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ORIGINAL STUDY

Radiation Exposure from Computed Tomography of the Upper Limbs

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To investigate exposure to radiation we identified a cohort of 312 patients who underwent standardized CT of an upper limb within a three years period. The effective dose per dose length product coefficient was used to calculate the effective doses of radiation. Mean effective doses were as follows: shoulder CT, 10.83 (SD 6.36) mSv; wrist CT, 0.15 (SD 0.07) mSv; elbow CT performed with the arm above the head, 0.21 (SD 0.11) mSv and with the arm adjacent to the torso, 13.1 (SD 10.8) mSv. The corresponding lifetime attributable risk of cancer was 0.6/1000 for males and 0.73/1000 for females for shoulder CT and 0.75/1000 for males and 0.96/1000 for females for elbow CT with the arm adjacent to torso. The effective doses for CT scans of the wrist and of the elbow performed with the arm above the head were low. For elbow CT scans, elevating the arm above the head decreases the radiation doses.

Keywords : Computed tomography ; effective dose; elbow ; lifetime attributable risk ; upper limbs.

INTRODUCTION

The use of computed tomography (CT) has increased dramatically in the last decade *(2,21)*. CT has been found to provide excellent image resolution in the assessment of musculoskeletal conditions involving bone, aiding clinicians in both diagnosis and preoperative planning. However, a typical CT scan delivers a much higher dose of radiation than plain radiography *(16)*. Patient exposure to radiation has been extensively investigated in CT of the head and body, but data on limb studies are still sparse *(4,19)*.

When an individual is exposed to ionizing radiation, the biological damage to the tissue can be grouped as deterministic or stochastic effects. The deterministic effects are caused by direct radiation injury to the cells, for example skin erythema or cataract formation, and are uncommon in medical imaging *(8)*. The stochastic effects are associated to damage to the cell DNA and cancer induction.

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The lifetime attributable risk (LAR) of cancer after radiation exposure is defined as the additional risk to develop cancer, above the baseline cancer risk.

According to the BEIR VII study *(18)*, the data collected from the survivors of the atomic bomb and from persons exposed to radiation from medical, accidental and occupational reasons supports a direct, linear relationship between the dose of radiation and the risk of cancer. This study also provides a method to estimate LAR of cancer, which is based on the magnitude of the radiation exposure, the patient's sex, and the age at the time of the exposure.

As opposed to accidental exposure where individuals receive uniform, whole-body doses, when a patient undergoes a particular radiological examination, only the organs and the tissues located in the area of interest are exposed to radiation. At low doses of radiation, the total health detriment to the patient is given by the sum of detriments to the individual exposed organs *(10)*.

The biological damage to the organs is proportional to the absorbed radiation dose and depends on the type of radiation involved and the sensitivity to radiation of the exposed organs and tissues (8, 17). Radiation weighting factors ω_R take account of the relative biological effectiveness of the different types of radiation (x-rays, alpha, beta, gamma, etc.). Tissue weighting factors ω_T take account of the relative biological sensitivity to radiation of the different organs and tissues (gonads, mucosa, bone and skin).

The effective dose (ED) is defined as the dose of radiation which, if delivered uniformly to the whole body, would produce the same health consequences as those caused by a dose delivered to one or more specific organs.

The ED is computed by multiplying the absorbed dose D for each irradiated organ by the biologic weighting factor specific for the organ ω_T and by the radiation weighting factors ω_R and summing the products for all exposed organs and types of radiation (8, 17), and is given by:

$$ED = \sum \omega_T \omega_R D_{T,R}$$

The ED can be used for radiation protection purposes to estimate the stochastic risk of cancer following radiation exposure (9,22).

For plain radiography and fluoroscopy, the exposure is maximal where the beam enters the skin, and one can measure or estimate the entrance skin exposure as an indicator of the radiation risk. For CT scans, the exposure is continuous and around the patient and it is no longer clear where the maximal exposure occurs. In order to determine the effective dose of radiation from CT scans, researchers used human body phantoms, wherein geometric shapes mimic the shape and location of radiosensitive organs, and measured the radiation doses delivered to each organ. Dose descriptors were developed to assist in calculations. A fundamental dose descriptor is the CT dose index (CTDI) which represents the radiation dose delivered normalized by the CT beam width.

For helical scanners, an appropriate descriptor is the volumetric CTDI ($CTDI_{VOL}$) which represents the normalized radiation dose delivered to the volume of tissue exposed for one 360-degree rotation of the x-ray beam. By multiplying the $CTDI_{VOL}$ with the scan length, one can calculate the total (integrated) dose delivered per scan, termed, the dose length product (DLP), and assess the effective dose of radiation *(14)*.

To estimate the effective dose for standardized CT scans, Jessen *(11)* introduced the normalized effective dose per DLP (E_{DLP}) coefficient, using catalogues with previously calculated effective doses. ED calculations using the DLP multiplied by E_{DLP} coefficient method are broad estimates that do not take into consideration any patient-specific factors *(6)*, but are easy to use in routine clinical practice.

Numerous studies *(5,7,13,14)* provide E_{DLP} coefficients for CT scans of the head and torso. We couldn't find similar coefficients for CT scans of the upper limbs.

The purpose of this study was to investigate the extent of exposure to ionizing radiation derived from CT scans of the upper limbs, to suggest appropriate E_{DLP} conversion factors, and to estimate the associated lifetime attributable risk (LAR) of cancer as a result of this exposure. We are not aware

Table I. CT protocols used in our institution for imaging the shoulder, elbow and wrist

	Shoulder	Elbow/torso	Elbow/head	Wrist
Scout	AP+LAT	AP+LAT	AP+LAT	AP+LAT
Scanned area	Top shoulder down to inferior scapula	Elbow	Elbow	Wrist and forearm
kV	140	120	120	120
Pitch	0.516	0.531	0.531	0.531
Thickness (mm)	1.25x0.8	0.625x0.6	0.625x0.6	0.625x0.6
Image matrix (pixels)	512	512	512	512
Delay	No	No	No	No
Reconstr (mm)	STAND (2.5x2.5)	STAND (2.5x2.5)	STAND (2.5x2.5)	STAND (1.25x1.25)
Dose reduction	40%	40%	40%	40%
ASIR	40%	50%	50%	50%
MPR	Coronal and sagittal	Coronal and sagittal	Coronal and sagittal	Coronal and sagittal

CT, computerized tomography; AP, antero-posterior; LAT, lateral; kV, kilovolt; reconstr, reconstruction; STAND, standard; ASIR, adaptive statistical iterative reconstruction; MPR, multiplanar reconstruction

of a similar study addressing radiation exposure from computed tomography of the upper limbs.

MATERIALS AND METHODS

Institutional Review Board approval was obtained prior to the study. The radiology information system (RIS) of a tertiary medical center was searched for all adult patients who underwent standardized CT examinations of the upper limbs in the last 3 years. Patients less than 18 years old were excluded as were patient who underwent upper-limb CT scans as part of a generalized trauma series, CT scans combining more than one specific body region, or contrast studies. Findings were compared with 40 patients who underwent a CT scan of the pelvis and otherwise fulfilled the same inclusion criteria. The CT scanner used for this study was a GE LightSpeed® VCT (General Electric Co., Schenectady, NY), a modern multidetector device that automatically records radiation dose descriptors and provides a radiation dose structured report (RDSR). Clinical parameters including age and sex and diagnostic reference dose values, including $CTDI_{VOL}$ (mGy), DLP (mGy-cm), and X-ray tube voltage (kV), were collected from the CT image files and the RDSR's archived in our PACS system.

All scans were performed according to standard protocols for specific body areas. Shoulders are examined with the patient in the supine position and the arm adjacent to the torso. Elbows are examined with the patient in the supine position and the forearm elevated above the head unless the patient is unable to lift the arm because of shoulder stiffness, pain, or other reason, in which case, the arm is placed adjacent to the torso. Wrists are examined with the patient prone and the hands above the head ("Superman position"). For the present study, both the position of the patient and the placement of the limb were recorded. The CT protocols for imaging the shoulder, elbow, and wrist in our institution are shown in Table I.

To calculate the effective dose, we multiplied the average DLP for the specific area of interest by the E_{DLP} conversion factors provided by the European Guidelines on Quality Criteria for Computed Tomography *(5)*. In the absence of upper limb conversion factors, we used chest CT conversion factors for the shoulder scans, lower limb CT conversion factors for the wrist scans, and abdominal CT conversion factors for the elbow scans performed with the arm adjacent to the torso. To obtain the effective dose for the elbow scans performed with the forearm above the head, we

Table II. Adaption of conversion factors by The European Guidelines on
Quality Criteria for Computed Tomography, Appendix C and Appendix B* 5.

Region scanned	**E_{DLP} conversion factors (mSv/mGyXcm)**
Shoulder	0.014 (chest)
Elbow (adjacent to torso)	0.015 (abdomen)
Elbow (above head)	0.002 – passes through skull (head) 0.0008 (limb)* – above skull
Wrist	0.0008 (limb)*
Pelvis	0.015 (pelvis)

EDLP, effective dose per dose length product ; mSv, millisievert ; mGy, milligray

counted the number of CT slices for each scan (N) and the number of slices that included the skull in addition to the limb (N1). For the percentage of the scan that included both the limb and the skull, we used head CT conversion factors, and for the percentage of the scan that included only the limb, we used lower-limb conversion factors. The calculations are summarized by the following formula:

$$ED_{(ELBOW\,ABOVE\,HEAD)} = \frac{DLP}{N}\left(N1 \times E_{DLP(HEAD)} + (N - N1) \times E_{DLP(LIMB)}\right)$$

An example is shown in Figure 1. Table II summarizes the E_{DLP} conversion factors used in this study. The LAR was calculated by multiplying the average ED for the specific area of interest with the appropriate estimate based on the patient's sex and age at exposure, as provided by table 12D-1 of the BEIR VII study *(18)*.

RESULTS

A total of 312 patients met the inclusion criteria, 144 women and 168 men of mean age of 48.5 (SD 11.5) years. Table III summarizes the demographic characteristics of the patients and shows the mean dose of radiation delivered to and the respective calculated effective dose by body area (shoulder, elbow, wrist). Figure 2 presents the distribution of effective doses by body area scanned. Application of the Shapiro-Wilk normality test yielded a non-normal distribution of the effective dose data, as, shown in Table IV. Table V shows the estimated LAR of cancer both for the current study cohort and for a hypothetical 20-year-old patient, based on the effective doses summarized in Table III.

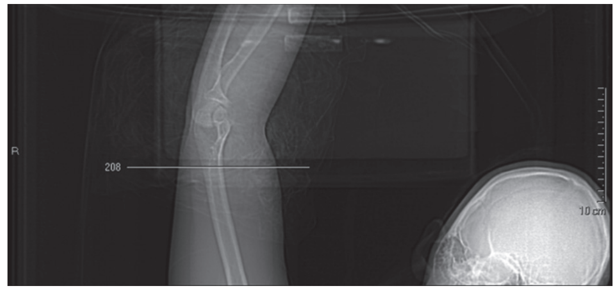

Figure 1. — Elbow CT scan performed with the arm above the head. In 63/271 slices, the beam passed through the skull in order to image the elbow. To calculate the effective dose, we used a head E_{DLP} of 0.002 mSv/mGyXcm for the portion of the scan that included the skull and the limb E_{DLP} of 0.0008 mSv/mGyXcm for the portion of the scan that included only the limb. The measured DLP was 146.09 mGyXcm. Applying the formula:

$$ED_{(ELBOW\,ABOVE\,HEAD)} = \frac{DLP}{N}\left(N1 \times E_{DLP(HEAD)} + (N - N1) \times E_{DLP(LIMB)}\right)$$

we obtained an effective dose of 0.158 mSv. EDLP, effective dose per dose length product; DLP, dose length product; ED, effective dose; mSv, millisievert; mGy, milligray; cm, centimeter.

DISCUSSION

Upper limb CT scans are generally considered to be responsible for a small percentage of the radiation delivered collectively by CT scans *(15)*. They account for 2.5% to 4% of the all CT scans performed *(1,15,20)*, which represents an impressive number of scans in the general population. Nevertheless, our search of the English language medical literature revealed only a few reports on the effective dose of radiation associated with shoulder CT scans *(3,4, 12)*, and only one report *(4)* on elbow and wrist scans. Compared to the study of Biswas *(4)* we found higher $CTDI_{VOL}$ values for shoulder CT scans, which may be explained by our use of a 140 kV tube voltage as opposed to 120 kV in the earlier work. Otherwise, our values were either similar to theirs (for the pelvis scans and elbow scans performed with the arm adjacent to the torso) or slightly lower (for the wrist scans and elbow scans performed with the arm above the head). By contrast, our DLP values were higher than reported

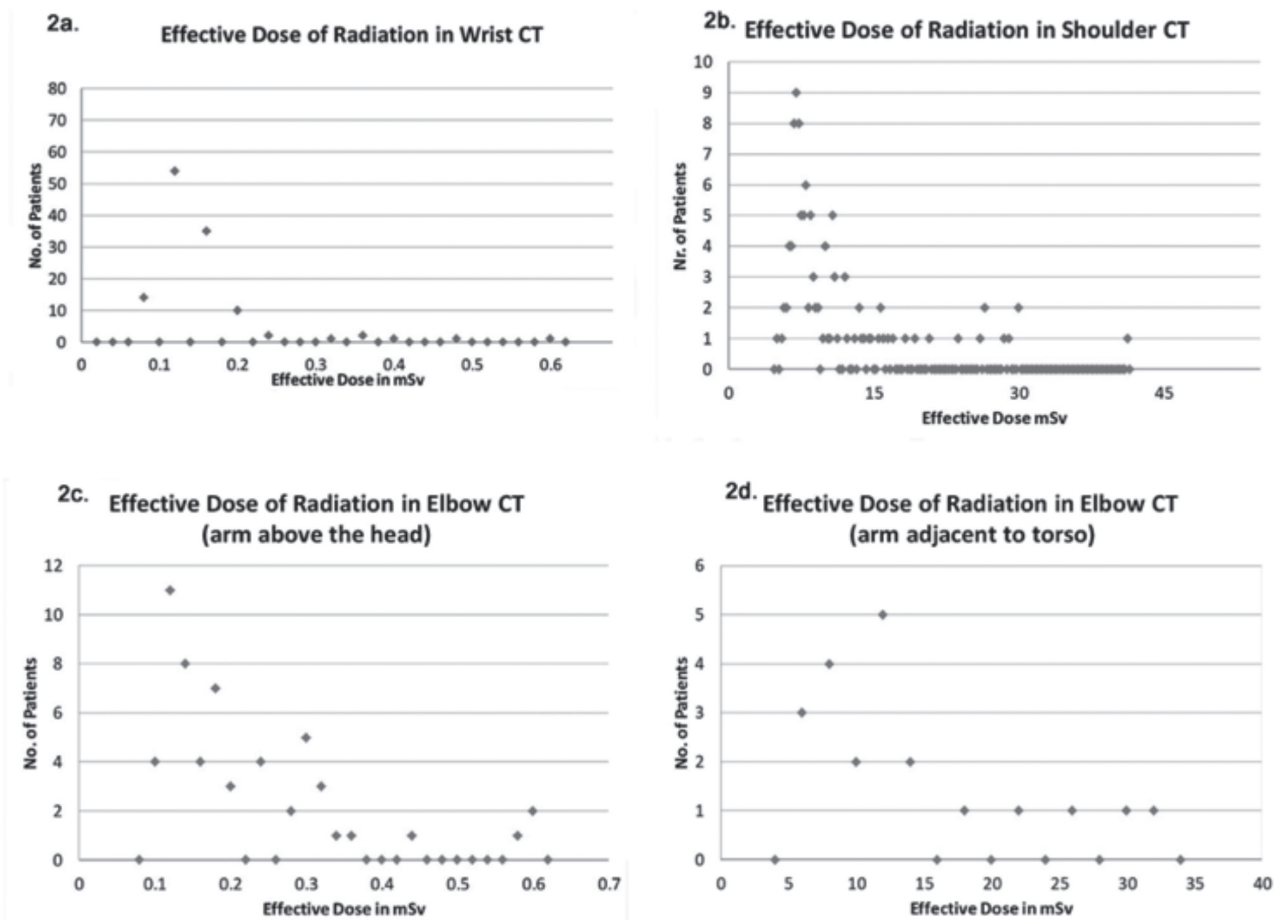

Figure 2. — Distribution of the absorbed effective doses for (2a) wrist, (2b) shoulder (2c) elbow with arm above the head, and (2d) elbow with arm adjacent to torso. The distribution is positively skewed for all imaged areas. mSv, millisievert

Table III. Patient demographics, $CTDI_{VOL}$, DLP, and calculated effective dose for each region scanned (n=312).

	No. scans	**Sex (M/F), n**	**Age (yr), mean**	**$CTDI_{VOL}$ (mGy), mean**	**DLP (mGyXcm), mean**	**ED (mSv), mean**
Shoulder	114	54/60	54.3 (SD 19)	31.8 (SD 17.9)	773.7 (SD 453.9)	10.83 (SD 6.36)
Elbow/head	53	31/22	44.5 (SD 18.8)	9.8 (SD 4)	209.8 (SD 77.6)	0.21 (SD 0.11)
Elbow/torso	20	7/13	49.3 (SD 21.2)	35.5 (SD 16.7)	869.7 (SD 517.5)	13.1 (SD 10.8)
Wrist	121	73/48	44.2 (SD 16.5)	9.9 (SD 14.1)	187.5 (SD 92)	0.15 (SD 0.07)
Pelvis	40	19/21	58.5 (SD 23.7)	22.9 (SD 11.1)	787.5 (SD 385.2)	11.81 (SD 5.78)

$CTDI_{VOL}$, computerized dose index by volume; DLP, dose length product; ED, effective dose; mGy, milligray; mSv, millisievert

Table IV. Distribution of effective dose data by the Shapiro-Wilk normality test*

	W statistic	**dF**	**P value**
Shoulder	0.708	114	0.000
Elbow above head	0.810	55	0.000
Elbow adjacent to torso	0.838	21	0.003
Wrist	0.660	122	0.000

*The null hypothesis that the distribution of the effective dose data is normal was rejected for all scanned areas.
ED, effective dose; dF, degrees of freedom

by Biswas *(4)* for all anatomic areas. This difference is probably attributable to the longer scans performed by the technologists in our department. For this study, we used region-specific conversion factors to calculate effective doses *(11)*. This method is fast and practical. It is not designed to account for such patient-specific factors as body size or habitus or for patient specific ED calculation *(6)*, nevertheless we considered it appropriate for our purpose, which was to broadly estimate the extent of exposure to ionizing radiation derived from CT scans of the upper limbs.

In the absence of published conversion factors for the upper limbs, we adapted the E_{DLP} conversion factors of the European Guidelines on Quality Criteria for Computed Tomography *(5)*. We used the conversion factors for chest, abdominal, and head CT to estimate the effective dose of, respectively, shoulder CT, elbow CT performed with the arm adjacent to the torso, and elbow CT performed with the arm above the head (for CT slices including the skull). Given the relative distance of the extremities from the radiation-sensitive organs, we considered the previously published conversion factor for the lower limbs appropriate for calculating the effective dose of wrist CT and elbow CT performed with the arm above the head (for the CT slices which did not include the skull). The average effective doses in the present study were higher than those reported by Biswas *(4)* for all regions of interest. This difference is partially explained by the higher DLP values in our study. Nevertheless, given that the effective doses for chest, abdomen, and pelvis CTs in the study of Biswas *(4)* were generally at the lower end of the reported spectrum *(16,22)*, we assume their results for shoulder, elbow, and wrist may be similarly low. Using a standard protocol Lalone *(12)* calculated an average effective dose of 10.4 mSv for shoulder scans, which is similar to our results, supporting the use of the chest E_{DLP} to calculate shoulder scan effective dose.

Figure 2 presents the distribution of effective doses for each region scanned in the study population. The distribution is positively skewed for all regions. Accordingly, we found that some patients received a much higher dose of radiation than the mean. For example, for wrist CT, the mean effective dose was 0.15 mSv, but 6 patients (5%) absorbed radiation doses of more than 0.3 mSv. Although the clinical implications for wrist scans may be minor, 9 patients with shoulder CT scans (7%) absorbed doses of more than 22 mSv (compared to the mean of 10.8 mSv), which may increase the LAR of cancer. Combining all scans performed with the arm adjacent to the torso yielded 9 of 134 patients (6.7%) who absorbed a radiation dose of more than 25 mSv.

The significantly lower (by 60-fold) dose of absorbed radiation when elbow scans were performed with the arm above the head rather than adjacent to the torso is particularly noteworthy. In this study 20 of 73 (27%) patients underwent the study with the arm adjacent to the torso. We believe that this number can be decreased and that effort should be made to assist the patient to elevate the arm. This may be difficult in cases of trauma, elbow fractures, and casting, but the short image acquisition times of the modern multidetector CT scanners may ease the task. For patients with limited shoulder range of motion an interesting solution could be positioning the patient on a chair with the elbow in the gantry. In our institution strict safety rules prevent such positioning nevertheless

Table V. Estimated LAR for the study cohort and for 20-year-old male and female patients using the average absorbed effective dose.

		LAR * study cohort			LAR* 20 year old	
	ED (mSv)	Age (yr), mean	Male	Female	Male	Female
Shoulder	10.83	54.3 (SD 19)	0.6	0.73	1.06	1.78
Elbow/head	0.21	44.5 (SD 18.8)	0.01	0.02	0.02	0.03
Elbow/torso	13.1	49.3 (SD 21.2)	0.77	0.96	1.27	2.15
Wrist	0.15	44.2 (SD 16.5)	0.01	0.01	0.01	0.02
Pelvis	11.81	58.5 (SD 23.7)	0.6	0.72	1.15	1.94

*Represents incidence of cancer cases directly attributable to the CT scan per 1000 patients. ED, effective dose; LAR, Lifetime Attributable Risk

the option can be further investigated in cooperation with the CT manufacturers. Meanwhile we strongly recommend that the orthopedic surgeon should be actively involved and specifically request CT scans of the elbow to be performed, when possible, with an elevated arm.

CT scans of the extremities are often not considered to be significant contributors to the amount of radiation delivered by medical procedures *(15,19)*. Our study shows that the contribution of CT scans of the shoulder and of the elbow when performed with the arm adjacent to the torso to the overall medical radiation dose may be an underestimated.

CT scans of the shoulder and elbow, in a young population, may lead to a small but certain increase in the LAR of developing cancer (Table V). Thus, we believe the advantages of CT scans should be carefully weighed against the risks on a case-by-case basis, taking into consideration the indication for the scan (for example a highly comminuted fracture versus a simple intra-articular fracture), patient age and sex, previous CT scans performed, and the availability of alternative imaging modalities such as magnetic resonance imaging.

This study is limited by its retrospective design and our use of data obtained from a single CT scanner in a single institution. Moreover, the methods of research were deliberately chosen to provide broad estimates. Nevertheless, the results are more than sufficient to raise awareness of the amount of radiation delivered by CT scans of the upper limbs. Additional studies using Monte Carlo simulations should be conducted to refine our results.

REFERENCES

1. **Berdahl C T, Vermeulen M J, Larson D B, Schull M J.** Emergency Department Computed Tomography Utilization in the United States and Canada. *Annals of emergency medicine* 2013 ; 62 : 8.
2. **Bhargavan M.** Trends in the utilization of medical procedures that use ionizing radiation. *Health physics* 2008 ; 95 : 15.
3. **Binkert C A, Verdun F R, Zanetti M, Pfirrmann C W, Hodler J.** CT arthrography of the glenohumeral joint: CT fluoroscopy versus conventional CT and fluoroscopy--comparison of image-guidance techniques. *Radiology* 2003 ; 229 : 153-8.
4. **Biswas D B J, Bohan M, Simpson AK, Whang PG, Grauer JN.** Radiation exposure from musculoskeletal computerized tomographic scans. *J Bone Joint Surg Am* 2009 ; 91 : 1882-9.
5. **Bongartz G, Golding S J, Jurik A G et al.** European Guidelines for Multislice Computed Tomography. Funded by the European Commission. Contract number FIGM-CT2000-20078-CT-TIP.
6. **Boone J M, Hendee W R, McNitt-Gray M F, Seltzer S E.** Radiation exposure from CT scans: how to close our knowledge gaps, monitor and safeguard exposure--proceedings and recommendations of the Radiation Dose Summit, sponsored by NIBIB, February 24-25, 2011. *Radiology* 2012 ; 265 : 544-54.
7. **Deak P D, Smal Y, Kalender W A.** Multisection CT protocols: sex- and age-specific conversion factors used to determine effective dose from dose-length product. *Radiology* 2010 ; 257 : 158-66.
8. **Gelieijns J, Tack D.** Medical Physics: Radiation Risks. *Grainger and Allison's diagnostic radiology*. 2014 ; 3-25.
9. **Harrison J D, Streffer C.** The ICRP protection quantities, equivalent and effective dose: their basis and application. *Radiation protection dosimetry* 2007 ; 127 : 12-8.

10. **Jacobi W.** The concept of the effective dose--a proposal for the combination of organ doses. *Radiation and environmental biophysics* 1975 ; 12 : 101-9.
11. **Jessen K A, Shrimpton P C, Geleijns J, Panzer W, Tosi G.** Dosimetry for optimisation of patient protection in computed tomography. Applied radiation and isotopes : including data, instrumentation and methods for use in agriculture, industry and medicine 1999 ; 50 : 165-72.
12. **Lalone E A, Fox A M, Kedgley A E, Jenkyn T R, King G J, Athwal G S, et al.** The effect of CT dose on glenohumeral joint congruency measurements using 3D reconstructed patient-specific bone models. *Physics in medicine and biology* 2011 ; 56 : 6615-24.
13. **McCollough C H, Christner J A, Kofler J M.** How effective is effective dose as a predictor of radiation risk? *AJR Am J Roentgenol* 2010 ; 194 : 890-6.
14. **McNitt-Gray M F.** AAPM/RSNA Physics Tutorial for Residents: Topics in CT. Radiation dose in CT. Radiographics. *Radiological Society of North America, Inc* 2002 ; 22 : 1541-53.
15. **Mettler F A, Jr., Bhargavan M, Faulkner K, Gilley D B, Gray J E, Ibbott G S, et al.** Radiologic and nuclear medicine studies in the United States and worldwide: frequency, radiation dose, and comparison with other radiation sources--1950-2007. Radiology 2009 ; 253 : 520-31.
16. **Mettler F A, Jr., Huda W, Yoshizumi T T, Mahesh M.** Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology* 2008 ; 248 : 254-63.
17. **Mettler F A, Upton A C**. Medical effects of ionizing radiation. 3rd ed. Saunders/Elsevier, Philadelphia, PA 2008.
18. **National-Research-Council**. Health risk from exposure to low levels of ionizing radiation:BEIR VII Phase 2. National Academies Press, Washington, D.C. 2006.
19. **Saltybaeva N, Jafari M E, Hupfer M, Kalender W A.** Estimates of Effective Dose for CT Scans of the Lower Extremities. *Radiology* 2014 : 132903.
20. **Scanff P, Donadieu J, Pirard P, Aubert B.** Population exposure to ionizing radiation from medical examinations in France. *The British journal of radiology* 2008 ; 81 : 204-13.
21. **Shannoun F, Zeeb H, Back C, Blettner M.** Medical exposure of the population from diagnostic use of ionizing radiation in luxembourg between 1994 and 2002. *Health physics* 2006 ; 91 : 154-62.
22. **Smith-Bindman R, Lipson J, Marcus R, Kim K P, Mahesh M, Gould R, et al.** Radiation dose associated with common computed tomography examinations and the associated lifetime attributable risk of cancer. *Archives of internal medicine* 2009 ; 169 : 2078-86.