ORGAN DOSES IN DIAGNOSTIC RADIOLOGY

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Extensive use has been made of a dosimetry technique for calculating organ doses in diagnostic radiology. The computations are made with a Monte Carlo radiation transport procedure and various mathematical anthropomorphic phantoms. This method simulates and records the energy deposition of x-ray photons in the phantoms by following the radiation interaction histories of a large number of incident photons using known physical descriptions of the interaction processes and recording energy depositions at the sites of interaction. The physical processes treated are limited to the photoelectric effect and Compton scattering, since the initial photon energies in the diagnostic range are less than 150 keV. A variety of dosimetry data of general applicability for estimating organ doses from diagnostic x rays have been developed.

TISSUE-AIR-RATIOS FOR A REFERENCE ADULT PATIENT

Tissue-air-ratios, expressed as the average absorbed dose (rad) to the organ per unit exposure (R, free-in-air) at the reference plane of the organ, have been tabulated for a reference adult phantom for collimated, normally-incident 4-cm x 4-cm monoenergetic photon beams in the range 20 to 100 keV (1). These tabulations are for beams incident upon the phantom on the front, rear and lateral surfaces.

The tissue-air-ratios can be converted to organ doses for a specific x-ray projection using pertinent information on x-ray spectra, projection geometries, and field sizes and locations. The tissue-air-ratios for component beams included in the x-ray field and for energies included in the x-ray spectrum are combined to simulate the desired conditions. A computer program in FORTRAN IV which performs these calculations on an IBM 370/168 system for several organs (lungs, active bone marrow, ovaries, testes, thyroid, uterus (embryo), and total body) is available (2).

ORGAN DOSES - REFERENCE ADULT PATIENT

Organ doses for a number of radiographic views and projections have been computed for a reference adult patient (3). These doses are normalized to a convenient numerical entrance exposure of one roentgen. Two parameters, entrance exposure at skin entrance (free-in-air) and beam quality must be measured or estimated by the user to convert these values to the conditions at a particular clinical facility. Utilizing typical technique factors (beam quality, entrance exposure and number of films of various views) observed in a 1970 nationwide study of diagnostic x-ray exposure conditions, organ doses were computed for common radiographic examinations. Table 1 presents some of these results.

TABLE 1. Organ doses for some common radiographic examinations

	Organ Dose (mrad)				
Examination	Thyroid	Active Bone Marrow	Breasts	Testes	Ovaries
Chest	7	4	14	< 0.01	0.06
Thoracic Spine	75	43	276	< 0.01	0.6
Lumbar Spine	0.3	126	not computed	7	405
Upper GI	7	117	53	0.4	45
Barium Enema	0.2	298	not computed	58	787
Pelvis	< 0.01	27	not computed	57	148
Full Spine	271	35	234	10	100

The conditions simulated assume good collimation (field size equal to film size) and proper alignment of the x-ray field with appropriate anatomical landmarks. Each examination type has a different combination of exposed organs and absorbed dose to these organs. The data clearly demonstrate that no single organ dose can serve as an indicator of total radiation impact for all x-ray examinations.

MAMMOGRAPHY

In many discussions of absorbed dose in the breast from mammography, the typical dose to the breast is derived from an assumed depth-dose of approximately 20 percent at the midline (3-cm depth). After correcting for backscatter and the exposure-to-absorbed dose conversion factor this is equal to about 250 mrad per 1 roentgen skin exposure (free-in-air). This assumption is an oversimplification, for there is a wide range of doses that result from the present day practice of mammography. Table 2 presents midbreast doses as a function of HVL per one roentgen exposure for mammography, interpolated from recent data of Hammerstein, et al (4).

TABLE 2. Mammography breast doses for 1 R entrance skin exposure (craniocaudad view)

	Midbreast Dose[a] (mrad/R)					
HVL, mm Al	0.2	0.4	0.6	0.8	1.0	1.5
Tungsten target, Aluminum filter	--	110	170	230	285	430
Molybdenum target, Molybdenum filter	25	85	145	--	--	--

a Absorbed dose in a small mass of mammary gland embedded at 3-cm depth in a 6-cm medium of 50 percent adipose and 50 percent glandular tissue.

Current work will compute absorbed dose in varying breast compositions using the Monte Carlo technique and a number of geometrically described breast phantoms. The dosimetric quantities that can be computed include the midbreast absorbed dose, the average absorbed dose throughout the breast, and the absorbed dose to only the glandular tissue within the breast. A wide range of mammography conditions are being studied.

ORGAN DOSES - REFERENCE PEDIATRIC PATIENTS

Organ doses for a number of radiographic views and projections have also been computed for three reference pediatric patients, a newborn, one-year old and five-year old (5). It was too costly to generate tissue-air-ratios for the three pediatric phantoms; therefore, a more direct approach was used. In addition, the variation in technique factors and the variety of x-ray projections are more limited in pediatric radiology (6). For each projection, the computation started with the specified characteristics of the x-ray projection including source-to-image receptor distance (SID), field size and location, and x-ray spectrum matched to the desired beam quality with respect to kVp and half-value-layer. The output of the computation is the organ dose (mrad) to the various organs for a one roentgen entrance exposure (free-in-air). Table 3 is a sample set of data for a pediatric projection.

TABLE 3. Pediatric organ doses for 1 R entrance exposure, AP abdomen

		Organ Dose (mrad/R)					
HVL, mm Al		2.0		2.5		3.0	
Collimation		a	b	a	b	a	b
Testes	Newborn	86	910	144	1,000	152	1,120
	1-year	105	1,070	105	1,070	105	1,070
	5-year	125	1,070	125	1,070	125	1,070
Active Bone Marrow	Newborn	91	159	127	211	137	225
	1-year	69	99	100	140	112	151
	5-year	55	69	83	101	90	112
Lungs	Newborn	49	439	66	497	67	498
	1-year	35	227	48	255	55	290
	5-year	39	102	47	123	54	135

a Field collimated to body part: newborn 13 X 13, 1-year old 18 X 21, 5-year old 23 X 30 (in cm).

b Field collimated to film size: newborn 20 X 25, 1-year old 25 X 30, 5-year old 28 X 36 (in cm).

SOMATIC DOSE INDEX

For somatic effects there are several organs at risk and each type of diagnostic examination results in a different spatial relationship between the significant organs and the x-ray beam. Each type of examination also employs different technique factors to yield the desired diagnostic information. Consequently, every examination results in a unique non-uniform distribution of absorbed dose among the organs, and some method of accounting for this non-uniform distribution is necessary to assess the overall impact from a given exposure.

A somatic dose index (I_D) has been formulated which represents the uniform dose to the organs at risk that has the same somatic detriment as the non-uniform doses absorbed by the individual organs (7).

$$I_D = \frac{\sum_{i=1}^{n} s_i \alpha_i \bar{D}_i}{\sum_{i=1}^{n} s_i \alpha_i}$$

where: s_i is the relative severity of the somatic effect induced in organ i,

α_i is the risk coefficient for the effect in organ i (cases/10^6 person-yr-rad),

$\bar{D}_i$ is the average absorbed dose in organ i.

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