulae is that the amount of fluid required is proportional to the percent of body surface burned and body weight. The type of fluid used includes colloids to replace the plasma constituents lost as well as crystalloids.
(iv) Care of burn wound
(v) Debridement and cleaning of the burn should be done to remove foreign material and dead tissue to minimise infection. Thorough irrigation and application of topical antimicrobial creams and sterile dressings should complete the initial procedures.

5.2 Specialised Acute Radiation Injury Management

- Medical management of radiation syndromes
- Radioprotectors
- Decorporating agents
- Anti-oxidants
- PTSD management
- Reassessment of treatment response and decision regarding OPD / ward management
- After math epidemic prevention and management

5.3 Treatment of Radiation Injuries

The following principles are used in the treatment of radiation injuries

(a) *Decontamination of patients as already discussed.*

(b) *Replenishment of blood loss and electrolytes:* There is going to be blood & electrolyte loss due to radiation effect on gastrointestinal tract. With the large number of casualties expected in such a disaster, adequate stocks of IV fluids (colloids and crystalloids) have to be stocked and kept ready for use at short notice. Blood of each group must be made available in blood bank.

(c) *Decorporation:* Decorporation is the procedure by which ingested radioactive particles and isotopes are prevented from entering their target organs and subsequently expelling them from the body. Internal contamination is minimised by

(i) Reducing the absorption of radionuclides and their deposition in target organs, and

(ii) Increasing excretion of the radionuclides from the body. A number of procedures are available for respiratory and gastrointestinal decontamination, including bronchial and gastric lavage.

Gastric lavage is done until washings are free of radioactive material (no more than two times background radiation or till repeated lavage does not result in further reduction of contamination or until otherwise directed by the treating physician). This is only effective if done within 1-2 hours of ingestion and should only be used for large single intakes of radioactive material. If radionuclides are ingested, antacids are indicated to reduce gastrointestinal absorption. Aluminum containing antacids are especially effective in reducing uptake of strontium. If large ingestions are suspected, *cathartics* to decrease residence time/radiation dose of materials in the bowel. A biscodyl or phosphate soda enema will empty the colon in a few minutes.

(d) *Decorporating agents:* The following decorporating agents are recommended for tackling internal emitters entering the body during nuclear explosion

- Barium sulphate–for Strontium and Radium in a dose of 300 gms orally
- Frusemide–40 mg a day orally
- Lugols iodine / Iodides/Iodates–1 ml a day orally for 7 days
- Ammonium chloride–for Strontium–6 gms a day for 6 days
- Dimercaprol–injections 100 mg 4 hourly for 2 days, as per requirement
- D-Penicillamine–250 mg orally 6 hourly for 8-10 days.
- Sodium Bicarbonate–3.5 gm in 250 ml.
- Desferrioxamine–1 gm IV in saline.
- Prussian blue–l gm TDS to a maximum of 10 gm a day.
- DTPA–250 mg IV daily.

(e) *Restitution of immune and circulatory system:* The immune system of the patients of radiation injuries is likely to be severely compromised due to damage to blood cells and bone marrow, which will lead to fulminating infections. Restitution of immune system will require the following

- Fresh blood transfusions
- Infusion of granulocyte concentrate
- Bone marrow transplant
- Use of Interleukin & Growth factors
- stem cell harvest
- Re-transfusion of autologous marrow preserved in bone marrow bank.

(f) *Control of infection.*

(g) *Proper nutrition, antiemetic, pain killers, vitamins E, B, C.*

(h) *Post-traumatic stress disorders.*

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