A Review of Radiation Hazards with Special Reference to Diagnostic Radiology

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Introduction

THE QUESTION OF radiation hazards has aroused public interest recently, as a result of publicity in the local press and the international controversy surrounding the French nuclear tests in the South Pacific. In view of the increasing clinical applications of ionising radiation, it is also important that doctors should have more than a casual knowledge of its potential dangers. It is felt therefore that a brief review of the subject will be timely and of general medical interest.

Exposure to radiation is by no means a new environmental hazard, since man has constantly been exposed to natural background radiation, both from cosmic rays and from radioactive material in the ground. But it is with 'man-made' radiation, and in particular medical radiation, with which we are concerned. A survey by the Medical Research Council of Britain (1960) revealed that the largest contribution to man-made radiation came from diagnostic radiology. This is not at all surprising because of the widespread availability of diagnostic radio-logical facilities and the frequent indications for their use.

For many years it has been known that radiation can produce deleterious effects in man. In the early days following the discovery of x-rays, the hazards of radiation were not appreciated and no precautions were taken to reduce occupation exposure. For instance, it was common for radiologists to test their x-ray beams by interposing their hands between the tube and a fluorescent screen (Stern and Lewis, 1970). This highly dangerous practice sometimes led to intractable skin burns and years later to malignant growths. Kerley (1961) analysed the causes of death amongst the early x-ray matyrs and reported that the great majority died from chronic radio-dermatitis and secondary malignant change. Other studies (Court Brown and Doll, 1957; MacMahon, 1962) have shown that radiation may induce leukaemia.

Biological Effects of Ionising Radiation

These may be broadly divided into: (1) somatic effects, i.e., those which directly affect the irradiated individual and (2) genetic effects, i.e., the effects on germ cells which may be transmitted to the progeny of the irradiated individual.

(1) **Somatic Effects**

Somatic effects may be acute or delayed.

(a) *Acute Effects*

These follow exposure to high doses and are manifest within a few weeks of the exposure. The effects are dose-dependent. The most sensitive change is a reduction in the lymphocyte count, which may occur with 25 rads of whole body exposure. Symptoms of the acute radiation syndrome become apparent with doses above 100 rads. Other effects include skin reactions, epilations, temporary sterility, and depression of the bone marrow. The lethal dose for man is in the range of 400 to 800 rads delivered to the entire body, death occurring from irreversible damage to the blood-forming organs (400 to 1200 rads), intestinal gangrene (1200 to 2000 rads) and central nervous system injury (above 2000 rads). These acute effects have been observed mainly in nuclear accidents and explosions, and will not occur with diagnostic x-ray exposure, where the absorbed doses range from a few millirads to perhaps 10 rads limited to a small part of the body.

(b) *Delayed Effects*

These may occur years after a single exposure to a large dose (as in nuclear accidents) or after chronic exposure to repeated smaller doses (as in occupational exposure). Delayed somatic effects include: (i) the induction of cancer; (ii) the production of developmental anomalies in the foetus; (iii) a non-specific reduction in life span; (iv) other effects, such as cataracts.

(i) (i) *Induction of Cancer*

A wide range of experiments with animals and observations on man provide convincing evidence that ionising radiation can cause cancer (International Commission on Radiological Protection, 1966). The most detailed studies relate to the induction of leukaemia.

Leukaemia

Studies of atomic bomb survivors and of patients irradiated for ankylosing spondylitis have shown that radiation exposure to high doses above 100 rads may result in leukaemia. The induction period has varied from about 15 months to 15 years. Only acute leukaemia and to a lesser extent chronic myeloid leukaemia have been induced in man. It has not been established that leukaemia in either children or adults can be caused through exposure to the small doses used in diagnostic radiology (Webster, 1971). There is however some evidence that leukaemia and other malignancies may develop postnatally after foetal exposure to these low doses (Stewart, Webb and Hewitt, 1958; MacMahon, 1962). The magnitude of the increased risk from leukaemia is indicated by the following figures. The risk of childhood leukaemia before age 10 is 44 per 100,000 in the absence of pre-natal x-rays, and 62 per 100,000 following pre-natal x-ray exposure. Thus about 30 per cent of the childhood leukaemia that develops in children who have been irradiated in utero appears to be attributable to the radiation. A typical foetal dose from a pelvimetric examination in the studies just mentioned was probably 2 to 3 rads. Hence the number of cases of leukaemia per million irradiated foetuses per rad is estimated to be 60 to 90.

There is no conclusive evidence of any relationship between current levels of occupational exposure and leukaemia. A study of causes of death amongst British radiologists (Court Brown and Doll, 1958) revealed no increased incidence of leukaemia or other cancers in those entering radiology subsequent to 1920, when the first radiation protection regulations came into force.

Other Cancers

Radiation is known to cause other malignancies in man. These include thyroid carcinoma following doses of over 100 rads to the thyroids of infants and children (Conti, Patton, Conti and Hempelmann, 1960; Latourette and Hodges, 1959; Saenger, Silverman, Sterling and Turner, 1960); bone sarcoma amongst employees in the luminising industry; bronchial carcinoma amongst cobalt and radium miners who were exposed to radioactive matter in the form of radon; and skin cancers in early radiation workers. In all these instances the exposures involved were well in excess of the present-day diagnostic range.

(ii) *Developmental Anomalies*

The Russels (1952) have shown that in experimental mice doses of 25 rads or more produced demonstrable changes in the foetus. It appears that irradiation before implantation tends to produce death of the foetus; during the period of major organogenesis (2 to 6 weeks in humans) it tends to produce malformations and neonatal death, rather than prenatal death. In man, different abnormalities have been attributed to irradiation. Children exposed to irradiation in utero from the Hiroshima and Nagasaki bombs showed an abnormaly high incidence of microcephaly and mental retardation. Lejeune, Turpin Rethore and Mayer (1960) found a significant excess of heterochromic wedges in the iris of children who had been irradiated in utero. Whether any abnormalities can be produced by doses of the order of those given in the course of diagnostic radiography is uncertain, but caution dictates that any radiation exposure of the maternal abdomen during pregnancy should as far as possible be avoided.

(iii) *Non-specific Reduction in Life-span*

In addition to causing death from cancer there is some evidence that radiation may have a non-specific effect in reducing the life-span of experimental animals, exposed to large doses. But there is conflict of opinion about whether this effect is produced with lower doses, given either acutely or spread out over many weeks. Human data bearing on the problem are few. Court Brown and Doll (1958) in their study of British radiologists found no evidence of shortening of life span. Other studies quoted by Henry (1969) have shown that in fact radiologists have a somewhat increased longevity as compared with either physicians as a whole or the general population. In the light of experimental evidence, this observation may not be entirely fortuitous and may have rather interesting implications. It has been demonstrated in animal experiments that while exposures of more than 10 rads per day resulted in shortening of life span, smaller doses of the order of 5 rads per day led to increased longevity.

(iv) *Other Effects*

Cataracts have been observed following doses of x and gamma rays above 200 rads and a latent period of about 10 years. Interference with skeletal development in children likewise requires large doses beyond the diagnostic range. While gonadal exposures of about 200 rads may cause temporary sterility, those above 600 rads may lead to permanent sterility.

(2) **Genetic Effects**

The genetic risks of radiation, especially from small doses, are much more difficult to evaluate than somatic risks, and the subject is one of great complexity.

The following is a summary of some basic observations in the light of current knowledge.

(1) Radiation can produce mutations in experimental animals. However, no new mutations have been produced.

(2) The relative frequency of various recognised genetic lesions is the same for radiation induced and sponteneously occurring mutations.

(3) 30 to 80 rads is the most probable range of the dose which would double the spontaneous mutation rate in man (doubling dose). Therefore genetecists recommend that the dose to the general population from man-made radiation should not exceed 10 rads per generation.

(4) There appears to be no threshold for the production of mutations, i.e. regardless of how low the exposure level some mutations will be produced.

It is clear that any irradiation to the gonads should be avoided wherever possible, or when dictated by clinical necessity, kept to the absolute minimum.

Summary of Radiation Hazards from Diagnostic Radiology

From the data we have considered, the hazards from diagnostic radiology can be summarised as follows:

(1) Irradiation to the unborn foetus can lead to leukaemia and other childhood malignancies.

(2) Foetal exposure in early pregnancy may be associated with developmental anomalies.

(3) Pre-conceptional irradiation may produce genetic damage in the children subsequently born. Gonadal irradiation of males may also carry a very small risk of genetic abnormalities in their progeny.

(4) There is no conclusive evidence of a relationship between diagnostic radiation received postnatally and development of malignant disease or shortening of life-span, in the irradiated individual.

Radiation Hazards in Perspective

While we should all be aware of the possible harmful effects of radiation, any discussion of radiation hazards may be misleading if due emphasis is not also given to the beneficial effects of many procedures that involve radiation exposure. The hazards of radiation should also be considered in relation to other man-made environmental hazards such as atmospheric pollution, automobile accidents, drugs, chemicals, and cigarette smoking. No one would seriously suggest that the use of x-rays and other ionising radiation in medicine should be banned because of their potential dangers. For it is beyond dispute that the appropriate medical use of radiation in diagnosis and therapy far outweigh the hazards, and indeed modern medical care would be inconceivable without proper radiological facilities. What is important is that there should be adequate control and supervision of all radiation sources, adequate protection of staff and patients, and not least a proper understanding on the part of doctors of the indications and limitations of various radiological procedures.

Control of Radiation Sources and Protection of Staff

Detailed recommendations and procedures have been laid down by international bodies such as the International Commission for Radiological Protection, the International Atomic Energy Agency and the World Health Organisation, with regard to maximum permissible doses, safety standards for equipment, medical surveillance of radiation workers and other protective measures. These are mainly of interest to those who have administrative responsibility for radiation protection in institutions and are beyond the scope of our discussion.

Protection of the Patient — The Role of the Medical Practitioner

It is primarily the responsibility of doctors to safeguard the patient from the over-enthusiastic or inappropriate use of radiation, particularly in diagnostic radiology. The role of the radiologist in education, in ensuring high standards of safety and quality in radiological techniques, and in being vigilant against unnecessary or ill-advised requests for radiological investigations is obvious. But the co-operation of his other clinical colleagues is equally important, and the routine observance of a few elementary precautions can be of tremendous help. It is suggested that every doctor should ask himself the following questions before referring any patient for an x-ray examination.

(1) Is the examination essential to the management of the patient? In considering this, special care should be exercised in the case of pregnant patients, and in examinations of the abdomen, pelvis and hips where some gonadal irradiation is inevitable. If the answer to the question is no, the examination can only rarely be justified. Exceptions to this are: (a) chest radiographs for routine medical examinations and (b) skull x-rays following head injury which may be required for medico-legal purposes.

(2) What is the most appropriate examination in the light of the provisional clinical diagnosis? In case of doubt, one should never hesitate to consult one's radiological colleague. Providing adequate clinical information on the request form will also enable the radiologist to decide whether the procedure requested is indicated, and if not to suggest an alternative. This inter-departmental communication should be encouraged and will help to ensure that the best diagnostic information is invariably obtained for each radiation exposure of the patient.

(3) In the case of young female patients, is the patient pregnant. The referring clinican is in the best position to ascertain this, as inquiry into the last menstrual period could be easily included as part of the routine medical history. There appears to be a case for observing the 'ten day rule' (Rugh, 1968; Hoare, 1968). This states that all radiation exposures of the pelvis of the female of reproductive capacity should be limited to the first 9 or 10 days after onset of menstruation, unless such exposure is of immediate importance for proper medical diagnosis or therapy. In this way the exposure of an unrecognised pregnancy during the period of greatest radiosensitivity can be avoided.

Conclusion

(1) The risks from diagnostic radiology are small but it is wise to assume that any radiation, no matter how low the dose, is potentially harmful, especially in its possible genetic effects.

(2) Irradiation of the unborn foetus is particularly hazardous and should be avoided except in the presence of over-riding clinical indications.

(3) Although all reasonable precautions should be taken to see that patients are not unnecessarily irradiated, one should not forgo a radiological examination whenever this is judged after due consideration to be in the best interests of the patient.

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