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Table of Contents

Factors Influencing Patient Dose in Diagnostic Radiography

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Abstract
Diagnostic radiography is a leading cause of manmade radiation exposure to the populace. The various types of examinations vary considerably with respect to patient dose. Surveys have shown that further to the variation due to technical advancements over time, the applied doses depend rather significantly on the standard of radiological practice in a specific setting and on the individual radiographer. Factors which affect patient dose in a standard radiological practice can be grouped into three; technical factors, patient characteristics and frequency of examination. The technical factors are as determined by the individual radiographer. If optimal performance is to be achieved, it is necessary to understand how these factors affect radiation dose and option available for reducing it.

Key words: entrance skin dose, image quality, exposure, effective dose, optimization

1.0 Introduction

In medicine, ionizing radiation is used for two main purposes; diagnosis and therapy. Consequently, individuals and the populace at large receive significant exposure to radiation. Diagnostic radiology is a leading cause of man-made radiation exposure to the population. It was estimated that diagnostic radiology and nuclear medicine contributed 96% to the collective effective dose from man made sources in the U.K (NRPB 1993). Similar estimate showed that this contribution was 88% in the U.S.A (NCRP 1987).

The International Commission on Radiological Protection (ICRP) in 1990 recommended that all medical exposure should be subjected to the radiation safety principle of justification and optimization. Optimization requires that the magnitude of radiation doses be as low as reasonably achievable, social and economic factors taken into account. The ICRP affirms that optimization of doses in medical exposures has been given less attention compare to other applications of radiation.

Patient dose studies (NRPB 1990, Warren 1996, NRPB 1996) completed had shown large variation in entrance dose for the same diagnostic procedure between one radiological centre and another. The National Radiological Protection Board (NRPB) in the U.K published the result of a nationwide survey (NRPB 1990) for a selection of x-ray examination in 20 U.K hospitals. The NRPB found that there was a ratio of almost 50 between the hospital with the highest dose and that with the lowest dose for an average size patient.

A similar national survey by the Food and Drug Administration of the U.S.A (Gray, 1999) revealed that the ratio of the maximum to minimum exposures ranged from 8.8 to 126.7.

Clearly these indicated that a good imaging technique was necessary to reduce patient doses to the lowest practicable levels consistent with the clinical purpose of the medical examination. It is a known fact (John & Cunningham, 1983) that the dose from diagnostic radiology can be reduced by a factor of at least 3 with little work and by a factor of 10 or more if equipment and radiological technique are optimized.

The formation of image in diagnostic radiology involves a complex interplay between many different parameters. It is very important to know what parameter can be changed and how they are likely to affect radiation dose to the patient.

For optimum performance in x-ray examinations, some of these factors are to be chosen appropriately in ranges which reduces the dose to patient to as low as reasonably achievable. The factors which affect patient dose fall into: technical factors (this include, the x-ray beam quality, use of diaphragm or collimation, film screen system), patient characteristics such as size and sex, age and frequency of x-ray examination. The patient characteristics, age and frequency of examination should be used to determine the choice of the technical factors for safe practice.

2.0 Radiation dose

There are two categories of doses to patient which are important in diagnostic radiology; the effective dose E (ICRP 1990) which takes into account of dose equivalent to radiosensitive organs and the entrance skin dose. Most interest in diagnostic radiology is concern with effective dose since this relates to the risk of stochastic effect such as cancer induction. Effective dose or effective dose equivalent combines a set of organ or tissue equivalent dose into one single quantity. For this, the organs equivalent dose (H_T) are multiplied by organ weighing factors (w_T) and then summed.

$$E = \sum H_T W_T \qquad (1)$$

However simple entrance skin dose (ESD) is the absorbed dose to air where the x-ray beam intersects the skin surface of the patient. It is a quantity that can be measured directly and can easily be compared with previous measurements and with measurement obtained at other practices and countries. It can also be used as an indicator of effective dose for particular radiographic projections. Another reason for evaluating skin doses is that the dose greatest at the surface where radiation enters the body of the patient and the skin is therefore the main organ for which there is a possibility of deterministic effect i.e. skin burn. Both doses are very important indicators of safe radiological practice, thus an investigation into how radiological parameters influence their value for various radiological examinations cannot be overemphasized.

3.0 Technical Factors

3.1. Beam Quality

The energy of an x-ray beam is determined by the applied potential (in kvp) between the anode and cathode, and the total filtration. These are sometimes referred to as the beam quality. X-rays as produced in a typical medical x-ray tube are bremsstrahlung and, as such are a distribution or spectrum of energies ranging from zero to the applied voltage. The efficiency of bremsstrahlung production increases rapidly when the electron energy (tube voltage) is raised (James, 1995). Thus the tube potential determines the proportion of high energy photon in the x-ray beam. For a typical x-ray spectrum without filtration, the average energy is about one third of the peak energy or applied potential (John & Cunningham 1983). Hence most of the x-ray produced have lower energy and are absorbed by the portion of the body being examined without reaching the film. These low energy photons are of little significance in diagnosis but contribute enormously to patient dose. The tube potential can be selected for each examination; the optimum choice depends on the part of the body being imaged, patient size, the type of information required, the image receptor and the display method. Research has shown (Hart et al 1996) that ESD and effective dose reduces has tube voltage is increased - figures 2 and 3. With optimum choice of kvp the dose to patient can be reduced at least by a factor of 1.5 (Boetticher & Hoffmann, 1997).Similarly, increasing the kvp will increase the beam intensity or exposure rate; many empirical studies of beam intensity as a function of kvp provide ample credible evidence to show that for a given amount of filtration, increasing the applied kvp will increase the beam intensity according to the 1.7 power of applied tube potential (Trout et al, 1952).

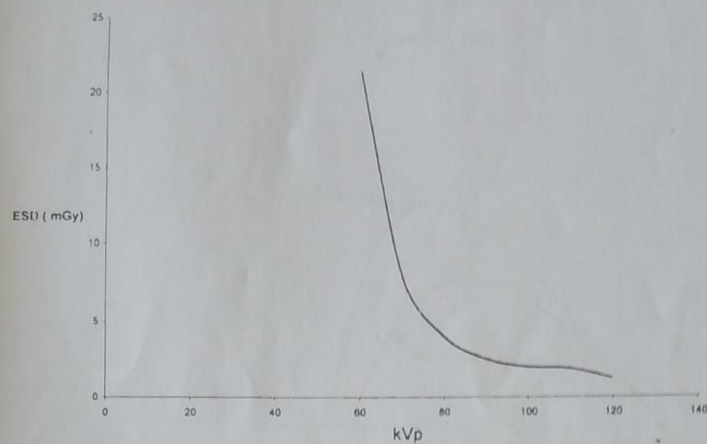

Figure 1: plot of ESD as a function of tube voltage

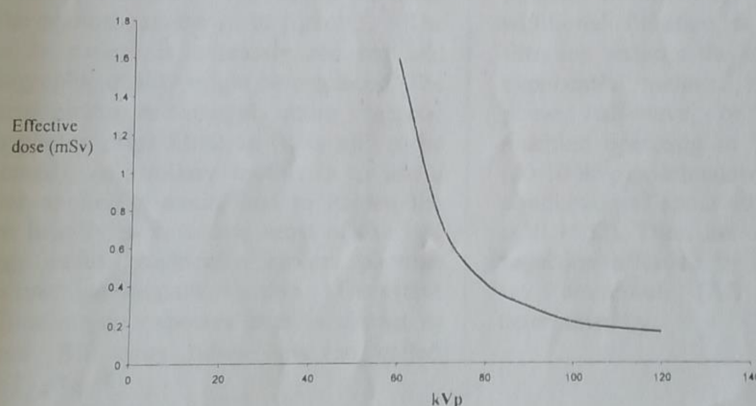

Figure 2: plot of effective dose as a function of tube voltage

3.2 Filtration

The X-ray beam coming off the cathode material is polychromatic. Usually only a portion of the beam spectrum is desirable. Filtering out the undesired portion of the X-ray spectrum can substantially reduce the radiation dose delivered to the patient. To reduce the dose to the patient due to low energy x-ray, filtration is achieved when a filter in the form of a specified thickness of absorbing material is added to the beam. This has the net effect of absorbing a large fraction of the lower energy (soft) X-ray which would contribute little or nothing to image quality while allowing most of the more energetic and thus radio- graphically useful x-ray photon to pass.

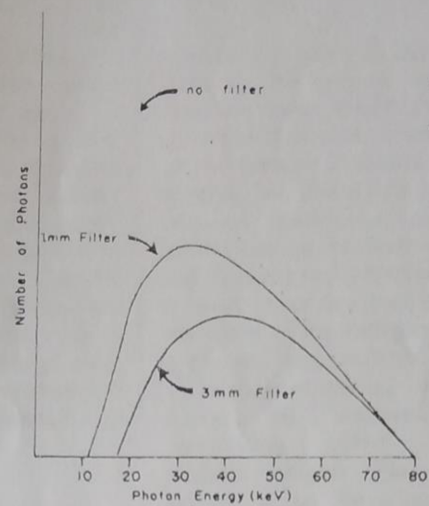

Figure 3.Effect of filter on photon energy band (Perry Sprawls)

The effect of the filter is to narrow the beam of the photon has shown in figure 5. The dose to patient is expressly reduced and radiographic quality might be enhanced. The filtered photon is averagely more energetic than photon prior filtration (It is said to be hardened). A corollary to this is to use a higher applied potential and to harden the beam heavily to eliminate most of the low energy radio graphically useless photons from reaching the patient's skin. The effect of filtration on exposure rate is shown in figure6. All x-ray tubes have so called inherent filtration, for optimal performance additional filtration is needed. Additional filtration reduces the ESD, generally in an exponential manner. For a typical single phase half-wave, or full-wave rectified machine operating in the diagnostic range (80-100kvp), each added filtration will effect a reduction of about 40% in ESD (Trout, E. et al 1952). Thus, the approximate intensity reduction afforded by any thickness (t) of say aluminum (Al) filtration can be determined by:

$$I = I_0 e^{-0.4t} \qquad (2)$$

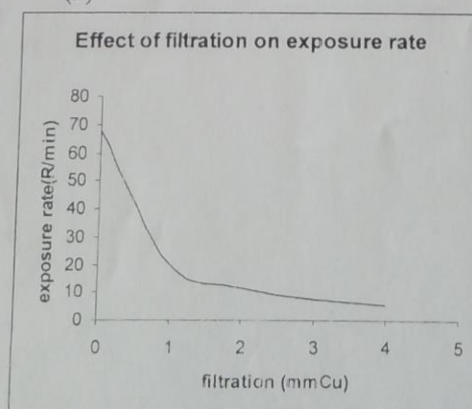

Figure 4: Effect of filtration on exposure (John and Cunningham, 1983)

3.3 Tube Current and Exposure Time

The current in an x-ray tube refers to the number of electrons accelerated across the evacuated volume of the tube flowing from cathode to anode. Diagnostic x-ray exposures are typically specified per milli-ampere-second (mAs), the product of tube current and exposure time. Radiation exposure is therefore proportional to the value of mAs if all other factors such as (kvp, filtration, and film speed e.t.c.) remain constant. For a given applied potential, the number of x-ray photon produced and hence the exposure will at least in theory be directly proportional to the tube current (Sante, 1946).

3.4 Focus to Skin Distance

The best possible protection from ionizing radiation is to maximize distance from radiation source. X-ray beam intensity is a function of distance form the target, approximating the inverse square at large distances from the tube. The radiation dose to a patient depends on the focus to skin distance (FSD). The smaller the FSD, the higher the dose to the patient. For example increasing FSD from 140cm to 180cm will reduce the ESD in air by about 10% and still obtain the same optical density on the film. It should be noted that the kvp remain the same but the mAs is increased by $(180/140)^2$ to ensure that the optical density remain the same (Cardillo et al 1997).

3.5 Collimation, Grids, and Radiographic Film Screen System:

Collimation refers to the size of the x-ray beam. If the beam is well collimated, the smallest beam consistent with the area of interest will be used, thereby limiting the area of the patient irradiated and consequently reducing the dose to the organs close to the area of interest. A practical check of collimation can be made by reference to the radiograph; a well collimated beam will leave a small unexposed area penumbra effect at the edges of the radiograph, while a poorly collimated beam will produce a radiograph that is exposed over all the area.

X-rays are scattered, primarily by photoelectric effect and/or Compton scattering effects. The scattered photons appear on the X-ray image as noise that degrades image quality and increases patient exposure. Therefore, great efforts are expended in minimizing scattering. The most effective method is to place an X-ray grid under the patient and before the detector as shown in Figure Grid strips are usually made of lead, which is an effective X-ray absorbing material. If the grid strips are thin enough, then their image on the detector may be negligible. However, if the image quality requirements necessitate thick lead strips, then the grid may be moved during exposure to blur out the image of the grid lines. The grid shown in Figure 5 is called a linear grid. Other forms of grid have been used. For example, when the grid strips are focused towards the X-ray source, then grid is called a focused grid.

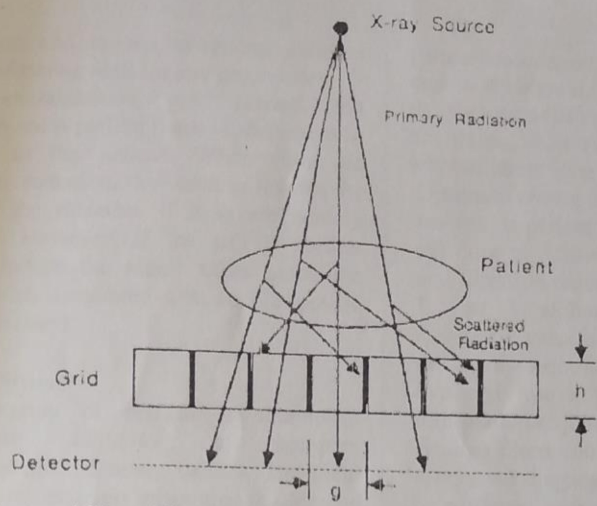

Figure 5: Scattered X-ray Photons

Scattered X-ray photons (Figure 5) can be removed from the image by positioning a grid between the patient and the detector (or film).

The use of grid will always increase the exposure because it will absorb some of the primary radiation. Surveys have shown that the use of grid can cause ESD to increase by a factor of 1.5.

The exposure needed for a suitable diagnostic radiograph is in some measure a function of film speed and development. Fine grain emulsion produces a superior radiograph image but require additional exposure in comparison to fast films. Underdevelopment of films also requires additional exposure in comparison to fast film (Hart, et at 1996). Intensifying screens should be used in the cassette to intensify the radiographic effect and thereby increase film speed and reduce patient dose.

4.0 Patient Characteristics and Repetition of X-Ray

The risk associated with exposure to ionization radiation is depended on the characteristics of the exposed individual. The size and structure of the individual influences the absorbed dose distribution in the organs. Organ dose conversion coefficients are always given with respect to sex, because of the sex dependence of some organ to radiation response.

For the same technical parameters the ESD varies directly with the patient thickness. This is simply due to the fact that for thicker patient, the skin is closer to the focus of the beam. Generally, the organ doses increases with increasing thickness' this increase is maximal for organs in the beam entrance side like the skin or eyes and continuously decrease with depth in the body. This is so because the attenuation of the x-ray depends exponentially on thickness.

The age at which exposure takes place is a critical factor in determining radiation risk (Richardson, 1990). During fetal development and childhood intense tissue generation and differentiation takes place and it is known that proliferating cells are more susceptible to the induction of cancer (Boothroyd, 1997). Evidence from the Hiroshima and Nagasaki bomb survivors and also from radiotherapy patients indicates that children under 10 years old are more susceptible than adult to cancer induction (Darby, 1986). There is obviously a need to take into account the increased sensitivity of

the tissues and organs of young children when performing radiological procedures.
When examinations are carried out repeatedly on a patient there is increment in the risk to the patient. When cells are exposed to radiation, they tend to reverse the effect of the radiation if it is not acutely delivered. However, if the cell is further exposed before the repair takes place the effect or risk associated with such exposure is thus increased.

5.0 Conclusion

The formation of images in diagnostic radiography involves a complex interdependence of many factors. The ideal balance is to obtain an image that is adequate for clinical purpose with minimum radiation dose to the patient. The imaging technique can be regarded as safe if it gives the patient the lowest dose practicable.

The physical factors which affect patient dose can be grouped into: technical factors, patient thickness and frequency of examination. The factors by which each of these affect dose to patient is given in table 1. Optimization of imaging process can be achieved through patient dose audit. To be effective, patient dose audit should be linked to an analysis of the factors which influences dose. If this is not done, audit can only reveal a problem without identifying the causes.

Optimum choice of the technical factors with respect to patient characteristics can reduce the dose to patient. Judicious choice of kvp and filtration reduces the ESD by a factor of 1.3 to 3 without deleterious effect on diagnostic value of the image. It is desirable that x-ray examination be done with high kvp and low mAs consistent with image information required and film screen used.

Enough filters should be used to remove soft x-rays; all diagnostic x-ray machines should be equipped with a total filtration of 3 mmAl permanently into place (John & Cunningham, 1983). ESD can also be reduced by increasing the speed of image receptor. For a patient who is not so thick air gap can be used instead of grid to reduce patient dose. It is also recommended that good imaging procedure be adopted consistent with information required so that repetition of examination will be totally avoided.

Table 1. Impact of dose factors on x-ray examinations

Factor	Relative increase of Dose
Beam quality (kVp and filtration)	1.5-3
FFD and use of grid	1.5-2
Film-screen system	2-3
Repetition of examination	1.1-1.5

(Source: Boetticher and Hoffman, 1997)

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