# Assessment of effective dose in paediatric CT examinations

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## Introduction

Effective dose (Deff) was introduced by the International Commission on Radiological Protection (ICRP) and is a quantity related to the radiation stochastic risk of carcinogenesis and is considered a useful quantity for optimization of techniques and comparison between different radiological procedures (ICRP 1999, ICRP 2007) . The recommended organ/tissue weighting factors used for its calculation represent the radiosensitivity of each organ/tissue and relate to their individual contribution to the overall detriment (Wall 2004).

For CT scanning, the simple practical way of estimating Deff is achieved utilizing appropriately normalized Deff/ Dose Length Product (Deff/DLP) conversion coefficients. These conversion coefficients have been previously published (European Commission 1999, Shrimpton 2000, Shrimpton 2004, Chapple 2002). However, in this study, the effect of the newest tissue weighting factors published in ICRP Publication 103 on previously published size and region specific coefficients is investigated.

## Purpose

The current work aims to update and extend previously published values of Deff/DLP based on the ICRP Report 60 tissue weighting factors (Chapple 2002) given as a function of patient size, by re-analyzing the data for the new ICRP 103 Report. Specifically the aims are:

- to investigate the effect of the new tissue/organ weighting factors and added organs and tissues on the Deff for a standard protocol across a range of anatomical regions and sizes
- the derivation of updated Deff/DLP coefficients, as a function of patient size, for CT dosimetry and validation across modern scanners
- to estimate Deff on routinely performed clinical protocols for all ages for different ages using the derived Deff/DLP coefficients

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## Materials and Methods (1):

- Anthropomorphic phantoms with newly adapted positions added for new additional organs
  - neonatal phantom,
  - 1 year old
  - 5 year old
  - 10years old

- Organ doses & skin doses were measured using thermoluminescent dosimeters (TLDs) loaded inside and on the surface of the phantom

- CT scans: 4 non-overlapping pre-defined anatomical areas, comprising: the head, the chest, the abdomen & the pelvis.

- Standard Protocol used as previously: (same for all phantoms sizes -different scan length):
  - 120 kVp  1sec/rotation
  - 200 mAs
  - 10mm slice

  used axial scanning so as to exclude different degrees of 'overscanning' due to spiral mode (pitch=1)

- 10 scans for each region (accumulated dose for better accuracy)

- Scanner type: Siemens Somatom Sensation Open (new data for neonate), Somotom Plus 4 Scanner (old data), Siemens Emotion Duo (for 110 kVp protocol)

- Dose Length Product was calculated from the CTDIw and the exposure factors

- Estimation of Effective Dose: weighted sum of tissue equivalent doses

$$E=\sum_T W_T * H_T = \sum_T W_T \sum_R W_R D_{T,R}$$

where $W_T$ is: the new ICRP 103 tissue weighting factor for tissue T (contribution of organs to radiation detriment from stochastic effects) $\Sigma WT = 1$

# Materials and Methods (2):

➢ Organs receiving the highest dose for each anatomical area:

| Anatomical Region | Organ | $W_T$ |
|---|---|---|
| HEAD | **thyroid** | 0.04 |
| | **salivary glands** | 0.01 |
| | **brain** | 0.01 |
| CHEST | thymus | remainder 0.12 |
| | **breasts** | 0.12 |
| | **lungs** | 0.12 |
| | **Oesophagus** | 0.04 |
| | spleen | remainder 0.12 |
| ABDOMEN | **liver** | 0.04 |
| | adrenals | remainder 0.12 |
| | **Stomach** | 0.12 |
| | kidneys | remainder 0.12 |
| | gall bladder | remainder 0.12 |
| | pancreas | remainder 0.12 |
| | intestines | Remainder 0.12 |
| PELVIS | uterus | remainder 0.12 |
| | **urinary bladder** | **0.04** |
| | **Ovaries/testes** | **0.08** |
| | **colon** | **0.12** |

## Important Changes in tissue weighting factors

**Organ**

| ICRP 1991 Publication 60 | ICRP 2007 Publication 103 |
|---|---|
| Breast **0.05** → | ↑ Breast **0.12** |
| Gonads **0.20** → | ↓ Gonads **0.08** |
| Liver, Ur. bladder, Oesophagus, Thyroid **0.05** → | ↓ Liver, Ur bladder, Oesophagus, Thyroid **0.04** |
| Brain – included in remainder | Brain 0.01 |
| | Added organ: Salivary glands 0.01 |
| Remainder tissues 0.05 → | Remainder tissues 0.12 |

Plus in the remainder organs:
- extrathoracic tissue
- Heart
- Lymphatic nodes
- Oral mucosa
- Prostate
- Gall bladder

# Results (1)

## The effect of the ICRP 2007 tissue weighting factors on ED/DLP conversion coefficients

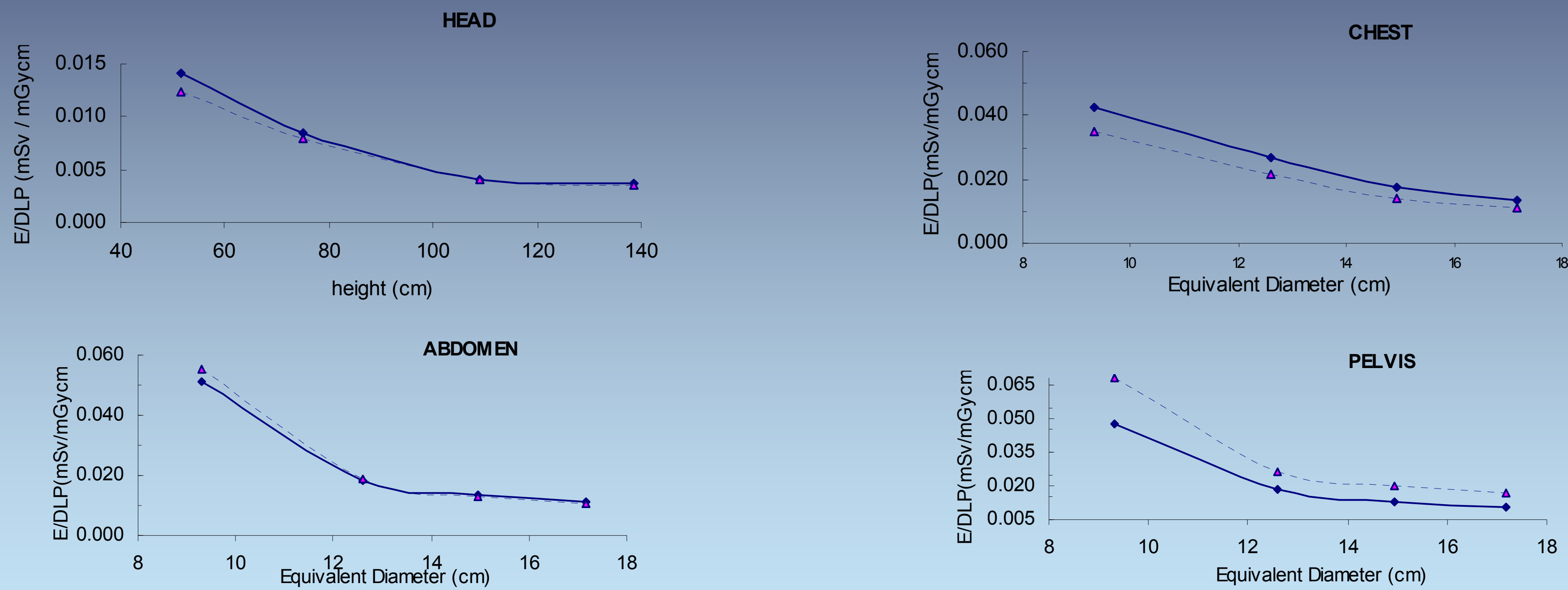


Figure 1. Variation of effective dose per dose length product with patient size for head, chest, abdomen and pelvis region.

- Dashed lines indicate Deff/DLP coefficients calculated utilizing the ICRP 1990 Report 60
- Solid lines indicate Deff values coefficients calculated utilizing the ICRP 2007 Report 103

# Results (2)

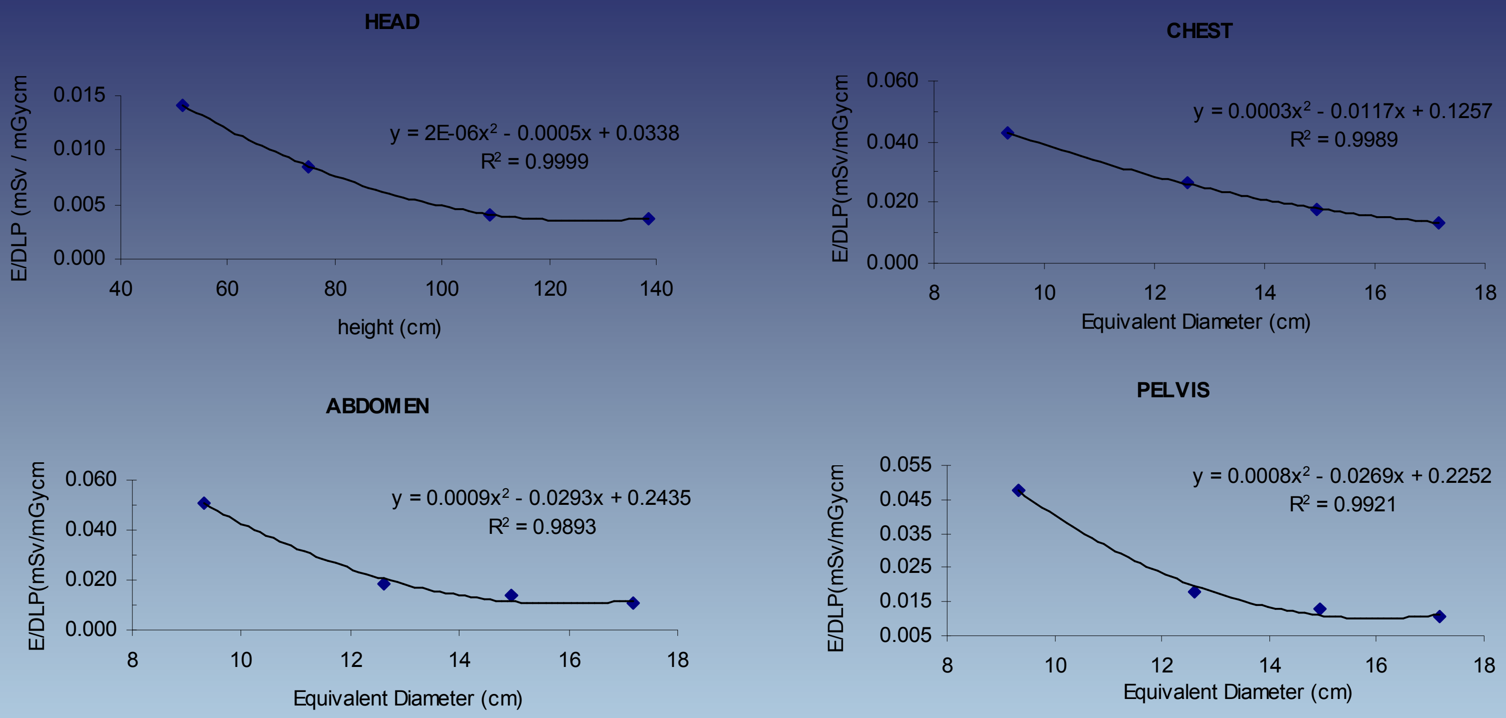


Figure 2. Size dependence of conversion coefficients and equations of fit for the curves for each anatomical region.

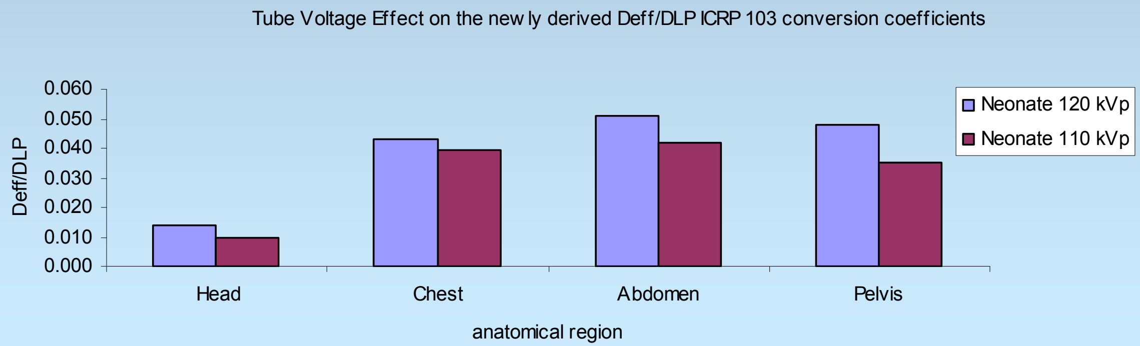


Figure 3.The effective dose per dose length product (ICRP 103) with regard to x-ray tube voltage for the neonatal phantom

# Discussion (1)

- For head examinations the effective doses have remained fairly similar across all ages. However, patients of smaller size where slightly more affected by the change in the set of tissue weighting factors . Since the new revised $W_T$ for breast is higher (from 0.05 to 0.12), this effect could be attributed to the closer proximity of the breast to the primary beam in neonates than larger patients.

  Also, the slight decrease of the $W_T$ for thyroid (0.05 to 0.04) combined with the new brain weighting factor of $W_T$=0.01 (which before used to be for 0.025- head CT scans only) has lowered the Deff. However the addition of salivary glands as an extra organ (WT=0.01) and mainly the new higher $W_T$ of the remainder organs compensate for this decrease bringing the Deff slightly higher than the initial Deff value.

- For scanning of the chest, an increase in Deff of about up to 25% is observed. This increase is primarily caused by the high doses received by the breast (which account for 90% of the increase), and possibly slightly due to increase in the $W_T$ of the remainder organs (thymus, heart, spleen lying within the primary beam). The decrease for the $W_T$ for the oesophagus is very small.

- In abdomen examinations, the doses have remained fairly similar, There have not been significant changes to weighting factors for doses in the abdomen. The organs receiving the highest doses are mainly remainder which contribute to an increase in the overall dose ($W_T$ from 0.05 to 0.12-accounts for 85% increase). Also, the gonads' $W_T$ decrease is balanced by the increase in the $W_T$ of breast. However, this is only partial (10%), as the former contributes more to the decrease of the Deff (70%), because of the position of the ovaries being closer to the beam.
  An additional decrease is attributed to the liver (-25%), which is within the primary beam and is now represented by a lower WT (from 0.05 to 0.04).

- During scanning of the pelvic region, the organs receiving the higher doses include the gonads, the urinary bladder, colon and the uterus. Thus, the lower $W_T$ that corresponds to gonads, and the slight decrease in the $W_T$ of the urinary bladder, have a strong effect on the Deff resulting in a decrease by up to 35% in the effective dose.

# Discussion (2)

- The derived conversion coefficients Deff/DLP show a decrease with increasing patient size, similar to that shown in the previous study.

- The effect of the new ICRP Report 103 weighting organ and tissue analogous to that on Deff.
Specifically:

➢ For chest scans, the derived Deff/DLP values seem to have increased by up to about 25% across all sizes.

➢ The result for the scans of the pelvic region is a decrease by up to 35%. This decrease is more pronounced in larger patients, possibly due to the fact that there is a larger distance from the start and end points of the scan to the breast than in patients of smaller size.

➢ For head and abdomen scans, the Deff/DLP values have remained fairly similar. Likewise, the slight increase noticed for neonates could be attributed to the closer proximity of the breast to the primary beam in neonates than larger patients.

- In this presentation, only initial results are described and on-going work is to be completed.

- A survey is initiated in order to collect paediatric data (technique factors, size, age etc) for application of the derived coefficients.

- In this study mainly protocols with 120 kVp are studied. A decrease in Deff/DLP was observed with decreasing X-ray tube voltage, but that was only tested for the neonatal phantom (and different batch of TLDs was used for pelvis). For example, in Chest CT scans a 9% decrease was observed for a change from 120kVp to 110 kVp, Huda et al. report about 4% decrease in Deff/DLP for every 10kVp step decrease for body scans (Huda 2008).

- It is essential that the effect of tube voltage is also investigated and incorporated in the derived set coefficients, since in many paediatric clinical CT procedures a tube voltage of 80 kVp or 100 kVp is applied.

## Conclusion

- The new set of tissue/organ weighting factors published in ICRP Report 103 has an impact on the effective dose mainly for chest and pelvis CT examinations, and yields similar differences in the derived Deff /DLP coefficients for paediatric patients undergoing CT examinations.
- The changes range from a decrease of approximately 35% for scans of the pelvis to an increase of about 25 % for chest CT examinations.
- The equations of fit presented enable the calculation of effective dose for a patient of any size. However, the effect of X-ray tube voltage should be further examined.
- The presented results are only preliminary and further work is necessary for the complete final set of conversion coefficients and validation on other scanners.

## References


- International Commission on Radiological Protection ICRP 2007 Recommendations of the International Commission on Radiological Protection, ICRP Publication 103, Pergamon, Oxford, 2007.
- International Commission on Radiological Protection ICRP 1991 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Pergamon, Oxford, 1991.
- Chapple C-L, Willis S and Frame J. Effective dose in paediatric computed tomography. Phys Med Biol 2002; 47:107-115.
- Wall BF. Radiation protection dosimetry for diagnostic radiology patients. Radiat Prot Dosimetry 2004; 109 (4);409-419
- Shrimpton PC and Wall BF. Reference doses for paediatric computed tomography. Radiat Prot Dosimetry 2000; 90(1-2);249-252
- Shrimpton PC. Assessment of patient dose in CT. NRPB- PE /1/2004, Chilton, 2004.
- Huda W, Ogden KM and Khorasani MR. Converting dose –length product to effective dose at CT. Radiology 2008; 248 (3): 995-1003