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Commentary

The clinical efficacy of effective dose

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Effective dose (E) is proposed by the International Commission on Radiological Protection (ICRP)[1] in 1975 to replace effective dose equivalent. Effective dose as defined by the ICRP is a dose quantity of health determinant due to scholastic effects from being exposed to low doses of ionising radiation. One of the goals of ICRP in proposing E is to quantitate radiation exposure for establishing and providing ionising radiation dose limits for radiological protection. E reflects the health determinant aspect from an ionising radiation exposure to any section of the human body whether it be external or internal exposure to uniform body ionising radiation exposure for a reference person.

To conceive the concept of E, the ICRP[1] relied on health determinant from ionising radiation exposure and using linear no-threshold (LNT) model to yield a single-dose value from internal and external exposure.

The equation to use to compute E is

$$E = Dm \times TWF \times RWF. \quad (1)$$

where E is the the effective dose; Dm the dose/exposure in a medium; TWF the tissue-weighting factor; and RWF the radiation-weighting factor.

To compute E, there are many innate uncertainties. These are as follows.

Effective dose (E) can only be calculated with inherent uncertainties. Direct measurement of E is not possible.

Exposure/dose measurement (Dm). The penetrating beam quality in kilovoltage is characterised by an X-ray tube potential (kVp) and the half value layer (HVL), although host of other factors also affect the beam quality.[2] It has been reported that clinically used energy (kVp) have a wide range of HVL values for a given kVp.[2,3] The HVL ranges from 0·3+ mm of pure aluminium (Al) for mammography to 2·3+ mm Al equivalent for 80 kVp for X-ray unit, to 3·0+ mm for fluoroscopy unit and 4·0+ mm Al for computerised tomography (CT) at 120 kVp. Let us assume that an X-ray unit with 2·5 mm Al HVL at 80 kVp yields an exposure of 1 R at 100 cm source to chamber distance to the human liver and so does CT. Is the effective dose for the liver the same?

Chambers-related factors also contribute to uncertainties in computing E.[3–7]

Tissue heterogeneity of imparted energy in an organ causes error in Dm measurement and in turn effective dose.

Tissue-weighting factor (TWF) provided by the ICRP does not bode well to compute E. First of all, organ weight, body weight, gender difference and age variation are not taken into consideration. Organ weight is an important radiological parameter as the radiation sensitivity of the human organs increases by assembling many cells of different functions, with increasing organ weight.[8] Akber[9] has proposed a new methodology to compute TWF. It is based on the ratio of organ weight to body weight. Akber[9] also showed that using the ratio of organ weight to body weight in both reference male and reference female, with radiation tolerance dose

(TD50), yield a nice correlation. In contrast, the ICRP TWFs do not yield any correlation with any biophysical factors.

Let us compare the biophysical factors of two organs such as the thyroid and liver. One weighs 20 g and the other 1,800 g; TD50 is 80 and 40 Gy, respectively.[8] The blood flows in the two organs are 50 and 350 mL/min, respectively. However, the ICRP TWF is the same for these two organs. The validity of the ICRP TWF is therefore very much in question.

Radiation-weighting factor (RWF). The ICRP without any scientific basis proclaimed that RWF should be one. This created an unprecedented problem in computing E. First of all, if we use RWF as 1, there is no differentiation/demarcation whether the exposure is in kV range or MV range or the calculated E is in kV or MV exposure. In addition, Akber[10] has shown that, as energy decreases, the potency of radiation at low energy increases. The relative biological effectiveness value increases as kV energy decreases. In addition, kV and MV energies interact differently in the human organs. Therefore, all exposures are not generated equally and may not have the same potency. Photoelectric effect and Compton effect interaction in the human organs depend on high atomic number elements in an organ, whereas hydrogen content will attenuate high-energy photons.

The best way to assess the RWF is to assess the potency of radiation in cell line such as CHO or HeLa cells in the mitotic phase as suggested by Akber.[10] For example, take cobalt 60 (Co-60) (1·25 MeV) RWF as one. Determine the mean lethal dose (Do) of a cell line in the mitotic phase of a given energy. Divide the Do of Co-60 to the Do value of energy in question. At lower energy, the RWF will be >1 and at higher energy RWF will be <1. This will provide a clear assessment/demarcation whether we are dealing with kV or MV effective dose (E).

Cell cycles. Radiation-induced cancer risk are ambiguous, erroneous, speculative and purely hypothetical.[11] For example, it is stated that 1 in 270 women who have CT coronary angiography will develop cancer.[11] No one asked the question. Why 269 other women, who have received the same amount of radiation exposure, do not have radiation-induced cancer. The answer is very simple. In radiation exposure or accidents, we have not taken into consideration the cell cycles in the organ during radiation exposure. Is this 1 woman in 270 women whose cells were in the mitotic phase during exposure? The damage to the mitotic cells may unfortunately lead to radiation-associated cancer and not by LNT model or the exposure was higher than 100 mGy. Beam penetration in the human organs depends on the energy and not on the dose.

The other question is: is the amount of exposure (dose) the primary factor in inducing radiation-associated cancer or the energy of the photons (exposure)? For example, in radiation therapy in breast treatment, the contralateral breast received from 150 to 300 cGy. This dose is much higher than 100 mGy, the so-called threshold value for radiation-induced cancer. However, there is no evidence that 300 cGy yield secondary cancer in the contralateral breast.[12] It is well known that mammography-ionising radiation (24–30 kV) does induce radiation-associated cancer. Therefore, selecting energy or an appropriate RWF based on energy criteria is of paramount importance than the effective dose itself. RWF becomes a very critical factor to compute E correctly.

To compute E in nuclear medicine, which uses radiopharmaceutical agent, the uncertainty increases compared with external exposure. It is difficult to correlate the whole-body external exposure to the internal exposure from radiopharmaceutical agent. The uncertainty in radiopharmaceutical dose estimates varies by a factor of two or more.[13] A host of other factors also affect the effective dose. These are route of radioactivity administered, total counts or imaging time acquisition. Choice of camera, detector thickness and choice of detector material, number of detectors, collimator choice, image processing and reconstruction. Therefore, computed E is not very reliable.

In conclusion, and in view of all the uncertainties in computing E, the estimated cancer risk based on E may underestimate and/or overestimate in

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different segments of the ageing population. Martin[14] pointed out that relative uncertainty in estimated values of E for medical exposure for a reference patient is about ±40%. Care should, therefore, be exercised in relying E as a single value of dose (effective) and of risk estimate (cancer).

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