RADIATION DOSIMETRY FOR EXTREMITY RADIOGRAPHS

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Abstract-The energy imparted, ε, to a patient undergoing an extremity x-ray examination may be obtained from the dose-area product incident on the patient. Values of energy imparted can be subsequently converted into the corresponding effective dose, *E*, using an extremity specific *E*/ε ratio. In this study, an *E*/ε ratio of 3 mSv/J was used to convert values of energy imparted into the corresponding upper limit of adult effective doses for all types of extremity examinations. A modification factor, based on the patient mass, was employed to determine the corresponding extremity effective doses to pediatric patients undergoing extremity examinations. Representative clinical technique factors for six common extremity examinations (hand, forearm, elbow, ankle, tibia/fibula, knee) were used to determine the dose-area product and the corresponding values of energy imparted. For adult extremity x-ray examinations, values of energy imparted ranged from 55 μJ to 920 μJ, with the energy imparted to 1-y-old patients being a factor of about 20 lower. Upper limits of effective doses for adult extremity x-ray examinations ranged from 0.17 to 2.7 μSv, whereas the corresponding doses to 1-y-old patients were about a factor of three lower.

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Key words: radiography; extremities; medical radiation; x rays

INTRODUCTION

THE EFFECTIVE dose, *E*, is a radiation dose parameter which takes into account the absorbed dose received by each irradiated organ and the organ's relative radiosensitivity (ICRP 1991). The effective dose is conceptually similar to the effective dose equivalent (ICRP 1977), and ratios of the effective dose equivalent to effective dose have been published for common radiographic examinations (Huda et al. 1991; Huda and Gkanatsios 1997). Since the effective dose may be taken as an approximate measure of the stochastic radiation risk, it may be used to quantify the amount of radiation received by patients undergoing diagnostic examinations (Wall et al. 1988). Despite problems associated with converting effective dose equivalents to a corresponding detriment (Huda and Bews 1990), patient doses in diagnostic radiology are now being reported in terms of the effective dose equivalent or effective dose by most national and international organizations (NCRP 1989; UNSCEAR 1993). The patient effective dose equivalent from a specific x-ray examination may be compared to that of any other radiologic procedure, as well as natural background exposure and regulatory dose limits (NCRP 1987; NRC 1995a, b). Another example of the use of effective dose data is for informed consent forms developed for patients and volunteers who are exposed to additional ionizing radiation during research studies (Castrovano 1993).

Measurement or computation of the effective dose for any type of radiographic x-ray examination is generally difficult and may be time-consuming. A practical method to estimate effective dose from common x-ray examinations has been proposed and makes use of measurements or calculations of the energy imparted, ε, to the patient during a radiographic examination (Huda and Gkanatsios 1997). This approach to computing the effective dose employs ratios of effective dose per unit energy imparted, *E*/ε, associated with a number of x-ray examinations. For example, the *E*/ε ratio for a lateral skull examination (5.3 mSv/J), which is relatively independent of the x-ray beam quality, may be combined with the energy imparted to the patient undergoing this type of procedure to yield an estimate of the corresponding patient effective dose. This approach to computing adult patient effective doses may also be applied to pediatric patients by taking into account the mass of the patient undergoing a diagnostic radiographic procedure (Huda and Gkanatsios 1997; Huda et al. 1997).

An estimated 12.8 million upper extremity x-ray examinations and 15.7 million lower extremity x-ray examinations were performed in the United States in 1980 (NCRP 1989). Effective dose data for extremity x-ray examinations are presently not available for either adult or pediatric patients. The approach developed by Huda and Gkanatsios (1997), which provided data for *E*/ε ratios for 68 different types of x-ray examinations, may be extended to extremity radiographic procedures provided an *E*/ε ratio is available for use with such procedures. In this study, we propose an upper limit on the value of the *E*/ε ratio for use in extremity radiographic procedures based on patient dosimetry data

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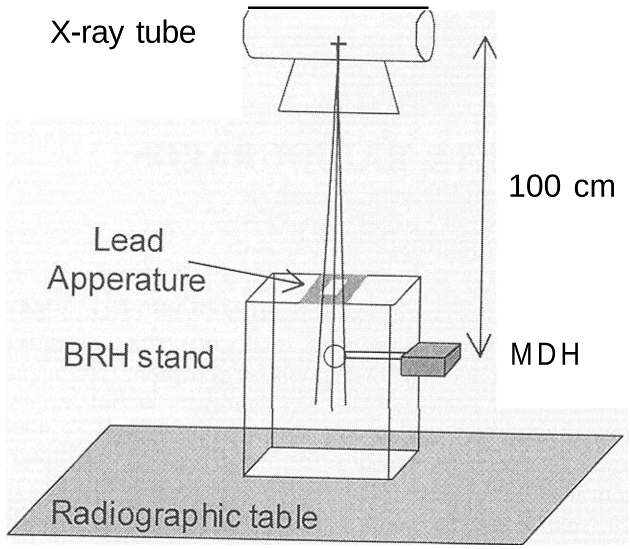

Fig. 1. Experimental setup of measuring tube output exposures.

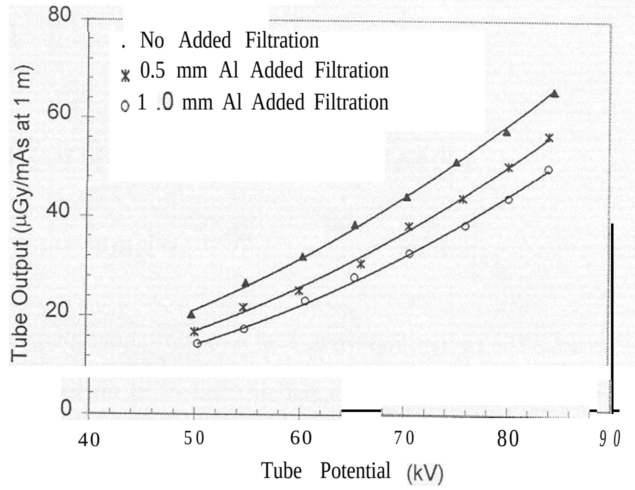

Fig. 2. Measured output (μGy/mAs) at a distance of 100 cm from the source for a radiographic x-ray tube used for extremity radiography.

obtained from CT scans of the head and upper thigh regions. Values of energy imparted to patients ranging from 1 y to adults undergoing a range of extremity x-ray examinations were computed from x-ray beam dose-area products and were converted into the corresponding upper limits of patient effective doses.

MATERIALS AND METHODS

Entrance exposures

Fig. 1 shows the experimental arrangement used to measure the entrance skin air kerma values, free-in-air, The radiographic unit was a Philips* Classic C-850 three-phase generator with a Eureka" ROT-350 x-ray tube (HVL at 80 kVp: 2.9 mm Al). Applied tube voltages were determined using a noninvasive Keithley kVp divider coupled to a Keithley digital display and to an oscilloscope. A Keithley mAs meter was used to measure the product of the x-ray tube current and exposure time (mAs). Exposure measurements were made free-in-air at a source-to-detector distance (SDD) of 100 cm using a calibrated MDH 1015C exposure meter with a 10X5-6 ionization chamber. A conversion factor of 2.58 X 10^{-4} C kg^{-1} (1 R) corresponding to an air kerma of 8.77 mGy was used to convert exposure to air kerma.

Three sets of measurements were made: (a) with no added filtration to the x-ray tube, (b) with 0.5 mm aluminum added filtration, and (c) with 1.0 mm aluminum added filtration. The experimental precision of the exposure measurements was 3.7%. Fig. 2 shows the experimentally measured radiation output in terms of air kerma per mAs at a distance of 1 m from the focal spot vs. the x-ray tube potential over the range of tube potentials commonly used to obtain extremity radiographs.

At Shands Hospital (University of Florida), most extremity radiographs are performed using table top exposures with manually selected exposure techniques and no scatter removal grids. A source-to-image receptor distance (SID) of 100 cm is generally used, with a Kodak[#] Lanex single fine screen with either Kodak EM film for 20 cm X 25 cm cassettes or MRM film for all other cassette sizes. Both of these screen-film combinations are reported by the manufacturer as having a nominal relative speed of 80. The data in Fig. 2 permit the entrance skin air kerma (free-in-air) to be estimated for typical extremity radiographs using the radiographic technique factors (kVp and mAs), source-to-image receptor distance, and patient thickness. Table 1 summarizes the representative technique factors (i.e., kVp and mAs) based on the clinical practice at Shands Hospital for each type of extremity x-ray examination for each patient age group. Also listed in Table 1 are the coresponding estimates of the entrance skin air kerma (free-in-air) obtained using the x-ray tube output data shown in Fig. 2.

Energy imparted

The energy imparted, ε, to a patient undergoing any radiographic x-ray examination can be estimated by modeling the patient as a slab of water using the expression

$$\varepsilon = \omega \times DAP, \quad (1)$$

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[§] Interay International X-Ray Corporation, 7290 Pepperdam Avenue, North Charleston, SC 29418.

[‖] Keithley Instruments, Inc., 28775 Aurora Road, Cleveland, Ohio 44139.

[¶] Radcal Corporation, Inc., 426 West Duarte Road, Monrovia, CA 91016.

[#] Eastman Kodak Company, 343 State Street, Rochester, NY 14650.

Table 1. Radiographic techniques (kVp/mAs) used in specified extremity examinations for patients of varying age Kristv and Eckerman 1987). In parentheses are the corresponding values of the entrance skin air kerma (free-in-air).

	kVp/mAs (and *air kerma*) for specified patient age/mass				
	1 y/9.3 kg	5 y/19 kg	10 y/32 kg	15 y/54 kg	Adult/71 kg
Hand	52 kVp/5 mAs *(115 μGy)*	54 kVp/5 mAs *(127 μGy)*	55 kVp/5 mAs *(133 μGy)*	55 kVp/5 mAs *(133 μGy)*	60 kVp/4 mAs *(130 μGy)*
Forearm	56 kVp/5 mAs *(139 μGy)*	60 kVp/5 mAs *(167 μGy)*	62 kVp/6 mAs *(223 μGy)*	65 kVp/6 mAs *(253 μGy)*	65 kVp/8 mAs *(350 μGy)*
Elbow	58 kVp/6 mAs *(187 μGy)*	60 kVp/6 mAs *(204 μGy)*	66 kVp/8 mAs *(365 μGy)*	66 kVp/8 mAs *(365 μGy)*	66 kVp/10 mAs *(471 μGy)*
Ankle	58 kVp/6 mAs *(187 μGy)*	62 kVp/6 mAs *(223 μGy)*	68 kVp/9 mAs *(455 μGy)*	68 kVp/10 mAs *(512 μGy)*	70 kVp/10 mAs *(555 μGy)*
Tibia/Fibula	60 kVp/6 mAs *(204 μGy)*	66 kVp/6 mAs *(263 μGy)*	68 kVp/10 mAs *(512 μGy)*	69 kVp/10 mAs *(535 μGy)*	70 kVp/10 mAs *(555 μGy)*
Knee	62 kVp/6 mAs *(223 μGy)*	68 kVp/10 mAs *(512 μGy)*	68 kVp/12 mAs *(631 μGy)*	70 kVp/10 mAs *(555 μGy)*	70 kVp/12 mAs *(687 μGy)*

where ω is a parameter that depends on the water phantom thickness, x-ray tube potential, and x-ray beam half-value layer; *DAP* is the dose-area product where the dose is the air kerma measured at the entrance plane (free-in-air) (Gkanatsios 1995; Gkanatsios and Huda 1997). Fig. 3 shows the behavior of ω as a function of water phantom thickness, obtained from the published data of Gkanatsios and Huda (1997), for three representative x-ray tube voltages (55 kV to 70 kV) normally encountered in extremity radiography.

For an extremity x-ray examination, the water equivalent phantom thickness is needed to determine the energy imparted to the patient. In this study, the thickness of water which generates a film density equal to the average film density in an extremity radiograph (i.e., optical density of 1.4) was taken to be the water equivalent phantom thickness. Fig. 4 shows the measured thickness of a water phantom (20 cm X 25 cm rectangular x-ray field) required to generate a constant gross film density of 1.4 as a function of radiographic technique factors for an x-ray tube powered by a three-phase generator with 2.9 mm aluminum equivalent x-ray tube filtration. For each ohantom thickness and selected x-ray tube potential, the mAs required to produce a film density of 1.4 was interpolated from measured film densities plotted as a function of the log (mAs) All experiments were performed in a single session to eliminate film processor variability. The measured precision of the mAs to generate the constant film density was measured to be ±0.06 mAs.

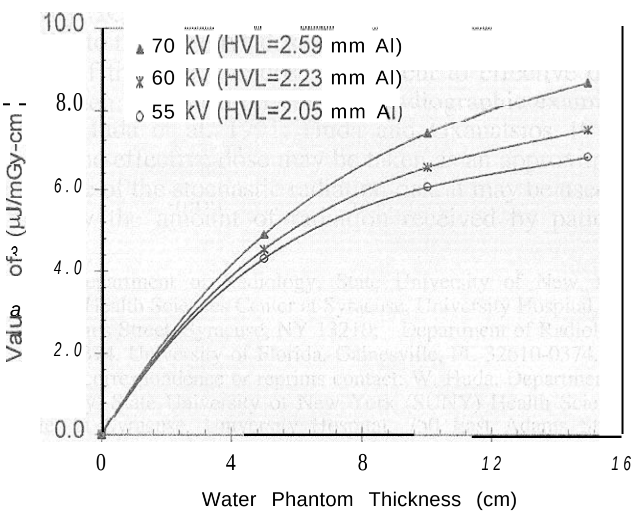

Fig. 3. Values of the ω parameter as a function of water phantom thickness.

Table 2 summarizes the water equivalent thickness for six extremity regions for patients ranging from l-y-old to adults. Also provided in Table 2 are data on the corresponding x-ray beam cross-sectional areas at the extremity entrance plane, which were estimated from measurements made on representative extremity radiographs for each age group, and correspond to the patient area that is directly irradiated. Water equivalent thickness values were obtained from the data shown in Fig. 4 using the radiographic techniques listed in Table 1, with appropriate interpolation and extrapolation used for kVps not shown in Fig. 4. For example, an adult hand examination is normally performed using 60 kVp and 4 mAs (Table I), and extrapolating the curve for 60 kVp in Fig. 4 yields a water equivalent thickness of 1.9 cm at the selected tube current exposure time product value of 4 mAs.

Effective dose (adult)

To convert the value of energy imparted associated with an extremity examination into the corresponding values of effective dose requires an estimate of the *E/ε ratio* for the extremity regions. Inspection of the data generated by Atherton and Huda (1996) for single 5-mm sections in axial CT examinations shows that values of E/ε as a function of location on the head-toe axis for an anthropomorphic phantom approached the same value of -3 mSv/J for the head region as well as for the thigh region below the male gonads. The lowest value of 68 radiographic examinations reported by Huda and Gkanatsios (1997) was 4.6 mSv/J for a lateral cervical spine examination, -50% higher than

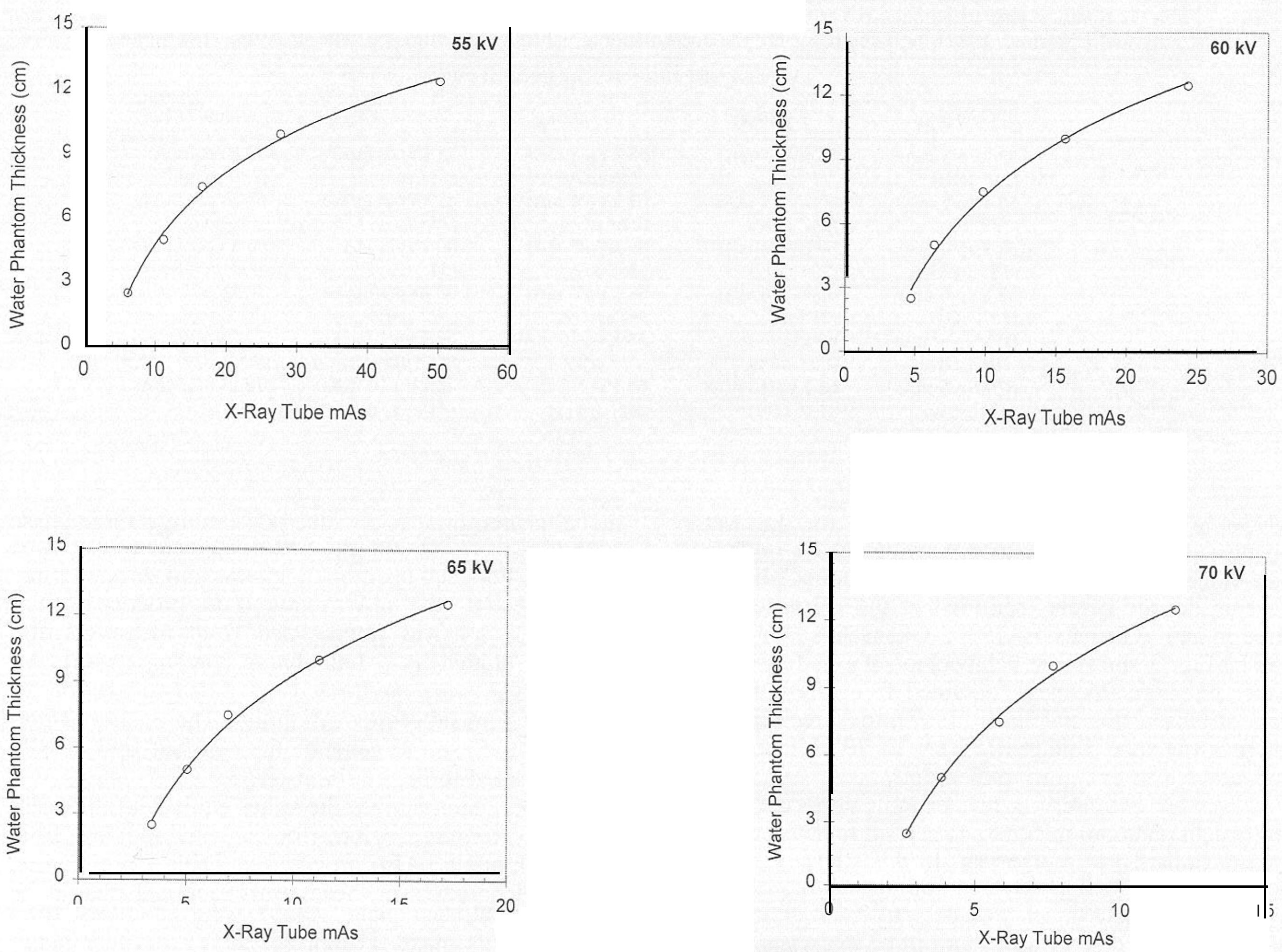

Fig. 4. Water phantom thickness required to generate a film with a gross film density of 1.4 vs. x-ray tube mAs (see text for details).

Table 2. Values of the thickness of a water phantom which is radiographically equivalent to the specified extremity. In parentheses are the corresponding cross-sectional x-ray beam areas at the beam entrance plane.

	Extremity equivalent water thickness (and *x-ray beam cross-sectional area*) for specified patient age/mass				
	1 y/9.3 kg	5 y/19 kg	10 y/32 kg	15 y/54 kg	Adult/71 kg
Hand	0.4 cm *(48 cm^2)*	1.1 cm *(59 cm^2)*	1.5 cm *(82 cm^2)*	1.5 cm *(117 cm^2)*	1.9 cm *(202 cm^2)*
Forearm	1.8 cm *(35 cm^2)*	3.3 cm *(84 cm^2)*	5.0 cm *(141 cm^2)*	6.2 cm *(196 cm^2)*	7.9 cm *(196 cm^2)*
Elbow	3.5 cm *(22 cm^2)*	4.3 cm *(49 cm^2)*	8.3 cm *(50 cm^2)*	8.3 cm *(71 cm^2)*	9.8 cm *(86 cm^2)*
Ankle	3.5 cm *(22 cm^2)*	5.0 cm *(49 cm^2)*	10.0 cm *(49 cm^2)*	10.6 cm *(58 cm^2)*	11.4 cm *(71 cm^2)*
Tibia/Fibula	4.3 cm *(55 cm^2)*	6.5 cm *(110 cm^2)*	10.6 cm *(185 cm^2)*	11.1 cm *(240 cm^2)*	11.4 cm *(268 cm^2)*
Knee	5.0 cm *(36 cm^2)*	10.6 cm *(56 cm^2)*	11.4 cm *(54 cm^2)*	11.8 cm *(75 cm^2)*	12.7 cm *(96 cm^2)*

observed at the periphery of a Rando phantom undergoing single section CT scans. The head and extremity regions differ in that the former region contains significant amounts of red bone marrow whereas the latter region generally has negligible amounts of red bone marrow (Cristy 1981). For CT examinations of the head, however, the contribution of the red bone marrow to the corresponding effective dose is only about 17% (Atherton and Huda 1996).

The extremities are no more radiosensitive than the peripheral body regions consisting of the upper head and upper thighs undergoing single section CT scans. The similarities in composition of the (upper) head region and extremities in terms of radiosensitive organs suggests that use of an E/ε ratio of 3 mSv/J will likely provide approximate absolute values of patient effective dose. In the absence of a definitive E/ε ratio for extremity examinations, however, it may be more prudent to consider the absolute values of patient effective doses obtained using this E/ε ratio as an upper limit.

Effective dose (pediatric)

By definition, uniform whole body irradiation to 1 Gy results in an effective dose of 1 Sv and is independent of the mass of the exposed individual. For a 70.9.kg anthropomorphic adult subject to uniform whole body irradiation, energy imparted can be converted into effective dose since one joule corresponds to an effective dose of 14.1 mSv. For uniform whole body irradiation, the effective dose E to an individual with a mass M who absorbs a total energy ε is given by

$$E = \varepsilon \times 14.1 \times \frac{70.9}{M} \text{ mSv}. \quad (2)$$

For the non-uniform exposures which occur in diagnostic radiology, the relative radiosensitivity of an irradiated region also needs to be taken into account when computing values of effective dose. Since the relative radiosensitivity of any body region remains approximately constant with age (ICRP 1991; Almen and Mattsson 1996), the effective dose to a patient of mass M kg for a given x-ray projection i, who absorbs ε joules of energy may be obtained from the expression

$$E = \varepsilon \times \left(\frac{E}{\varepsilon}\right)_i \times \frac{70.9}{M} \text{ mSv}, \quad (3)$$

where $(E/\epsilon)_i$ is the ratio of the effective dose to energy imparted (mSv/J) obtained for the same projection i in the adult anthropomorphic phantom with a mass of 70.9 kg. Data on the standard mass of patients ranging from 1 y old to 15 y old were taken from Cristy and Eckerman (1987) and are listed in the tables with the nominal patient age. Use of eqn (3) with the age-related patient mass data permits an estimate to be obtained of the relative effective dose to pediatric patients undergoing extremity examinations.

RESULTS

Table 3 summarizes the computed values of energy imparted, obtained using eqn (1) and data from Tables 1 and 2, for six common extremity radiographic examinations and for patients ranging from 1 y old to adults. For adults, values of energy imparted ranged from 55 μJ to 920 μJ. The energy imparted is reduced as the patient mass (age) decreases because of a reduction in x-ray beam area, patient thickness, and entrance skin air kerma. For 1-y-old patients, the average energy imparted was about a factor of 20 lower than the corresponding energy imparted for adults.

Table 4 summarizes the computed values of effective dose, obtained using eqn (3) and an E/ε value of 3 mSv/J, for six common extremity radiographic examinations for 1-y-old patients to adults. For adults, upper limits on the values of effective dose ranged from 0.17 μSv to 2.7 μSv. Effective doses were generally reduced as the patient age (mass) was reduced. For 1-y-old patients, the average effective dose was about a factor of 3 lower than the corresponding average value of the effective dose for adults.

Table 3. Energy imparted (μJ) for representative extremity examinations.

	Energy imparted (μJ) for specified patient age/mass				
	1 y/9.3 kg	5 y/19 kg	10 y/32 kg	15 y/54 kg	Adult/71 kg
Hand	2.89	9.63	17.6	25.2	55.2
Forearm	9.60	44.1	131	236	363
Elbow	13.6	38.1	100	140	229
Ankle	13.6	45.3	129	175	241
Tibia/Fibula	42.4	143	561	778	917
Knee	33.5	170	207	259	402

DISCUSSION

The traditional parameter used to specify the amount of radiation received by a patient undergoing a radiographic extremity examination is the entrance skin air kerma (or exposure), which is a poor indicator of the patient risk since no account is taken of the tissue radiosensitivity, x-ray beam area, penetrating ability of the x-ray beam, or of the patient thickness. In addition, use of entrance skin air kerma for extremity examinations does not permit a meaningful patient dose comparison with other types of radiologic procedures. For example, a chest x-ray examination involves the exposure of a more radiosensitive body region, with a much larger area of exposure, and both of these factors make the direct comparison of the entrance skin air kerma of an extremity examination with that of a chest examination

Table 4. Upper limits on the effective doses (μSv) for representative extremity examinations obtaining by converting values of energy imparted by using an E/ε ratio of 3 mSv/J^{-1}.

	Upper limit of effective dose (μSv) for specified patient age/mass				
	1 y/9.3 kg	5 y/19 kg	10 y/32 kg	15 y/54 kg	Adult/71 kg
Hand	0.066	0.11	0.12	0.10	0.17
Forearm	0.22	0.49	0.87	0.92	1.1
Elbow	0.31	0.43	0.67	0.55	0.69
Ankle	0.31	0.51	0.86	0.68	0.72
Tibia/Fibula	0.97	1.6	3.7	3.0	2.7
Knee	0.77	1.9	1.4	1.0	1.2

inappropriate. CT procedures have traditionally used the computed tomography dose index (CTDI) to specify the patient dose (Shope et al. 1981) and nuclear medicine studies most frequently specify either critical organ doses or effective dose (Johansson et al. 1984). The use of CTDI parameters in CT or the critical organ dose/ effective dose in nuclear medicine makes any direct comparison with the entrance skin air kerma in radiographic extremity examinations problematic.

For adults, entrance skin air kerma for radiographic extremity examinations ranged from 130 μGy to 690 μGy. For all radiographic examinations, the entrance skin air kerma was reduced as the patient age decreased. Entrance skin air kerma values were a factor of about 2.5 lower for l-y-old patients in comparison with those for adults. The observed variation of entrance skin air kerma with patient age, however, is a result of the changes in both mAs and x-ray tube voltage to compensate for changes in the patient thickness. Larger patients are generally radiographed at higher x-ray tube voltages (kVp), as depicted in Table 1, which will reduce the entrance skin air kerma in comparison to x-ray examinations in the same patients obtained at lower tube voltages. This increase of kVp with patient age (i.e., size) reduces the variation in entrance skin air kerma that would occur if a fixed x-ray tube potential were to be used for patients of all sizes.

In addition to the method used in this study to determine values of energy imparted (Gkanatsios and Huda 1997), there are several alternative ways to measure or calculate the energy imparted to a patient undergoing a given type of radiographic examination. Commercial dose-area product meters (DAP) may be used to estimate the energy imparted to a patient from the exposure-area or air collision kerma-area product (Shrimpton et al. 1984; Faulkner et al. 1992; Wagner 1992). Other published methods make use of measured depth dose data to determine energy imparted (Carlsson 1965; Harrison 1983). Monte Carlo techniques may also be used to obtain values of energy imparted (Persliden and Carlsson 1984; Boone 1992). Measurements of the exposure-area product have been reported to result in an accuracy of energy imparted between 10% and 20% (Berthelsen and Cederblad 1991; Shrimpton et al. 1984). The energy imparted to a patient undergoing any type of radiographic examination is a well defined parameter that may be determined with an accuracy that is sufficient for most patient dosimetly applications.

Our method for determining energy imparted to patients undergoing an extremity examination makes use of a homogeneous water slab model with a thickness estimate based on x-ray transmission (see Fig. 4). For a typical ankle examination (see Table 2), a change in water phantom thickness of 1 cm changes the computed value of energy imparted only by about 7%. The use of a homogeneous slab of water to simulate patients for estimating the energy imparted has recently been investigated by comparing the energy imparted to an anthropomorphic phantom with that computed using the exposure-area product as given by eqn (1) (Gkanatsios and Huda 1997). For a radiographic examination covering the head, thorax, abdomen, or pelvis, the average accuracy of eqn (1) for determining energy imparted in comparison to the anthropomorphic phantom was 3% at 60 kV, 10% at 80 kV, and 22% at 120 kV. It is important to note that at the low tube voltages used for extremity examinations, coupled with the presence of a large amount of bone, the photoelectric effect will account for most of the x-ray interactions reducing the relative importance of scatter. As a result, simulating an extremity with a semi-infinite slab of water is not expected to result in significant errors for the purposes of estimating energy imparted.

Values of energy imparted in extremity examinations may be compared with energy imparted in other types of radiographic examinations such as chest examinations (-5 mJ), skull examinations (-10 mJ), abdomen examinations (-25 mJ), or 1 min of fluoroscopy (-55 mJ) (Gkanatsios and Hnda 1997). The energy imparted to a patient undergoing a radiographic examination has been taken to be a relative indicator of patient risk (Wall et al. 1988). For example, for a given age group the radiation risks of a hand examination with that of an ankle examination will be approximately the ratio of the corresponding values of energy imparted. Energy imparted may also be used to compare the relative radiation risk as the radiographic technique factors (kVp, mAs, etc.) are changed when the same region is irradiated. It is important to note, however, that the energy imparted parameter does not take into account either the mass of the patient or the relative radiosensitivity of the irradiated organs. As a result, there will be occasions when specification of energy imparted alone may not be a good indicator of the (relative) patient radiation risk.

The absolute values of patient effective doses are clearly dependent on the choice of the E/ε ratio used to convert energy imparted into the corresponding values of effective dose. The chosen value for the E/ε ratio of 3 mSv/J used in this study is much lower than the average E/ε ratio of 17.8 ± 1.4 mSv/J for 68 other types of radiographic examinations, or the value of 14.1 mSv/J for uniform whole body irradiation in adults. To our knowledge, no studies exist which have computed extremity effective doses as well as the corresponding values of energy imparted and direct evidence for an appropriate E/ε ratio is not presently available. Attempts to obtain a direct estimate of the effective dose for extremity examination will likely be problematic because of the conceptual difficulties of dealing with the dose to the "remainder," which is the organ(s) receiving the highest radiation absorbed dose in extremity radiographs (Huda and Sandison 1984). In the absence of any measured or computed values of the E/ε ratio for extremity examinations, the data in Table 4 provide upper limits on typical extremity effective doses. The extremities contain very similar types of radiosensitive tissues to the upper thighs and peripheral head regions used to obtain the E/ε ratio of 3 mSv/J used in this study, which suggests that the data in Table 4 are unlikely to be gross overestimates of the "true" extremity effective doses, The remaining uncertainties in the effective dose data presented in Table 4 will not be a practical problem for many dosimetry applications, such as the specification doses in informed consent forms for a research protocol or comparing patient doses from different types of radiographic examination.

Radiology departments that use different speed image receptors, or x-ray tube voltages which result in different entrance skin doses, could readily scale the effective dose values computed in this study as listed in Table 4. Thus a screen-film combination with half the nominal speed of our system, or twice the entrance skin dose, would imply that the corresponding effective dose to the patient would need to be doubled. Use of eqn (3) permits the determination of the approximate values of effective doses to pediatric patients who undergo radiographic procedures. This approach has been shown to agree to -17% with MC computations made in pediatric anthropomorphic phantoms of different ages ranging from newborns to 15-y-old anthropomorphic phantoms (Huda and Gkanatsios 1997). This level of agreement compares favorably with the use of different types of anthropomorphic phantoms to determine pediatric effective doses in planar radiology, which can result in typical differences in effective dose of -30% (Hart et al. 1996).

The adult effective dose data given in Table 4 can be directly compared to those associated with different radiographic procedures. Typical values of the effective dose for common radiographic examinations include head radiographs (50-150 μSv), chest radiographs (20-50 μSv), abdominal radiographs (300-600 μSv), or barium contrast studies (3-8 mSv). Extremity radiographs have effective doses that are very low in comparison with most other radiographic examinations (UNSCEAR 1993). Although this finding is not unexpected the amount of radiation received by patients during different types of radiologic procedures is only evident when all of these doses are expressed in terms of the effective dose. The data provided in Table 4 would be appropriate for "se by hospital Institutional Review Boards for inclusion in informed consent/assent forms for use in research studies that employ radiation exposure of the extremities. Quantifying patient extremity exposures "sing the effective dose parameter will thus improve understanding by patients and radiology professionals of the amount of radiation any patient receives during an extremity examination.

Use of the effective dose parameter to quantify the radiation received by a patient undergoing an extremity examination may also permit an estimate of patient risk to be obtained by using current stochastic risk factors, The use of such risk factors needs to be treated with great caution, however, given the current uncertainties of extrapolating radiation risks from high doses to those normally encountered in diagnostic radiology (NCRP 1985; NRC 1990; Fry 1996; Puskin and Nelson 1996). Although knowledge of the effective dose associated with an x-ray procedure is clearly helpful, it is nonetheless important to note that any resultant detriment will also depend on the age of the exposed individual. Stochastic radiation risks of carcinogenesis and genetic effects are generally greater for children than for adults, and these factors would need to be taken into account whenever any attempt is made to convert effective doses to a given population into the corresponding value of risk or detriment.

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