1996, *The British Journal of Radiology*, 69, 422–425

Patient doses in bone mineral densitometry

[1]W HUDA, PhD and [2]R L MORIN, PhD

[1]University of Florida, Department of Radiology, PO Box 100374, JHMHC, Gainesville, Florida 32610-0374, and [2]Diagnostic Radiology Department, Mayo Clinic Jacksonville, 4500 San Pablo Road, Jacksonville, Florida 32224, USA

Abstract

Procedures were developed to compute effective dose equivalent (H_E) values for patients undergoing bone mineral densitometry (BMD) measurements such as dual energy X-ray absorptiometry (DEXA) and quantitative computed tomography (QCT). Representative values of H_E were determined for patients undergoing each type of BMD procedure. Typical DEXA measurements are associated with an H_E of about 2.5 μSv. For QCT, the values of H_E are 300 μSv for single energy techniques and 1 mSv for dual energy techniques, respectively. By comparison, a single well collimated abdominal X-ray examination often taken in conjunction with DEXA studies results in an H_E of about 100 μSv. BMD patient doses are at the lower end of the exposure range encountered in diagnostic radiology. As a result, radiation dose is not a primary factor in choosing the method for BMD determination.

Diagnostic techniques employing ionizing radiation are utilized for performing bone mineral densitometry (BMD). Currently, the most popular of these techniques are single energy quantitative computed tomography (SEQCT) [1], dual energy quantitative computed tomography (DEQCT) [2, 3] and dual energy X-ray absorptiometry (DEXA) [4]. Comparisons among these diagnostic techniques have generally focused on their respective accuracy, precision and ability to differentiate adjacent structures [1].

Traditional parameters used to quantify radiation doses in BMD are the entrance skin exposure (ESE) in DEXA and the computed tomography dose index (CTDI) in QCT [5]. Values of ESE and CTDI, however, do not permit a direct comparison of the patient doses associated with DEXA and QCT examinations. These descriptors do not provide any quantitative estimate of the radiation risk to patients undergoing these examinations. Use of the effective dose equivalent (H_E) as the patient radiation dose descriptor overcomes these limitations [6, 7].

Computation of the effective dose equivalent normally requires an estimate of the radiation dose to all irradiated organs and tissues. Obtaining these organ doses by measurement or calculation is generally time-consuming and cumbersome [8–12]. In addition, measurements or calculations on one system may not be applicable for new BMD equipment, or when different technique factors are used on existing equipment. In this paper, a simple method is proposed to determine approximate values of H_E for any type of BMD examination. Representative H_E values to patients undergoing lumbar spine DEXA, SEQCT and DEQCT bone mineral density measurements were determined, as well as the conventional film radiographs that are often taken during BMD measurements.

Received 1 September 1995 and in revised form 8 January 1996, accepted 5 February 1996.

Methods and results

DEXA dosimetry

The effective dose equivalent, H_E, to patients undergoing DEXA BMD measurements is obtained using a two step procedure. The first step requires an estimate of the product of the entrance skin dose (mSv) and the X-ray beam cross-sectional area in cm^2 associated with the DEXA procedure. This value is known as the dose–area product and is expressed in mSv–cm^2. The second step uses a conversion factor to obtain the value of H_E from the dose–area product. This conversion factor is a function of X-ray beam quality as determined by X-ray tube potential and filtration. A representative value for commercially available BMD X-ray systems was taken to be 80 kVp with 2.5 mm Al filtration. Accordingly, anteroposterior (AP), posteroanterior (PA) and lateral conversion factors used in this study are 0.05 μSv/mSv–cm^2 and 0.04 μSv/mSv–cm^2, respectively [13].

The total irradiation area in a representative DEXA study is between 200 and 300 cm^2 and the corresponding entrance skin dose is between 50 and 300 μSv [14]. The range of H_E for DEXA measurements is thus 0.5–4.5 μSv. A representative value for typical DEXA BMD measurement may be taken to be the average of this range, or about 2.5 μSv.

QCT dosimetry

Patient radiation doses were estimated for a GE 9800Q CT scanner. CT scanners may be utilized in two different manners for QCT. In the first, the patient is moved through the circular aperture to generate a planar scan projection radiograph (SPR). In this mode, the

X-ray tube is stationary with an X-ray beam collimation slit of 1.5 mm. The X-ray tube voltage and current are generally 120 kVp and 40 mA, respectively. The resultant planar SPR images correspond to conventional radiographic images and may be AP or lateral views depending on the positioning of the X-ray tube.

For BMD measurements the total length of the scan is in the range 250–350 mm. H_E values of patient dose for lateral and AP SPRs are in the range 40–70 μSv [15]. To a good approximation, the patient dose will scale in a linear manner with the total energy imparted [13]. As a result, H_E will be directly proportional to both the scan length and selected tube current.

After the initial SPR (scout) view, three locations in the lumbar vertebrae (*e.g.* L1, L2 and L3) are selected for acquisition of tomographic images. Typical CT technique factors for SEQCT as used at our institutions are 10 mm thick CT slices, a tube voltage of 80 kVp, tube currents in the range 70–140 mA and scan times of 2 s. For DEQCT, a second series of the three lumbar spine CT images is generated with the voltage across the X-ray tube increased to 120 kVp.

A standard abdominal CT examination on a GE 9800Q scanner performed at 120 kVp, 400 mAs and consisting of 22 tomographic images results in an H_E of 10.8 mSv [15]. For a given body part, the effective dose equivalent in a CT examination may again be taken as directly proportional to the energy imparted. CT images of the abdomen obtained using N 10 mm slices and X mAs will thus result in H_E values given by

$$H_E = 10.8 \frac{N}{22} \frac{X}{400} \text{ mSv} \quad (1)$$

Reducing the applied X-ray tube voltage from 120 kVp to 80 kVp lowers the energy deposited in the patient by the ratio of mean CTDI values at these two kVps with the effective dose equivalent at 80 kVp ($H_E(80)$) given by

$$H_E(80) = \frac{\text{CTDI}(80)}{\text{CTDI}(120)} H_E(120) \quad (2)$$

where $H_E(120)$ is the effective dose equivalent at 120 kVp and CTDI(80) and CTDI(120) are the mean body computed tomography dose indices at 80 and 120 kVp, respectively. The ratio of CTDI(80) to CTDI(120) for a typical GE 9800 CT scanner is 0.3 [16] and is the amount by which H_E is reduced when the kVp is lowered from 120 kVp to 80 kVp with all other technique factors remaining constant.

CT technique factors described above are typical of BMD measurements for QCT studies. An SPR and three CT images associated with an 80 kVp SEQCT measurement correspond to H_E ranging from 0.2 to 0.36 mSv. An SPR and six CT slices associated with the 80 and 120 kVp DEQCT measurement correspond to H_E ranging from 0.7 to 1.4 mSv. Representative values for SEQCT and DEQCT may be taken to be the average of each range, and equal to approximately 0.3 mSv and 1 mSv, respectively.

Radiograph dosimetry

Patients undergoing BMD often have conventional radiographs taken for spine localization reasons or to check for compression fractures and the presence of calcium in the aorta anterior to the spine. It is of interest to determine patient H_E values associated with these AP and lateral radiographs. The method of computing H_E for these conventional radiographs is similar to that employed in DEXA examinations described above and requires a dose–area product with the corresponding conversion factor.

Patient doses in radiography are predominately influenced by the X-ray beam collimation and the sensitivity (speed) of the screen–film combination. For an AP projection, entrance skin dose values for current screen–film combinations may be taken to be between 2 and 4 mSv, with the collimated cross-sectional X-ray beam area at the patient entrance between 400 and 600 cm^2. For lateral projections, the entrance skin dose may be taken to be a factor of two higher [17] than the AP dose with an X-ray cross-sectional area range equal to that used in AP views.

AP and lateral lumbar X-ray examinations are generally performed at X-ray tube voltages close to 80 kVp. Conversion factors for these views are the same as for DEXA measurements given previously. The range of H_E values for a *collimated* AP view is 40–120 μSv, and for a *collimated* lateral view is 60–190 μSv. Representative values for *collimated* AP and lateral views are therefore 80 μSv and 130 μSv, respectively. For *uncollimated* X-ray views of the spine, the irradiated area increases by about a factor of two resulting in H_E values which are twice the collimated values.

Discussion

Table I summarizes representative values of patient dose, expressed in terms of H_E for each type of BMD examination. These doses are clearly dependent on the assumptions made for exposure techniques, but scaling these values to different technique factors and systems is easy to achieve using the method described in this paper. Our approach makes the assumption that the effective dose equivalent is directly proportional to the energy imparted to the patient. This simplification is partly justified by the very low doses associated with BMD. In addition, for most applications it is the relative patient

Table I. Represenatative approximate radiation dose (H_E) in BMD

Type of BMD measurement	H_E (μSv)	Comments
DEXA	~2.5	Representative value for single PA scan
SEQCT	~300	SPR + 3 CT slices @ 80 kVp
DEQCT	~1000	SPR + 3 CT slices @ 80 kVp + 3 CT slices @ 120 kVp
Radiographs	~100	Single (collimated) view (AP or lateral)

doses that are of primary interest rather than the absolute values. An approximate method with a consistent methodology will provide the relative changes in patient risk as technique factors are changed or when different equipment is used.

The results for DEXA obtained in this study are similar to the doses published by other workers [8–11]. Effective dose equivalents which neglect the gonad dose are of the order of 1 μSv whereas those which incorporate the gonad dose can be up to several times higher. Dose values for any specific BMD system could differ from this average by up to a factor of three, due to differences in radiographic techniques used. The one published study for QCT is consistent with the values shown in Table I once account is taken of differences in technique factors (*i.e.* number of CT sections and mAs) used to perform these types of examination [12].

All published studies agree on the low radiation doses associated with BMD studies. Differences in published patient doses relate to the assumptions made regarding technique factors and on the inclusion or exclusion of the female gonads in the dose computation. Our approach includes the irradiation of gonads, but the gonad dose was of less significance since much larger regions of the body were irradiated when computing the H_E per unit dose area product conversion factors [16]. Most women undergoing BMD examinations are postmenopausal and this factor would need to be taken into account when estimating any resultant radiation detriment.

It is of interest to compare doses to patients undergoing BMD measurements with H_E values associated with common radiological examinations which are summarised in Table II [6, 7, 16, 17]. Doses to patients undergoing DEXA measurements are very small in comparison with all other diagnostic procedures. SEQCT is comparable with the low dose procedures (chest and skull X-rays), whereas DEQCT is comparable with pelvis or abdominal screen–film examinations commonly performed in radiology departments. These doses are also very low in comparison with natural background which is about 2.4 mSv per year [7]. BMD doses are comparable to exposures associated with travel by aeroplane where the exposure rate from cosmic radiation is of the order of 5 μSv h^{-1} [18]. Most BMD doses are considerably lower than current recommendations for regulatory annual dose limits for radiation workers and members of the public which are 20 mSv and 1 mSv, respectively [19].

Table II. Representative values of radiation doses (H_E) in diagnostic radiology [6,7,16,17]

Radiographic procedure	Range of effective dose equivalent (μSv)
Chest (PA + lateral)	10–50
Skull	100–200
Thoracic spine	500–1100
Pelvis	700–1400
Abdomen	600–1700
Lumbar spine	1300–2700
Cholangiography	700–3800
Barium meal	1900–4800
Intravenous urogram	2500–5100
Barium enema	5100–8800
Head CT scan	2000–4000
Body CT scan	5000–15000
Nuclear medicine	2000–10000

Radiation risk estimates have been recently revised and a new parameter was introduced to replace the effective dose equivalent [19]. This new parameter, the effective dose (E), is conceptually very similar to H_E, except that a revised set of weighting factors are employed. *Relative* values of patient dose will be comparable regardless of whether the computed dose parameter is H_E or E. A recent study computed H_E and E values for both lumbar spine and hip BMD scans and found relatively minor differences between them [10]. Hence the conclusions drawn in this study may be taken to be valid regardless of whether patient doses are expressed using H_E or E.

The as low as reasonably achievable (ALARA) principle is also applicable to patient exposures in diagnostic radiology [20]. Patients should only undergo BMD measurements if this is likely to generate information that will benefit the patient. Given a benefit accruing from the information generated by the diagnostic procedure, all unnecessary patient exposure should be eliminated. For example, it is necessary to ensure that only the patient areas that are of clinical interest are exposed to the X-ray beam, using collimation to shield the remainder of the patient. Provided that these radiation protection guidelines are followed, radiation doses in BMD measurements should not be of concern to physicians or patients undergoing these procedures. Furthermore, the low radiation levels associated with BMD show that patient dose is not a significant factor in the choice of method for BMD determination.

References

1. CANN, C E, Quantitative CT for determination of bone mineral density: A review, *Radiology*, *166*, 509–522 (1988).
2. KALENDER, W A, PERMAN, W H, VETTER, J R and KLOTZ, E, Evaluation of a prototype dual-energy computed tomographic apparatus. I. Phantom studies, *Med. Phys.*, *13*, 334–339 (1986).
3. MONTNER, S M, LEHR, J L and ORAVEZ, W T, Quantitative evaluation of a dual energy CT system, *JCAT*, *11*, 144–150 (1987).
4. BORDERS, J, KERR, E, SARTORIS, D J ET AL, Quantitative dual-energy radiographic absorptiometry of the lumbar spine: *In vivo* comparison with dual-photon absorptiometry, *Radiology*, *170*, 129–131 (1989).
5. SHOPE, T B, GAGNE, R M and JOHNSON, G C, A method for describing the doses delivered by transmission X-ray computed tomography, *Med. Phys.*, *8*, 488–495 (1981).
6. NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS, *Exposure of the US Population from Diagnostic Medical Radiation (Report No. 100)* (NCRP, Bethesda, MD) (1989).

7. UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION (UNSCEAR), *Sources, Effects and Risks of Ionizing Radiation* (United Nations, New York) (1988).
8. PYE D W, HANNAN, W J and HESP, R, Effective dose equivalent in dual X-ray absorptiometry, *Br. J. Radiol.*, *63*, 149–151 (1990).
9. LASKEY, M A, FLAXMAN, M E, BARBER, R W ET AL, Comparative performance *in vitro* and *in vivo* of Lunar DPX and Hologic QDR-1000 dual energy X-ray absorptiometers, *Br. J. Radiol.*, *64*, 1023–1029 (1991).
10. RAWLINGS, D J, FAULKNER, K and CHAPPLE, C-L, The influence of scan time on patient dose and precision in bone mineral densitometry. In *Current Research in Osteoporosis and Bone Mineral Measurement II* (British Institute of Radiology, London), pp. 23–24 (1992).
11. LEWIS, M K, BLAKE, G M and FOGELMAN, I, Patient dose in dual X-ray absorptiometry, *Osteoporosis Int.*, *4*, 11–15 (1994).
12. KALENDER, W A, Effective dose values in bone mineral measurements by photon absorptiometry and computed tomography, *Osteoporosis Int.*, *2*, 82–87 (1992).
13. HUDA, W and BISSESSUR, K, Effective dose equivalents, H_E, in diagnostic radiology, *Med. Phys.*, *17*, 998–1003 (1990).
14. WAHNER, H W, DUNN, W L, BROWN, M L ET AL, Comparison of dual-energy X-ray absorptiometry and dual photon absorptiometry for bone mineral measurements of the lumbar spine, *Mayo Clin. Proc.*, *63*, 1075–1084 (1988).
15. SHRIMPTON, P C, JONES, D G, HILLIER, M C ET AL, *Survey of CT Practice in the UK. Part 2: Dosimetric Aspects (NRPB-R249)* (NRPB, Chilton) (1991).
16. HUDA, W, SANDISON, G A and LEE, T Y, Patient doses from computed tomography in Manitoba from 1977 to 1987, *Br. J. Radiol.*, *62*, 138–144 (1989).
17. SHRIMPTON, P C, WALL, B F, JONES, D G ET AL, *A National Survey of Doses to Patients Undergoing a Selection of Routine X-ray Examinations in English Hospitals (NRPB-R200)* (NRPB, Chilton) (1986).
18. BARISH, R J, Health Physics concerns in commercial aviation, *Health Phys.*, *59*, 199–204 (1990).
19. INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, *1990 Recommendations of the International Commission on Radiological Protection (Publication 60)*, *Ann. ICRP*, *21*, 1–3 (1991).
20. INTERNATIONAL COMMISSION OF RADIOLOGICAL PROTECTION, *Protection of the Patient in Diagnostic Radiology (Publication 34)*, *Ann. ICRP*, *9*, 2–3 (1982).