PROTECTION AGAINST RADIATION IN THE DIAGNOSTIC X-RAY DEPARTMENT*

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It should be the aim of every radiologist to reduce to the lowest possible amount the radiation received by himself, his staff, his patients and those living and working around and about him. Radiology needs no champion as an important diagnostic accessory, but the ionizing radiations used are harmful to all who are exposed to them. The main object of protective measures is to allow the use of these radiations with the least possible damage to exposed persons.

To reduce the amount of radiation received by any of the categories of people listed above, 6 broad principles must be observed.

1. THE QUALITY OF THE BEAM

The quality of the beam must be improved to remove as much as possible of the useless and harmful 'soft' or low-energy radiation which forms part of the spectrum emerging from the tube at the usual diagnostic ranges of kilovoltage.

Improvement in the quality of the beam can be achieved in 2 ways:

(*a*) By passing it through aluminium filters up to 3 mm. in thickness as it emerges from the tube. It will be found that this additional filtration requires little adjustment in the setting normally used for most techniques, since it is only the useless soft radiation, which plays little part in the production of the film, which is removed. This soft radiation is absorbed in the tissues if filters are not used, and raises the dose received by the patient without improving the film. By filtration, the skin dose can be reduced by as much as 40%. The film dose will be reduced by as much as 20 - 30%, but this amount is not detectable in the normal diagnostic film, which can tolerate variations of almost 100% in film dose with little change in the quality of the picture produced.[1]

(*b*) By using the highest kilovoltage setting, and thus the shortest exposure times, compatible with good photographic results on the film. This method of improving the beam, from the protection point of view, is necessarily limited, particularly for the thinner and lighter parts of the body and limbs, by the restricted range of toleration to kilovoltage variations of the films commonly used. Thus, though the quality of the films should not suffer, the highest voltage that the film will allow should be used. In fluoroscopy this usage allows lower milliamperage settings, with consequent reduced dosage to the patient in the direct beam and to the radiologist and his staff from scattered radiation. It should be remembered, however, that the radiation scattering from the patient has, under these conditions, increased penetration and should be well guarded against.

2. THE USE OF THE INVERSE SQUARE LAW

(*a*) To reduce the radiation received from scatter, persons who have to be in the room where radiography or screening is being done, should remain as far as possible from the patient and the X-ray tube. The screening table should be placed as far as possible from the walls to protect the radiologist and his staff from back-scatter.

(*b*) Within the limits of tube output, the tube to table-

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top distance should be increased to the maximum compatible with a reasonable time of exposure. This increases the 'depth dose' effect, as the radiotherapists call it, and a larger proportion of the beam, in relation to the amount which strikes the upper surface of the patient, passes through to be usefully employed on the film. In other words, the ratio of the amount of radiation striking the patient to the amount emerging from the patient and passing to the film is reduced in proportion to the square of the distance from the tube to the table-top.

On most screening installations, the tube is usually closer to the table surface than it is in radiography. This distance should never be less than 18 inches, since a shorter distance leads to an unnecessarily high skin dose of radiation to the surface of the patient nearer to the tube. Skin doses as high as 127 roentgens per minute have been recorded from screening installations, most of the radiation being soft and of low penetration. Correct application of the first, second, and third principles outlined in this article will reduce the skin dose received during fluoroscopy. It has been suggested[2] that every screening machine should, on installation and periodically thereafter, be tested for output in roentgens under normal screening conditions, and the dose at the table-top, measured in air, should not exceed 10 roentgens per minute.

There is recent evidence[3] to indicate that these principles, while reducing the skin dose, tend to raise the gonad dose, owing to increased penetration of the beam and the scatter, and owing to decreased sensitivity of the X-ray film in normal use to high kilovoltage. Over-application of the principles should, therefore, be avoided. In practice, additional filtration of more than 1-1·5 mm. of aluminium on the radiographic tube and 2 mm. on the screening tube tends to nullify the benefit of the added filtration and is not recommended for the usual diagnostic procedures and techniques. Though the gonad dose may be somewhat raised by these procedures, the skin dose and total dosage is decreased and scatter is reduced, though it tends to become more penetrating.

3. THE USE OF CONES AND DIAPHRAGMS

The smallest cone which will cover the film at the selected tube to table-top distance should always be used. This will not only reduce the exposed area and volume of the patient and thus lower the amount of radiation received, but will also, by reducing the scatter, improve the quality of the film. The size of film on which the cone size is based should be the smallest which will cover the part to be examined without danger of cutting off relevant anatomy. It should also allow a narrow border for normal tissues on the film margins for comparative purposes and for showing that the whole of the pathology in that part has been included.

In fluoroscopy the diaphragm aperture should always be as small as will allow adequate visualization of the part being examined. In addition, the radiologist should make the examination as short as possible and, while screening, the technique of flash viewing should be developed. With this technique the screen is only illuminated for 2 - 3 seconds at a time with an intervening period of up to 10 seconds between flashes. With practice this intermittent viewing loses the rather distracting effect it has at first. A useful accessory on the screening machine is a clock which records the total screening time taken for each examination. This time should not exceed 5 minutes for any of the usual screening procedures. If high kilovoltages are used, milliampere settings in excess of 3 ma. are rarely called for, and when screening children the milliamperage should be markedly reduced. The diaphragms should be so adjusted that, even when the screen is pulled away from the table-top to accommodate a stout patient, there is an unilluminated border when the diaphragms are fully open. The radiologist should be fully dark adapted before commencing screening. Image intensification offers great improvement in radiation dosage during screening.

Of all the principles, that of reducing the cross-section of the beam has the greatest single lowering effect on the gonad dose.[3]

4. THE USE OF LEAD, BARIUM AND OTHER RADIOABSORPTIVE MATERIALS, TO PROTECT THE RADIOLOGIST, HIS PATIENTS, HIS STAFF AND THE PUBLIC AGAINST EXPOSURE

(a) Patients

A large number of ingenious devices have been produced to protect the patient, and especially the patient's gonads, against direct and scattered radiation. Many of them are cumbersome and awkward to use and have been dropped by common consent in most departments. During chest radiography, a mobile, adjustable lead shield placed between the patient and the tube protects the abdomen and pelvis from direct radiation and reduces indirect radiation. Its upper border should be adjusted to cover the iliac crest posteriorly. A simpler, cheaper and more versatile variation of the same idea is to make a lead-rubber apron of suitable lead equivalent with a belt attached to its upper border. Before being radiographed the patient fastens the apron around the waist with the lead-rubber portion posteriorly and the strap in front. For the lateral view the shield is pulled to the appropriate side. Infants, particularly, benefit from this type of protection during chest radiography since, in them, more of the abdomen and pelvis tends to be included in the beam than in the adult.

Protection of the male gonads from the main beam is not difficult, but indirect radiation is not so easy to exclude. Several types of radiation-proof container in which the male gonads can be practically entirely enclosed have been described. All offer a high degree of protection, and their use is recommended where repeated exposures are called for in the pelvic region. Objections to their use have been encountered from adult patients, and from a practical point of view the male gonads can easily be shielded from the direct beam by an anterior lead shield during antero-posterior exposures. If the shield is folded to form a split tube and adjusted firmly, but comfortably, outside the cotton gown (for hygienic reasons) scattered radiation can be largely excluded.

The female gonads offer a more difficult problem. At best they can be shielded from the direct beam only, though shielding does, of course, reduce the amount of scattered radiation they will receive. The easiest and most effective method of protection during antero-posterior projections about the pelvis is to place a tapered lead shield, with its broad end directed cranially, over the lower abdomen and pelvis.

The following routine is suggested where multiple examinations of the pelvic regions can be anticipated, as in injuries to the neck of the femur or hip joints, tuberculous disease of the hips, congenital dislocation of the hip, Perthes' disease, etc. At the first examination of the pelvis or hip joint no shields are used so that none of the anatomy is hidden, thus reducing the chance of overlooking any pathology not actually in the part being examined. If repeated examinations are to follow, the shields are applied in all subsequent examinations. With practice, radiographers become adept at adjusting the shields to give maximum protection without obscuring relevant anatomical parts.

(*b*) *Radiologist and Staff*

The use of protective gloves and aprons should be insisted on whenever there is a chance of exposure. Most modern tubes and other X-ray apparatus have a high degree of built-in protection, but, on installation, it is well to check the amount of radiation leakage from the tube covers and on the margins of the screening table. If necessary, protective lead or lead-rubber shields can be added. Radiographers moving about in the screening room often turn their backs to the screening stand and should, therefore, wear the double or sandwich type of apron which protects from the rear as well as from the front.

When patients have to be held during radiography, parents and relatives should be used as far as possible. If radiographers must do this, the task should be rotated among the staff. Whoever has to hold the patient should be protected with gloves, apron and any other appropriate shielding. When not occupied during screening, radiographers should be trained to stand behind the radiologist. They will then receive the benefit of the protection afforded by the lead-glass screen backing and other shielding arranged about this screen, and by the radiologist in his gown and gloves. Frequent testing of gloves, aprons and other shielding is advised to ensure that the expected protection is, in fact, being given.

In the literature numerous devices to shield the radiologist and staff from direct and scattered radiation are mentioned. Not many are in general use in the average X-ray department, since most apply to special examinations. However, where these examinations are done, e.g. cardiac catheterization, adequate protection for the operators and the radiographic staff must be provided by appropriate shielding. On the whole, reliance is largely placed on the time-honoured gloves and apron and a protective screen or wall, with lead-glass window, between the radiation source and the control stand. Properly designed and used, these give a very high degree of protection to those working in an X-ray department.

(*c*) *The General Public*

The average diagnostic department does not offer much hazard to the public at large, but persons who have to live and work in rooms adjacent to or below an X-ray installation must be shielded, by lead sheeting or barium plaster of appropriate thickness, from direct and scattered radiation.

5. THE USE OF FAST FILMS AND INTENSIFYING SCREENS

Fast films and intensifying screens have been much improved in recent years, and produce films of quality equal to those of the slower screens and films of the past in most radiographic spheres. Their use, wherever possible, should be encouraged. This will result in smaller exposures and reduced dosage to the patient and diminished scatter to the radiographer. The development and improvement in image intensification, closed-circuit television and allied electronic devices, offers previously undreamed-of improvement in radiation dosage to patient and staff and, with their more general adoption, many of the problems now facing us will disappear. This branch of X-ray engineering is still in its infancy and vast improvements can be anticipated.

6. IMPROVEMENT IN ADMINISTRATION

Improvement in administration and coordination between departments is necessary to cut down the number of examinations requested, and to avoid unnecessary and dangerous duplication. The radiologist must advise and instruct his colleagues in the selection of patients for examination and the choice of the most efficient procedure appropriate to the investigation required. Involved multiple examinations should be reduced to a minimum and useless routine examinations avoided. Simultaneous multiple tomography should replace the single-cut method wherever practicable. The reappraisal of traditional routine views is required and many of these could be discarded. The potential dangers to the patient inherent in any examination must be weighed against the possible benefits.

Insistence on all safety measures being properly applied by the radiographic staff should be the constant concern of all radiologists. The use of film badges and other radiation recording devices is nowadays accepted as almost obligatory. They allow the dosage received by the wearer to be recorded by the radiologist for future reference and immediately indicate careless or incorrect habits in those occupationally exposed to radiation. Regular blood counts should be carried out on all radiographic staff.

COMMENT

An excellent illustration of the improvement in skin dose which can be expected following the application of the principles enumerated in this article was described by Ardran in 1956.[4] He quoted the figure of 1·4r given by Barclay in 1938 as the skin dose when examining a five-inch diameter area of human abdomen with the film between intensifying screens. In 1939 Barclay measured the skin dose, using 2 mm. aluminium of additional filtration and increasing the focus-film distance, and recorded a dose of 0·8r. Increased filtration of 1 mm. aluminium and a longer focus-film distance further reduced the dose to 0·25r in 1950 when a faster film was used. In 1952 high-speed screens and a higher kilovoltage further decreased the skin dose to 0·13r which is about 9% of the original dose of 1·4r. Using an image intensifier and 35 mm. film, Ardran and Wyatt in 1953 recorded a skin dose of 0·012r for the same examination, approximately one-tenth of the lowest dose recorded with conventional radiography.

CONCLUSION

The principles which are briefly outlined in this article present no new or startling facts on radiation protection, but it is hoped that, by dividing the problem into its fundamental parts and presenting it in this form, those interested will review the protection measures used in their own departments and ensure that the 6 principles are being applied in practice.

Our aim must be to provide only the benefits of the diagnostic use of X-rays, and to ensure that our patients and those about them receive such microscopic doses of radiation that the natural mutation rate is not materially affected and that no measurable somatic effects will occur.

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