Effective Dose for Hologic Horizon and Discovery Scan Modes*

Procedure	Scan Mode	*Effective Dose (μSv)
AP Spine DXA exam	Express	5
	Fast	7
	Array	14
Hip DXA exam	Express	1.5
	Fast	2
	Array	4
Forearm DXA exam		0.1
Lateral DXA exam	Fast	21#
Adult Whole Body exam	Discovery A	3
	Discovery W	8
Infant Whole Body exam	Discovery A	10 (neonate)
		7 (1 year old)
IVA (single energy)	AP	7
	Lateral	5
IVA HD (single energy)	Lateral	4#
OTHER SOURCES (FOR	**REFERENCE)**	
Lateral spinal X-rays		600
Technetium bone scan		3000
CT Examination		10000
1 day natural background		8
Transcontinental flight		40

*Discovery effective dose measurements courtesy of Glen Blake, Ph.D., Guys and St. Thomas Hospitals, London, United Kingdom (personal communication). Horizon effective dose was not measured but is assumed same as Discovery based on same x-ray beam geometry, x-ray energies, data acquisition protocols, and same entry dose (see following table).

#Effective dose for Lateral DXA exam and IVA HD single energy imaging exam estimated by Hologic from the following Table of Nominal Entry Dose and the manuscript by Blake *et al*.

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Table 1. Horizon Series Nominal Entry Dose.

Exam	*Scan Mode*	*Measured Entry Dose (mGy) Horizon W s/n 04112013*	*Measured Entry Dose (mGy) Horizon A s/n 102816*	*Discovery Specification Entry Dose (mGy)*
AP Spine	Express	0.040	0.042	0.04
AP Spine	Fast	0.063	0.065	0.07
AP Spine	Array	0.126	0.133	0.13
AP Spine	Hi Def	0.142	0.150	
Hip	Express	0.040	0.043	0.04
Hip	Fast	0.064	0.066	0.07
Hip	Array	0.126	0.132	0.13
Hip	Hi Def	0.142	0.148	
Forearm	Array	0.035	0.038	0.035
VFA – AP Spine	IVA	0.029	0.029	0.03
VFA – Decubitus Lateral	IVA	0.028	Not Supported	0.03
VFA – Supine Lateral	IVA	Not Supported	0.025	0.03
VFA – AP Spine	IVA HD	0.025	0.025	0.025
VFA – Decubitus Lateral	IVA HD	0.024	Not Supported	0.025
VFA – Supine Lateral	IVA HD	Not Supported	0.023	0.025
Whole Body (isocentric)	Array	Not Supported	0.006	0.008
Whole Body (co-linear)	Array	0.011	Not Supported	0.012
Whole Body (isocentric)	Infant	Not Supported	0.008	0.01
Whole Body (co-linear)	Infant	0.009	Not Supported	0.012
Lateral (Decubitus)	Array	0.25	Not Supported	0.35
Lateral (Supine)	Fast	Not Supported	0.23	0.3
SE Femur	SE Femur	0.024	0.025	0.05

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Comparison of effective dose to children and adults from dual X-ray absorptiometry examinations

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Abstract

Dual X-ray absorptiometry (DXA) is increasingly used to measure bone density in children. If the system software does not include pediatric scan modes, then child examinations must be performed using adult scan modes that give a higher radiation dose to children than adults. This report describes a study to compare the effective dose to children and adults from DXA scans performed on the Hologic Discovery and QDR4500 models. Depth dose measurements were made using thermoluminescent dosimeters in a Rando phantom and were mapped onto the Cristy mathematical phantoms representing a 5-, 10- and 15-year-old child and an adult, and effective dose (ED) was calculated using the ICRP Publication-60 tissue weighting factors. The ED for spine (hip) examinations performed with the Express mode using the default adult scan lengths were 16.1 (9.8), 11.1 (6.7), 5.6 (3.9) and 4.4 (3.1) μSv for a 5-, 10- and 15-year-old child and adult respectively. However, if care is taken to adjust scan lengths appropriately, the child doses were reduced to 9.1 (7.4), 7.1 (5.9) and 5.0 (3.7) μSv. ED figures for the Fast and Array modes were larger by factors of 1.5 and 3 respectively. EDs for whole body scans for a 5-, 10- and 15-year-old child and adult performed on the A-model (W-model) were 5.2 (10.5), 4.8 (9.6), 4.2 (8.4) and 4.2 (8.4) μSv. Using the infant whole body mode (only available on the A-model), they were 7.5 μSv for a 1-year-old and 8.9 μSv for a neonate. Although doses from child DXA examinations are low, it is still important to keep them as small as possible. DXA operators using Discovery systems can do this by using the Express scan mode, by setting appropriate values of the scan length before scan acquisition and by avoiding mistakes that lead to scans having to be unnecessarily repeated.

Keywords: Dual X-ray absorptiometry; Effective dose; Pediatric examinations

Introduction

Dual X-ray absorptiometry (DXA) scans are widely used to measure bone density [1] and evaluate risk of fracture [2]. Although the majority of patients are postmenopausal women [3], DXA examinations are also performed in children [4]. In older children and adults, the preferred sites of measurement are the spine and hip [4–6]. In pre-pubertal children, the spine is the most useful site [4], although whole body examinations are also performed. In neonates and infants, it is usual to perform whole body examinations.

One of the advantages of DXA as a method for investigating skeletal status is the low radiation dose received by patients [7]. Measured in terms of the effective dose [8], the radiation dose to an adult from a spine and hip examination with current systems is between 1 and 20 μSv depending on the make, model and scan mode used [7]. This compares with a dose of 7 μSv/day from natural background radiation [9], 20 μSv from a chest X-ray [10] and 40 μSv from a transcontinental flight [11].

Although several studies [7,12–15] have reported the effective dose to adults from DXA examinations, there have been fewer studies of the dose received by children [16,17]. Because the exposure factors (tube voltage, filtration, tube current, scan width, scan length) are optimized for adults and because the operator often has little control over these factors, the effective dose received by children is likely to be considerably larger than adults. This is because children are thinner, and doses to internal organs are higher since there is less attenuation of radiation by overlying tissues. In addition, for fan

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beam DXA systems such as the models investigated in this report, the scan width is fixed by the width of the collimator, and in children, a greater proportion of the body is exposed to the X-ray beam (Fig. 1). The shorter scan times on newer DXA systems help reduce movement artefacts. However, shorter scan times may also affect radiation dose in children because there is less time for the operator to intervene and end scan acquisition before the default adult scan length is reached (Fig. 1).

The aim of this investigation was to estimate and compare the effective dose from DXA examinations in children and adults using a consistent methodology.

Methods

Dose measurements were made on four different Hologic DXA scanners (Hologic Inc., Bedford, MA). The models were a Discovery-A, a Discovery-W, a QDR4500-A and a QDR4500-W. The two QDR4500 systems had both been upgraded with the Discovery software. Patient dose was estimated for three spine and hip scan modes: Array mode (60-s scan time, 1-mm collimator); Fast mode (30-s scan time, 1-mm collimator); and Express mode (10-s scan time, 2-mm collimator). The default scan lengths were 20 cm for the spine and 15 cm for the hip. Dose measurements were also made for whole body scans on all four systems and for the infant whole body mode on the two A-models.

Overview of dose calculations

An overview of the method of dose calculation is given in Fig. 2. Detailed depth dose measurements for the Array mode on the QDR4500-W system were made using thermoluminescent dosimeters (TLDs) set in an adult anthropomorphic phantom (Rando phantom, Alderson Research Laboratories, Stanford, CA) [18,19]. Since the X-ray generator and beam geometry are identical on all four models, only small differences were expected in effective dose. The exception is for whole body scans where there are differences in scan geometry between the W- and A-models. The four machines were therefore compared by measurements of entrance dose using an ionization chamber. The ionization chamber measurements were also used to measure the differences between the Array, Fast and Express spine and hip modes and to check the TLD measurements of entrance dose (Fig. 2).

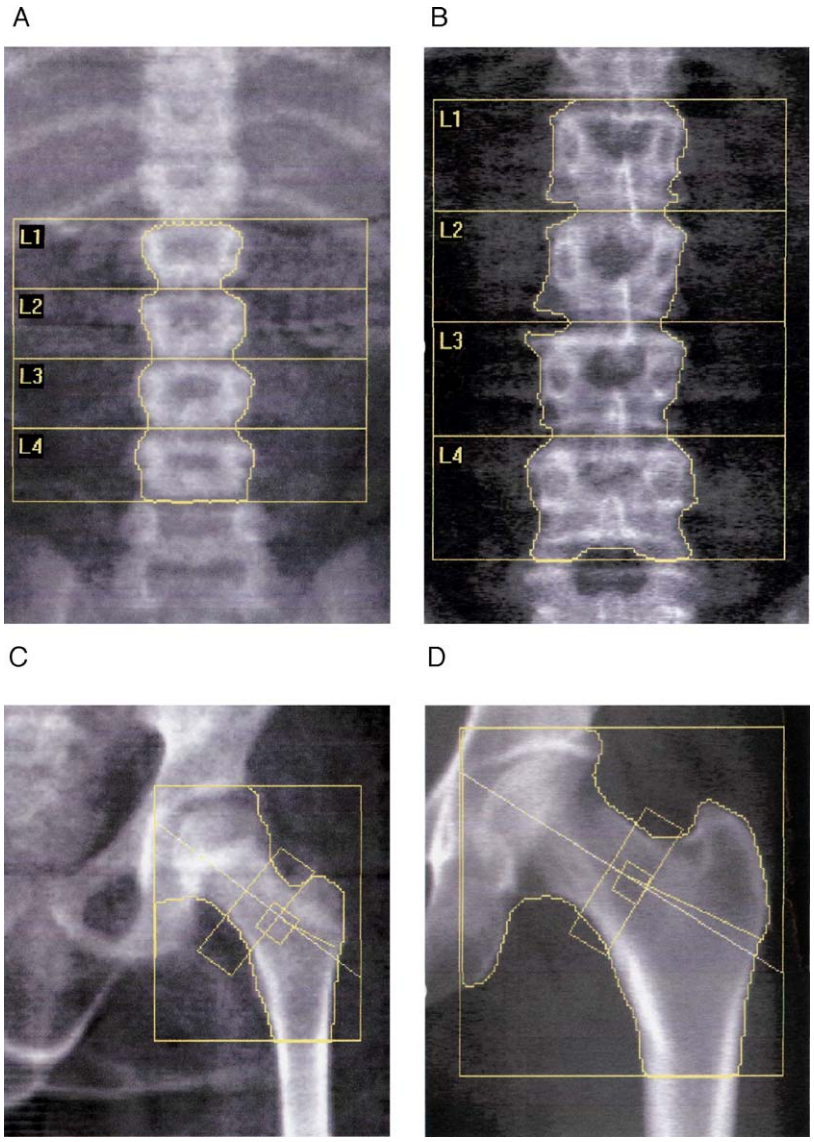

Fig. 1. Spine and hip DXA scan images for a 9-year-old child and an adult woman performed on a Hologic Discovery system: (A) child spine scan; (B) adult spine scan; (C) child hip scan; (D) adult hip scan.

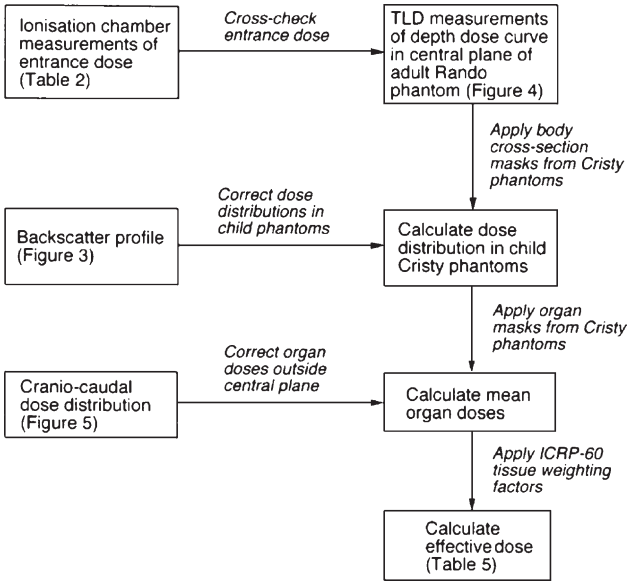

Fig. 2. Overview of the method of dose calculation used in the present study.

The depth dose data obtained using the Rando phantom were used to estimate the mean dose to individual organs in the body using the set of mathematical phantoms of children and adults developed by Cristy [20]. The method of adapting the adult Rando phantom data to allow dose estimates in children is explained below. Dose calculations for spine and hip DXA examinations were performed for the 5-, 10- and 15-year-old child and the adult Cristy phantoms. Effective doses for the Array, Fast and Express modes were calculated from the organ doses using the tissue weighting factors published by the International Commission on Radiological Protection (ICRP) [8]. In addition, the Cristy phantoms were used to estimate the dose from whole body DXA examinations for neonates, 1, 5-, 10- and 15-year-old children and adults.

Entrance dose measurements

Entrance doses for the Array, Fast and Express scan modes on each of the four DXA scanners were compared using a 180 cm^3 ionization chamber (Radcal Model 2025, MDH Industries, Monrovia, CA) set in a phantom with 10-cm thickness of tissue equivalent material to provide backscatter. Measurements of entrance dose were also made for the whole body BMD scan mode on all four systems and for the infant whole body scan mode available only on the A-models. One scanner was also measured with a Radcal Model 9010 radiation monitor and a 60 cm^3 chamber that had recently been calibrated against a secondary standard and the measurements on the other scanners scaled to obtain accurate measurements of entrance dose for all four systems. These included the correction for standard pressure and temperature [21]. Figures for entrance dose were converted from units of exposure (mR) to absorbed dose (μGy) using a conversion factor of 9.17 μGy/mR [12]. Measurements of exit dose for the 10-cm-thick phantom were also made on each system to check the consistency of the transmission factors. Finally, the 180-cm^3 chamber was used to measure the backscatter profile by measuring the change of entrance dose with the thickness of backscatter material as the latter was varied in 1-cm intervals from zero to 15 cm (Fig. 3).

Depth dose measurements

A total of 100 TLD chips (lithium fluoride doped with magnesium and titanium) were used for the study. The chips were a batch used for routine monitoring of patient dose by the Radiotherapy Physics Department at Guy's Hospital and were individually calibrated. Five chips were kept to measure the background signal, and a further five were used to measure the entrance dose to the Rando phantom. The remaining 90 were distributed uniformly throughout slice 25 of the Rando phantom (this slice is at the level of L3) and the reassembled phantom scanned 400 times on the QDR4500-W system using the Array spine

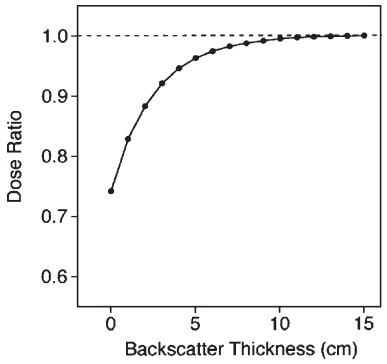

Fig. 3. Backscatter curve measured with an ionization chamber showing the variation of entrance dose with the thickness of soft tissue equivalent material behind the chamber. Results are shown normalized to a dose ratio of 1.0 for thickness greater than 15 cm.

scan mode with 20 cm scan length. The TLDs were read out on a Harshaw Model 3500 TLD Reader (Thermo Electron Corporation, Waltham, MA) and the individual readings corrected for the calibration factor of each chip and for background using a computer programme written in Microsoft Excel. The programme incorporated a batch calibration factor measured by the Radiotherapy Physics Department. The results were entered into a spreadsheet with the same layout as the Rando phantom slice (Fig. 4) and interpolated onto a 1-cm grid for calculating organ doses. To estimate the precision of the TLD measurements, the study was repeated with 400 Array mode scans of the Rando phantom performed with 50 TLDs placed at the entrance surface and 50 at the beam exit.

Because the TLD depth dose measurements were all made in a single transverse plane at the center of the 20-cm scan field, the dose distribution in the cranio-caudal direction was measured using a small (3 cm^3) ionization chamber set at 10 cm depth in a tissue equivalent phantom. Measurements were made from the center of the 20-cm scan field to 10 cm below the scan starting point (Fig. 5).

Organ dose calculations

Organ doses were estimated from the dose distribution measured in the Rando phantom using the set of mathematical phantoms representing an adult and children of various ages (0, 1, 5, 10 and 15 years) developed by Cristy [20]. The Cristy phantoms define the size and positions of organs in terms of simple geometrical shapes with organ masses that are consistent with ICRP Reference

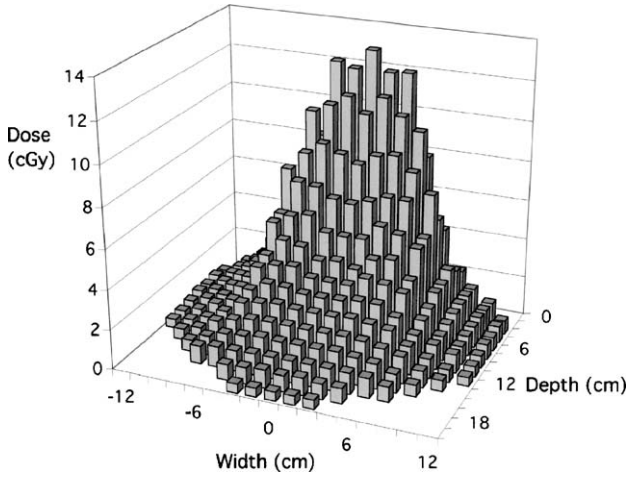

Fig. 4. Results of TLD measurements of the dose distribution in a cross-sectional slice of the Rando phantom through the 3rd lumbar vertebra (L3). The figures are the integrated dose after performing 400 Array mode scans on a Hologic QDR4500-W DXA system.

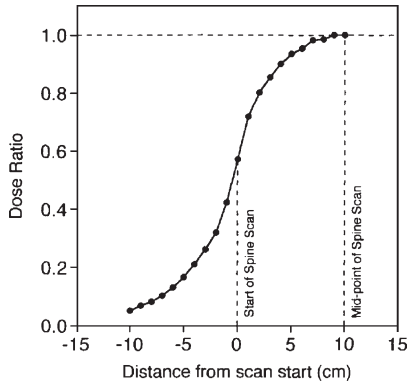

Fig. 5. Dose distribution along the midline of a spine DXA scan measured with a 3-cm^3 ionization chamber. Measurements are made at a depth of 10 cm in a tissue equivalent phantom. The dose profile starts at a point 10 cm below the start point of the spine scan and finishes at the mid-point of the 20-cm-long scan. Results are shown normalized to a dose ratio of 1.0 at the scan mid-point.

Man [22]. The information given includes the distribution of hemopoietically active bone marrow. A summary of the heights and weights of the different phantoms is given in Table 1.

For Hologic DXA systems, the X-ray beam enters the patient's back. Hence, the dose distributions in the various phantoms for spine BMD examinations were estimated by applying the cross-section of the trunk of the Cristy phantom at each age as a mask to the depth dose distribution measured in the adult Rando phantom with the posterior surface of the Cristy phantom touching the posterior surface of the Rando phantom. However, this procedure fails to allow for the fact that where the beam leaves the body, the depth dose values will be modified by the backscatter profile shown in Fig. 3. The adult Rando phantom measurements were therefore corrected by dividing each point in Fig. 4 by the backscatter profile shown in Fig. 3 according to its proximity to the exit surface. After creating the approximate child dose distributions using the Cristy phantom masks, the backscatter profile was reapplied to create the appropriate depth dose distribution for children. A similar method was used to create the depth dose distributions for the hip scan but with the X-ray beam centered over the femoral neck.

For adult spine scans, the scan field was assumed to be a 20-cm-long strip centered at the mid-point between L2 and L3. In the adult Cristy phantom, this is sufficient to include the whole of T12 and L5 in the scan field. For adult hip scans, the scan field was assumed to be a 15-cm strip centered on the femoral neck. The left hip was chosen since it includes a significant dose contribution to the lower large intestine. Since the Cristy phantoms do not include a detailed model of the hip joint, the center of the hip scan was assumed to lie within the pelvis on the projection of the vertical axis of the femur at a height 20% of the total height of the pelvis. This position was chosen based on an analysis of whole body DXA scan images. For pediatric spine and hip examinations, two scan lengths were studied: (1) assuming the same scan length as used for adults; (2) by scaling down in proportion to the length of the child's spine or leg [20] for spine and hip scans respectively. Because of the self-similar way in which the child Cristy phantoms are scaled from the adult phantom [20], the second approach means that the same anatomical region in the cranio-caudal direction is included in pediatric scans as in adults. However, in the first approach, relatively more of the spine and other organs such as the stomach, liver and colon are included in pediatric studies compared with adults. The mean organ dose was estimated by applying the cross-section of each organ as a mask over the depth dose distribution in each 1-cm-thick transverse plane and averaging dose voxel by voxel over each organ. For each successive plane, the TLD dose figures were adjusted according to the cranio-caudal dose profile shown in Fig. 5.

Effective dose for spine and hip examinations

Effective dose was calculated by taking the average dose to each organ and multiplying by its ICRP Publication 60 tissue-weighting factor [8]. Most studies of DXA patient dose have used these factors [12–17]. However, in 2005, a draft version of new regulations was posted on the ICRP web site that included revised factors [23]. For this reason, we also examined the effect of using the new ICRP 2005 tissue factors.

Effective dose for total body examinations

A simplified method was used to estimate the effective dose from whole body DXA scans by using the depth dose distribution in the primary X-ray beam to calculate the mean dose in the child and adult Cristy phantoms as a fraction of the entrance dose. These factors were then applied to the measured entrance dose for the whole body scan modes to estimate effective dose.

Results

The ionization chamber measurements of entrance dose for spine, hip and whole body scans for each of the four DXA systems studied are summarized in Table 2. For the Discovery systems, the entrance dose was 310 μGy for the Array mode, while for the QDR4500 systems, the figure was 10% higher. As expected from the scan times and collimator widths, the entrance doses for the Express, Fast and Array modes were in the ratio 1:1.5:3 (Table 2). Entrance doses were twice as large for whole body scans performed on the W-models compared with the A-models (26.1 μGy vs. 13.0 μGy). When the transmission factors through the 10-cm-thick phantom measured as the ratio of exit to entrance dose were compared for the four systems, the coefficient of variation was 0.5% compared with 6.7% for the entrance dose measurements.

Measurements of the backscatter profile (Fig. 3) were normalized to 100% for a backscatter thickness of 15 cm or greater. In comparison, entrance doses were 95% of the asymptotic value for 4-cm thickness of backscattering material and 74% for none. The dose distribution in the Rando phantom was plotted showing the integrated dose for 400 Array mode scans (Fig. 4). The entrance dose per scan measured on the QDR4500-W system was 352 μGy using TLDs compared with 345 μGy for the ionization chamber measurements. The TLD

Table 1
Heights and weights of the Cristy mathematical phantoms [20]

Age (years)	Weight (kg)	Height (cm)
0	3.51	51.5
1	9.36	75.0
5	19.1	109.0
10	32.1	138.6
15	54.5	164.0
Adult	71.1	174.0

Table 2
Measurements of entrance dose for spine, hip and whole body scan modes

QDR system	Array spine and hip (μGy)	Fast spine and hip (μGy)	Express spine and hip (μGy)	Whole body (μGy)
Discovery-A	310	156	104	13.0
Discovery-W	311	156	103	26.1
QDR4500-A	352	177	117	14.8
QDR4500-W	345	175	116	30.7

precision study gave coefficients of variation of 1.2% at the entrance surface and 3.4% at the beam exit. Measurements of the dose profile in the cranio-caudal direction (Fig. 5) were normalized to 100% at the mid-point of the scan area. In comparison, dose values decreased to 50% of the peak dose at the edge of the scan field and to 5% at a point 10 cm below the scan starting point.

Estimates of the effective dose to each organ and the total effective dose for spine (Table 3) and hip (Table 4) Array mode examinations are shown for an adult and for a 15-, 10- and 5-year-old child. Because of the different contributions from the gonad dose, the total effective dose in Tables 3 and 4 are given separately for male and female subjects as well as their average. Child figures are given both for the scaled scan lengths adjusted to the size of the child's body and for the adult scan lengths. Table 5 lists the effective doses for spine and hip examinations for the Array, Fast and Express modes using the ICRP-60 tissue weighting factors [8] and for the Express mode using the draft ICRP2005 factors [23]. Table 5 also lists the estimates of effective dose for whole body DXA examinations on the A- and W-models. Effective dose for the infant whole body mode was 8.9 μSv for a neonate and 7.5 μSv for a 1-year-old infant.

Discussion

Knowledge of the effective dose received by patients during DXA scanning is necessary for assessment of the radiation risks involved in routine clinical examinations and research studies. Previous studies of DXA radiation doses have usually examined the effective dose to adult women, and there have been fewer studies of the doses received by children. If the system software does not include pediatric scan modes, then child examinations must be performed using adult modes, and these will give a higher dose to children than adults. This is because doses to internal organs are larger in children since there is less attenuation of X-rays by overlying tissue. A second factor is that in children, a greater proportion of the body is exposed to the X-ray beam than in adults. This is illustrated in Fig. 1, which shows spine and hip scan images in a 9-year-old child performed on a Discovery system compared with those for a postmenopausal woman. From a comparison of the two sets of images, it can be seen that significantly larger proportion of the abdomen and pelvis are included in the child's scans. This is because the same collimator is used for children and adults, and the physical width of the X-ray beam where it enters the patient's back is the same. A second reason for the greater anatomical area in children is that the child and adult scans shown in Fig. 1 were both acquired using the adult scan lengths of 20 cm for the spine and 15 cm for the hip. When performing scans, it is common practice for the operator to stop the acquisition once the required anatomical area is seen on the display screen. Operator intervention is easier for slower scans such as the 60-s Array and 30-s Fast modes on the Discovery system, but it is more difficult for the 10-s Express mode which is often allowed to run on for the default adult scan length. For this reason, the present study considered two scan lengths for child examinations, the default adult length and a shorter scan length in which only the same anatomical region as adult scans was included in the child scan.

Table 3
Effective dose (μSv) for a Discovery/QDR4500 Array mode spine scan calculated using the ICRP-60 tissue weighting factors

Scan length (cm)[a]	Tissue factor	Adult	15-year-old child		10-year-old child		5-year-old child	
		20	18	20	14.5	20	11.7	20
Organ[b]								
Ovaries	0.20	3.4[c]	4.1	5.0	6.3	13.5	7.6	19.8
Testes	0.20	0.1	0.1	0.2	0.4	0.8	0.9	2.3
LLI[d]	0.12	0.9	1.2	1.3	2.2	3.2	3.1	6.1
Bone marrow	0.12	3.3	2.9	3.2	2.5	3.4	2.1	3.6
Stomach	0.12	2.6	3.3	3.5	5.1	5.9	6.6	8.1
Lung	0.12	1.1	1.4	1.7	2.1	4.0	3.1	6.2
Bladder	0.05	0.1	0.1	0.2	0.3	0.5	0.4	1.1
Esophagus	0.05	0.5	0.6	0.7	0.9	1.6	1.3	2.6
Breast	0.05	<0.1	<0.1	<0.1	0.1	0.2	0.2	0.5
Liver	0.05	0.9	0.9	1.2	1.7	3.0	2.6	3.9
Bone surfaces	0.01	0.1	0.1	0.1	0.1	0.2	0.1	0.2
Skin	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Remainder	0.05	2.1	2.2	2.3	3.0	4.1	3.5	4.9
Effective dose (μSv)								
Female		14.9	16.8	19.4	24.2	39.7	30.7	57.0
Male		11.7	12.9	14.5	18.4	27.1	24.0	39.5
Gender average		13.3	14.8	16.9	21.3	33.4	27.3	48.3

[a] Default adult scan length for the spine is 20 cm. Shorter scan lengths for children to include only T12-L5 have been scaled down from the relative lengths of the spine in the Cristy phantoms.
[b] Organs with effective dose contributions below 0.1 μSv have been omitted.
[c] All dose figures are rounded to one decimal place.
[d] LLI—lower large intestine.

Table 4
Effective dose (μSv) for a Discovery/QDR4500 Array mode hip scan calculated using the ICRP-60 tissue weighting factors

Scan length (cm)[a]	Tissue factor	Adult	15-year-old child		10-year-old child		5-year-old child	
		15	14.6	15	12.4	15	9.0	15
Organ[b]								
Ovaries	0.20	2.2[c]	2.8	2.9	4.6	6.8	5.4	11.3
Testes	0.20	3.6	4.9	5.0	10.4	11.3	15.2	18.9
LLI[d]	0.12	4.9	5.4	5.5	7.5	8.0	8.6	10.2
Bone marrow	0.12	0.4	0.5	0.5	0.6	0.6	0.5	0.5
Bladder	0.05	1.0	1.1	1.1	1.9	2.0	2.5	2.9
Bone surfaces	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Skin	0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Remainder	0.05	0.1	0.1	0.1	0.2	0.3	0.3	0.6
Effective dose (μSv)								
Female		8.6	10.0	10.2	14.9	17.8	17.3	25.7
Male		10.0	12.2	12.3	20.7	22.4	27.2	33.2
Gender average		9.3	11.1	11.3	17.8	20.1	22.2	29.4

[a] Default adult scan length for the hip is 15 cm. Shorter scan lengths for children to include the same anatomical region as an adult have been scaled down from the relative lengths of the legs in the Cristy phantoms.
[b] Organs with effective dose cobtributions below 0.1 μSv have been omitted.
[c] All dose figures are rounded to one decimal place.
[d] LLI—lower large intestine.

Table 5
Effective doses (μSv) from spine, hip and total body DXA examinations for different Discovery/QDR4500 scan modes

	Adult	15-year-old child		10-year-old child		5-year-old child	
Scan length	Default	Scaled	Default	Scaled	Default	Scaled	Default
Spine scan modes							
Array (ICRP-60)	13.3	14.8	16.9	21.3	33.4	27.3	48.3
Fast (ICRP-60)	6.7	7.4	8.5	10.6	16.7	13.7	24.1
Express (ICRP-60)	4.4	5.0	5.6	7.1	11.1	9.1	16.1
Express (ICRP2005)	4.4	4.9	5.5	6.9	10.2	8.8	14.4
Hip scan modes							
Array (ICRP-60)	9.3	11.1	11.3	17.8	20.1	22.2	29.4
Fast (ICRP-60)	4.7	5.5	5.6	8.9	10.0	11.1	14.7
Express (ICRP-60)	3.1	3.7	3.9	5.9	6.7	7.4	9.8
Express (ICRP2005)	2.4	2.7	2.8	4.1	4.5	4.9	6.1
Whole body scans							
Discovery-A	4.2	–	4.2	–	4.8	–	5.2
Discovery-W	8.4	–	8.4	–	9.6	–	10.5

Dose figures are the average for a male and female. Doses for the Express mode are shown for both the ICRP-60 and the new ICRP2005 tissue factors.

The results of the radiation dose calculations using the Cristy phantoms confirmed the expectation that child scans performed using adult scan modes lead to higher radiation doses to children. For a 5-year-old child, the effective dose for a spine or hip examination is double the adult dose if the shorter scan length is used and three times greater if the adult scan length is used (Table 5). The dose factor due to the reduced attenuation by overlying tissue can be estimated from the mean dose in the primary X-ray beam in the adult and child phantoms. For the adult phantom, the mean dose in the X-ray beam was 32% of the entrance dose, while for the 5-year-old child the figure was 40%. It follows that for a 5-year-old child, the effect of reduced attenuation by overlying tissue increases organ doses by an average factor of 1.25. It follows that the principal reason that children receive higher doses than adults is the relatively greater area of the child's body exposed to the X-ray beam. For total body scans, the whole body is exposed, and so the increased effective dose in children reflects only the effects of reduced attenuation by overlying tissue.

The results presented in Table 5 are the average of dose figures for males and females since this is clearly the intention of the ICRP publications [23]. Nevertheless, there are large differences between the ovary and testes doses, and therefore, separate figures for male and females are given in Tables 3 and 4 as well as average dose. The height and weight data for the Cristy phantoms (Table 1) give an indication of the size of child to which the dose results apply. The data for the adult phantom are an average of males and females, and therefore, a more realistic estimate of the effective dose to a typical woman having a DXA examination may be the results for the 15-year-old child since there is better correspondence with the average height and weight of adult female patients. The new ICRP2005 tissue factors [23] differ from the ICRP-60 factors [8] principally in the reduction of the gonad weighting factor from 0.20 to 0.05. Since gonad dose makes a significant contribution to the effective dose for spine scans in females and hip scans in both sexes, this explains the modest reduction in dose when the revised weighting factors are used (Table 5).

The measurements of entrance dose for the spine and hip scan modes showed a 10% lower figure for the newer Discovery compared with the older QDR4500 models. The transmission factors through a tissue equivalent phantom were almost identical on all four machines so the differences in entrance dose in Table 2 reflect similar differences in effective dose. The dose figures in Tables 3–5 were calculated from the TLD measurements made on the QDR4500-W system, and so the figures for the other models should be scaled in proportion to the entrance dose data in Table 2. The largest difference between the 4 systems was for the whole body scan mode on the A- and W-models. Due to different scan geometry, the Discovery-W and QDR4500-W make 7 passes over the patient's body compared with 3 for the Discovery-A and QDR4500-A, and effective dose is twice as large for whole body scans performed on the W-models.

The differences in effective dose between adult and pediatric DXA investigations do not fully account for the true differences in the radiation risk. The relative risk for different examinations in adults is believed to scale in proportion to effective dose with an absolute risk of fatal cancer of 5% Sv^{-1} [8]. However, due to the greater sensitivity of growing tissues and longer remaining life expectancy, the absolute risk at a given dose is two to three times higher in children [8]. Therefore, the real differences in radiation risk between children and adults are significantly larger than the differences in effective dose.

Two previous studies have examined the radiation dose to children having DXA scans. Njeh et al. [16] estimated effective dose for the pediatric scan modes on a Lunar DPX-L system using TLDs and anthropomorphic phantoms representing 5- and 10-year-old children. Effective doses for a pediatric spine scan were 0.28 and 0.20 μSv for the 5- and 10-year-old respectively compared with 0.21 μSv for an adult spine scan.

The lower adult doses for the DPX system compared with the Discovery are due to the lower entrance dose (10 μGy for the DPX vs. 100 μGy for the Discovery Express mode) [7] together with the greater attenuation in tissue due to the lower peak tube voltage (76 kV vs. 140 kV). In the Njeh study, child doses were found to be comparable to the adult dose because the pediatric scan mode used a lower tube current (0.3 mA vs. 0.75 mA for an adult scan). In the Lunar DPX system, the decreased entrance dose for pediatric scans due to the lower tube current offsets the increased effective dose due to smaller body size and results in approximately equal doses in children and adults.

In the other published study of pediatric DXA doses, Thomas et al. report measurements on a Hologic QDR4500 system [17]. Effective doses were estimated from depth dose measurements made in plexiglass slabs combined with information on organ depths based on the Cristy phantoms. Dose figures for an adult spine examination performed using the QDR4500 Fast mode were 2.2 μSv compared with 6.7 μSv in the present study, while the figures for a 5-year-old child were 3.3 and 13.7 μSv respectively. We note that Thomas et al. do not mention the scan lengths assumed for their dose calculations [17]. However, from the data presented in their paper, the fraction of organs included in the spine scan field are considerably smaller than we found using the Cristy phantoms, and we conjecture that they may have assumed too small a scan area and not fully allowed for the larger proportion of the child's body exposed compared with an adult.

This study has several important limitations. The dose distributions assumed for children were inferred from measurements in an adult Rando phantom rather than the pediatric phantoms used by Njeh et al. [16]. However, by allowing for the effects of backscatter on the body outline masks applied to the adult dose distribution, it was possible to calculate the dose distribution in children. Knowledge of the positions of organs in the scan field is essential to the calculation of organ doses, and the study relies on the accuracy of the anatomical data provided by the Cristy phantoms [20]. In the present study, the dose distribution was measured by placing all the TLDs in one central slice in the Rando phantom and making detailed measurements of the primary beam and scatter in that slice (Fig. 4). This contrasts with the usual method of distributing TLDs throughout the phantom two or three per organ. The approach of placing all the TLDs in one slice was adopted to increase the number of points in each organ used to calculate the mean dose and to improve the measurements of scatter dose in the plane outside the primary beam. Although all the TLD measurements were made in one plane, these data were supplemented by ionization chamber measurements of the dose profile in the cranio-caudal direction to allow estimates of the scatter dose outside the immediate scan field.

In summary, we have presented estimates of effective dose for adult and pediatric spine, hip and whole body DXA examinations on the Hologic Discovery system. Because the Discovery software does not include pediatric scan modes for spine and hip examinations, the dose for a 5-year-old child is double that for an adult if the operator is careful to use an appropriately adjusted scan length and three times larger if the adult scan length is used. Although doses from child DXA examinations are low, it is still important to keep them as small as possible. DXA operators using Discovery systems can do this by using the Express scan mode for spine and hip examinations, by taking care to limit the scan length and by avoiding mistakes that lead to scans having to be unnecessarily repeated.

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RadiologyInfo.org

The radiology information resource for patients

Patient Safety:

Radiation Dose in X-Ray and CT Exams

What are x-rays and what do they do?

X-rays are forms of radiant energy, like light or radio waves. Unlike light, x-rays can penetrate the body, which allows a radiologist to produce pictures of internal structures. The radiologist can view these on photographic film or on a TV or computer monitor.

X-ray examinations provide valuable information about your health and play an important role in helping your doctor make an accurate diagnosis. In some cases x-rays are used to assist with the placement of tubes or other devices in the body or with other therapeutic procedures.

Measuring radiation dosage

The scientific unit of measurement for radiation dose, commonly referred to as effective dose, is the millisievert (mSv). Other radiation dose measurement units include rad, rem, roentgen, sievert, and gray.

Because different tissues and organs have varying sensitivity to radiation exposure, the actual radiation risk to different parts of the body from an x-ray procedure varies. The term effective dose is used when referring to the radiation risk averaged over the entire body.

The effective dose accounts for the relative sensitivities of the different tissues exposed. More importantly, it allows for quantification of risk and comparison to more familiar sources of exposure that range from natural background radiation to radiographic medical procedures.

Naturally-occurring "background" radiation exposure

We are exposed to radiation from natural sources all the time. According to recent estimates, the average person in the U.S. receives an effective dose of about 3 mSv per year from naturally occurring radioactive materials and cosmic radiation from outer space. These natural "background" doses vary throughout the country.

People living in the plateaus of Colorado or New Mexico receive about 1.5 mSv more per year than those living near sea level. The added dose from cosmic rays during a coast-to-coast round trip flight in a commercial airplane is about 0.03 mSv. Altitude plays a big role, but the largest source of background radiation comes from radon gas in our homes

(about 2 mSv per year). Like other sources of background radiation, exposure to radon varies widely from one part of the country to another.

To explain it in simple terms, we can compare the radiation exposure from one chest x-ray as equivalent to the amount of radiation exposure one experiences from our natural surroundings in 10 days.

Following are comparisons of effective radiation dose with background radiation exposure for several radiological procedures described within this website:

For this procedure:	* Your approximate effective radiation dose is:	Comparable to natural background radiation for:	** Additional lifetime risk of fatal cancer from examination:
ABDOMINAL REGION:			
Computed Tomography (CT)-Abdomen and Pelvis	10 mSv	3 years	Low
Computed Tomography (CT)-Abdomen and Pelvis, repeated with and without contrast material	20 mSv	7 years	Moderate
Computed Tomography (CT)-Colonography	10 mSv	3 years	Low
Intravenous Pyelogram (IVP)	3 mSv	1 year	Low
Radiography (X-ray)-Lower GI Tract	8 mSv	3 years	Low
Radiography (X-ray)-Upper GI Tract	6 mSv	2 years	Low
BONE:			
Radiography (X-ray)-Spine	1.5 mSv	6 months	Very Low
Radiography (X-ray)-Extremity	0.001 mSv	3 hours	Negligible
CENTRAL NERVOUS SYSTEM:			
Computed Tomography (CT)-Head	2 mSv	8 months	Very Low
Computed Tomography (CT)-Head, repeated with and without contrast material	4 mSv	16 months	Low
Computed Tomography (CT)-Spine	6 mSv	2 years	Low
CHEST:			
Computed Tomography (CT)-Chest	7 mSv	2 years	Low
Computed Tomography (CT)-Chest Low Dose	1.5 mSv	6 months	Very Low
Radiography-Chest	0.1 mSv	10 days	Minimal
DENTAL:			
Intraoral X-ray	0.005 mSv	1 day	Negligible
HEART:			

Coronary Computed Tomography Angiography (CTA)	12 mSv	4 years	Low
Cardiac CT for Calcium Scoring	3 mSv	1 year	Low
MEN'S IMAGING:			
Bone Densitometry (DEXA)	0.001 mSv	3 hours	Negligible
NUCLEAR MEDICINE:			
Positron Emission Tomography - Computed Tomography (PET/CT)	25 mSv	8 years	Moderate
WOMEN'S IMAGING:			
Bone Densitometry (DEXA)	0.001 mSv	3 hours	Negligible
Mammography	0.4 mSv	7 weeks	Very Low

Note for pediatric patients: Pediatric patients vary in size. Doses given to pediatric patients will vary significantly from those given to adults.

* The effective doses are typical values for an average-sized adult. The actual dose can vary substantially, depending on a person's size as well as on differences in imaging practices.

**** Legend:**

Risk Level	Approximate additional risk of fatal cancer for an adult from examination:
Negligible:	less than 1 in 1,000,000
Minimal:	1 in 1,000,000 to 1 in 100,000
Very Low:	1 in 100,000 to 1 in 10,000
Low:	1 in 10,000 to 1 in 1000
Moderate:	1 in 1000 to 1 in 500
Note: These risk levels represent very small additions to the 1 in 5 chance we all have of dying from cancer.	

Please note that the above chart attempts to simplify a highly complex topic for patients' informational use. The effective dose listed above may be used to estimate cancer and cancer related deaths.

The International Commission on Radiological Protection (ICRP) Report 103 states: "The use of effective dose for assessing the exposure of patients has severe limitations that must be considered when quantifying medical exposure", and "The assessment and interpretation of effective dose from medical exposure of patients is very problematic when organs and tissues receive only partial exposure or a very heterogeneous exposure which is the case especially with x-ray diagnostics."

If you are interested in researching the use of effective dose further, following are a few resources:

- ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection

- Limit on whole-body exposure for a radiation worker for one year: 50,000 microsieverts
- One year's worth of exposure to natural radiation from soil, cosmic rays and other sources: 3,000 microsieverts
- One chest X-ray: 100 microsieverts
- One dental X-ray: 40-150 microsieverts
- One mammogram: 700 microsieverts
- CT scan (abdomen): 8,000 microsieverts
- Full-body airport X-ray scanner: 0.0148 microsieverts
- Airplane flight from New York to Los Angeles: 30-40 microsieverts
- Smoking a pack a day for one year: 80,000 microsieverts
- Average dose to people living within 10 miles of 1979 Three Mile Island accident: 80 microsieverts
- Average radiation dose to evacuees from areas highly contaminated by the Chernobyl disaster: 33,000 microsieverts (Of 600,000 of the most-affected people, cancer risk went up by a few percentage points -- perhaps eventually representing an extra 4,000 fatal cancers on top of the 100,000 fatal cancers otherwise expected.)

Sources: TSA (APL report); CDC; FDA; NRC; ANS; IAEA; Wright State University in Dayton, Ohio

- Mini C-arm fluoroscopy: 3000 microsieverts

  Mini C-arm assumptions: 90 second fluoroscopy on time, hand midway in field, shallow dose quoted, mrem converted to mSv by multiplying by 0.01
  Reference: Giordano, B *et al* J Bone Joint Surg Am. 2009 Feb;91(2):297-304