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Determination of the conversion factor for the estimation of effective dose in lungs, urography and cardiac procedures

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"In the beginning was the word" (John 1:1).

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Contents

Abstract

Patient dose in diagnostic radiology is usually expressed in terms of organ dose and effective dose. The latter is used as a measure of the stochastic risk. Determinations of these doses are obtained by measurements (Thermoluminescent dosemeters) or by calculations (Monte Carlo simulation).

Conversion factors for the calculation of effective dose from dose-area product (DAP) values are commonly used to determine radiation dose in conventional x-ray imaging to realize radiation risks for different investigations, and for different ages. The exposure can easily be estimated by converting the DAP into an effective dose.

The aim of this study is to determine the conversion factor in procedures by computing the ratio between effective dose and DAP for fluoroscopic cardiac procedures in adults and for conventional lung and urography examinations in children.

Thermoluminescent dosemeters (TLD) were placed in an anthropomorphic phantom (Alderson Rando phantom) and child phantom (one year old) in order to measure the organ dose and compute the effective dose. A DAP meter was used to measure dose-area product.

MC calculations of radiation transport in mathematical anthropomorphic phantoms were used to obtain the effective dose for the same conditions with DAP as input data.

The deviation between the measured and calculated data was less than 10 %. The conversion factor for cardiac procedures varies between 0.19 $mSvGy^{-1}$ cm^{-2} and 0.18 $mSvGy^{-1}$ cm^{-2}, for TLD respective MC. For paediatric simulation of a one year old phantom the average conversion factor for urography was 1.34 $mSvGy^{-1}$ cm^{-2} and 1,48 $mSvGy^{-1}cm^{-2}$ for TLD respective MC. This conversion factor will decrease to 1.07 $mSvGy^{-1}$ cm^{-2} using the TLD method, if the new ICRP (ICRP Publication 103) weighting factors were used to calculate the effective dose.

For lung investigations, the conversion factor for children was 1.75 $mSvGy^{-1}$ cm^{-2} using TLD, while this value was 1.62 $mSvGy^{-1}$ cm^{-2} using MC simulation. The conversion value increased to 2.02 $mSvGy^{-1}$ cm^{-2} using ICRP's new recommendation for tissue weighting factors and child phantom.

1. Introduction

1.1. Background

The first radiation induced cancer in a human was reported in 1902 (Little, 2000) when skin cancer was observed on the hand of a radiologist working with x-rays. In a few years, a large number of such skin cancers had been observed, and the first report of leukemia occurring in five radiation workers appeared in 1911(Kim, 2003). Consequently the interest in radiation risk was increased. The effects of the atomic bomb in Japan are the most important source of information on human whole-body irradiation. For risk estimates the variation of age, sex and quantity of people gave a much better possibility to estimate the effects of the dose received.

The number of x-ray facilities in medicine increased rapidly with time. The number of examinations per thousand in Sweden is (568), Iceland (689), Norway (708), and Finland (704) (UNSCEAR, 2000) and it is well-known that diagnostic x-rays are the largest artificial source of radiation exposure to the general population as shown in Table 1. Recent estimates by NRPB have put the contribution from patients undergoing x-ray examination to nearly 90 % of the total effective dose from all artificial sources in the UK (Hart et al, 2002).

Table 1. Worldwide average annual effective doses at year 2000 from natural and man-made sources of radiation (UNSCEAR, 2000).

Source of radiation		Dose (mSv)	
Natural background	Inhalation (mainly radon)	1.2	2.4
	Terrestrial gamma rays	0.5	
	Cosmic rays	0.4	
	Ingestion	0.3	
Diagnostic medical examination		**0.4**	
Atmospheric nuclear testing		0.005	
Chernobyl accident		0.002	
Nuclear power production		0.002	

With this increase in quantity of x-ray examinations, a growing quantity of cancer cases can be expected, despite the fact that transformation from analogue to digital system can give lower doses (Sjöholm & Persliden, 2003)

In paediatrics this increase of x-ray examinations is more risky, since diagnostic radiology examinations in children cause higher risks when compared to the ones carried out on adults. Young individuals have a longer life expectancy and their developing tissues are more radiosensitive. The risk factor for children for development of cancer is four to five times that of adults 40-50 years of age (ICRP 60, 1990).

Interventional radiological procedures aim to diagnose or treat diseases without surgery like cardiac arrhythmia. In recent years there has been an increase in the number and complexity of these procedures. As a consequence, the x-ray doses to patients may be high and both stochastic and deterministic effects have to be considered. The dose of ionizing radiation received by patients during cardiac catheter ablation can be amongst the largest from medical application except those from radiation oncology, and longer fluoroscopy time in some cases lead to higher radiation doses, always limited to a small area of the patient's skin surface. This in turn can induce deterministic effects, such as skin erythema as shown in Fig 1. The risk for such effects can be estimated by measuring the entrance surface dose for example.

The stochastic risks of carcinogenesis effects can be estimated through the effective dose, which is central in the radiation protection process to realize radiation risks for different investigations. The effective dose can be obtained by using an anthropomorphic phantom loaded with TL dosimeters located at anatomical positions corresponding to radiosensitive organs, or by using the MC method to simulate the interaction of x-rays in an anthropomorphic mathematical phantom.

Dose-area product (DAP) is an easily available measurement, but information about the radiological risks can not be deduced directly from this value, since the patient age and size, beam position and effect of scattered radiation are not taken into consideration. The effective dose which is a weighted sum of equivalent doses in selected organs is measurable in phantoms, but difficult in the human body. Consequently, the effective dose can be measured by combining relatively simple measurements of DAP, and calculated dose conversion factors.

The risk related with exposure to x-ray is dependent on the characteristics of the exposed individual. The size, age and sex of the individual influence the absorbed dose distribution in the organs. Nevertheless, little dosimetry data and conversion factors exist for paediatric examinations due to great size variation despite the close relationship between risk and age.

1.2. Effects of radiation

Ionizing radiation is known to cause damage. High radiation doses tend to kill cells, while low doses tend to damage or alter the genetic code (DNA) of irradiated cells. The biological effects of ionizing radiation are divided into two categories: *deterministic* and *stochastic* effects.

1.2.1. Deterministic effects

Health effects whose severity depends on radiation dose (usually with a threshold) and dose rate are called deterministic effects. Some interventional procedures with long fluoroscopy time and multiple image acquisition (e.g. percutaneous coronary intervention, radio-frequency ablation, etc) may give rise to deterministic effects in both staff and patients as shown in Fig 1 and 2. The deterministic effects include nausea, hair loss, damage to the blood and bone marrow, damage to the intestines, and damage to the central nervous system. Table 2 shows the potential effects of radiation.

Table 2. Potential effects of fluoroscopic exposures on reaction of skin and lens of the eye with data from ICRP population 85 (Cardella, 2000).

Injury	Threshold Dose to Skin (Sv)	Minutes fluoro at 0.02 Gy/min	Minutes fluoro at 0.2 Gy/min
Transient erythema	2	100	10
Permanent epilation	7	350	35
Dry desquamation	14	700	70
Dermal necrosis	18	900	90
Telangiectasia	10	500	50
Lens/Cataract	>5	>250 to eye	>25 to eye

1.2.2. Stochastic effects

Effects whose frequency is an increasing function of dose, usually without threshold, are called *stochastic effects*. Such effects are seen at some time after irradiation, possibly decades later. Stochastic effects include cancer and leukaemia. Table 3 shows the annual risk of death compared with cancer from radiation exposure.

Table 3. Risk of death per year from common causes (Reek, 2004)

Causes	Risk of death per year
Smoking 10 cigarettes/day	1 in 200
Natural causes (40 year old)	1 in 850
Accidents on road	1 in 9500
Accidents at work	1 in 43.500
Cancer from radiation exposure of 1 mSv	1 in 25.000*

* ICRP 60

1.3. Aim of the work

The aims of the present study are:

1. To determine data necessary for the computation of conversion factors in all the projections which are used in the examinations 1-3 below.
2. To calculate conversion factors for the investigations with MC simulation, and TLD.
3. To compare MC simulations and TLD measurements with other measurements.

The reasons behind the choice of these investigations:

1. Interventional cardiology procedures (adults) are known to give high radiation doses to patients as shown in Figure 1 due to long-lasting use of fluoroscopy, multiple projections, and complexity of procedures.

2. Urography in children since it gives a high effective dose, because the large fraction of the body with high weighting factor such as gonads (this value decreased from 0,20 to 0.08 in ICRP's new recommendations (ICRP Publ. 103, 2007) are irradiated by the x-ray beam.

3. Lung radiography in children is the most frequently performed radiological procedure in children.

Figure 1. Deterministic effects in cardiac procedure. Figure shown with permission from the publisher. (Shope, 1996).

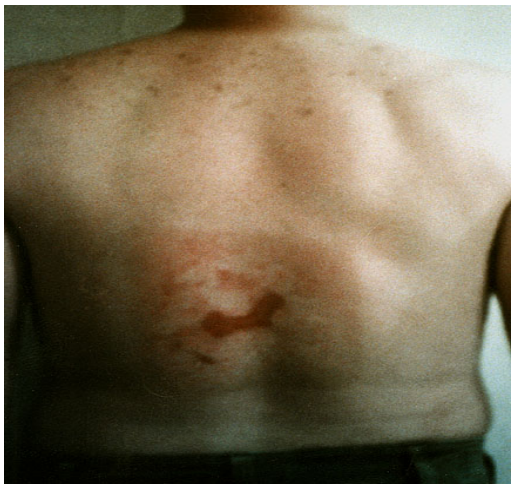


Figure 1(a). Condition of patient's back six to eight weeks following multiple coronary angiography and angioplasty procedures.

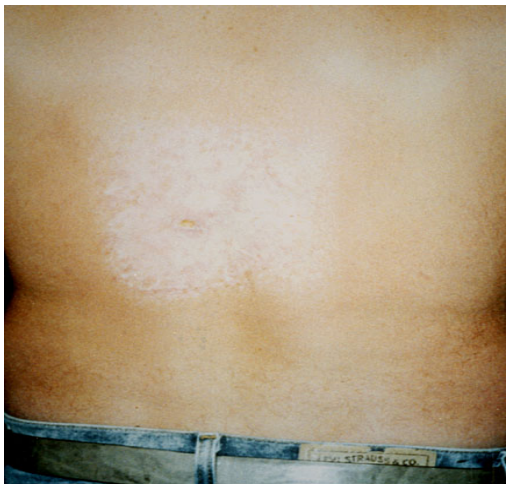


Figure 1(b). Appearance of skin injury approximately 16 to 21 weeks following the procedures with small ulcerated area present.

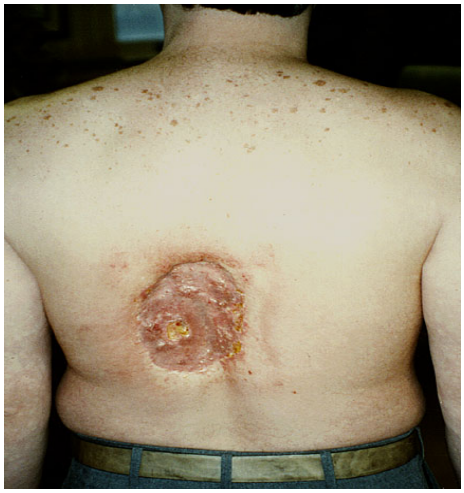


Figure 1(c). Appearance of skin injury approximately 18 to 21 months following procedures.

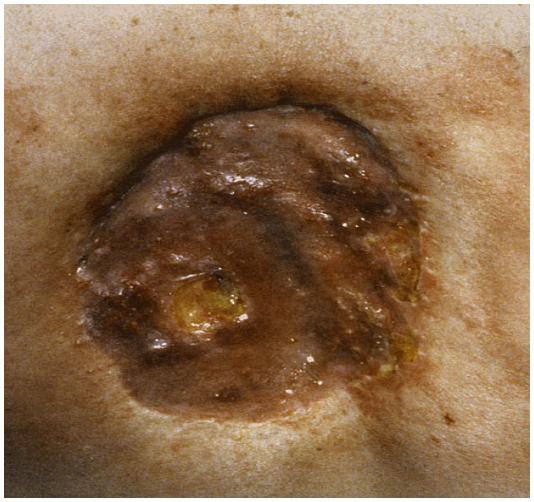


Figure1 (d). Close-up view of lesion shown in 2(c).

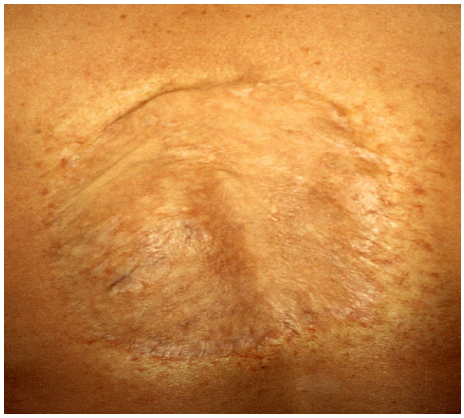


Figure1 (e) Appearance of patient's back following skin grafting procedure

2. Material and methods

2.1. Phantom

The phantom is used to absorb and/or scatter radiation equivalently to a patient, and hence to estimate radiation doses and test imaging systems without actually exposing a patient. It may be an anthropomorphic or a physical test object. In this study two anthropomorphic phantoms are used to simulate the irradiation conditions for adult and paediatrics where sizes were close to the average sizes of a one year old child and a full-grown patient (male).

2.1.1. Alderson Rando Phantom

The Alderson Rando Phantom (ARP) is replaced to match a standard male as defined by ICRP (ICRP, 1975) of weight of 73.5 kg and height of 173 cm. The phantom contains bone equivalent in form of human skeleton surrounded by soft tissue equivalent material of 0.985 gcm^{-2} density and 7.3 effective atomic number. The phantom is composed of 35 transverse slices of 2.5 cm thickness each. Every slice has a group of holes filled with pins of tissue equivalent material which can be removed to put dosimeters in the holes. The ARP was developed for measurements in radiotherapy with higher photon energies. The attenuation property in the diagnostic energy range differs somewhat from human tissue. This difference is considered to result in less than 1 % in the calculation of the effective dose (Shrimpton, 1981)

2.1.2. Child phantom

The child phantom (CIRS Atom Dosimetric Phantom,Virginia,USA) as shown in Figure 2 is manufactured to have the same absorption as human tissue. In this study a one year old phantom has been used and consists of 30 transversal slabs each 2.5 cm thick where TLDs can be placed in 19 different organs. The phantom has 9 kg weight and 70 cm in length. Density and effective atomic numbers for the different tissues are shown in Table 4.

Tabell 4: The density and atomic composition by weight-per cent of the three tissues in the phantom.

	Density(g/cm3)		H		C		N		O		P		Ca	
	Jan[1]	PC[2]	Jan	PC	Jan	PC	Jan	PC	Jan	PC	Jan	PC	Jan	PC
Skeleton	1.40	1.49	5.4	7.04	51.2	22.79	3.9	3.87	21.0	48.56	5.0	7.68	10.7	10.06
L. tissue	0.45	0.296	9.9	10.21	71.6	10.01	2.6	2.80	11.8	75.96	1.1	0.78	0.2	0.24
S. tissue	1.05	0.99	10.2	10.47	77.3	23.02	3.5	2.34	4.0	63.21	2.3	0.39	2.2	0.58

1. Child phantom (Söderberg & Persliden, 1996)
2. PCXMC (Tapiovaara et al, 1999).

2.2. Monte Carlo simulation

The estimation of the effective dose in the ARP is a difficult process, but in PCXMC (PC program for x-ray Monte Carlo) it is easy to compute effective dose or organ doses from easily measurable quantities. PCXMC, developed at the Medical Radiation Laboratory of the Finnish Radiation and Nuclear Safety Authority, is a special purpose code for calculating patient dose in diagnostic radiology from either measured DAP($Gy \cdot cm^2$) or entrance surface dose (Gy) (Tapiovaara et al, 1999). The program is based on stochastic mathematical

simulation of the interactions between photons and matter, where photons are emitted from a point source into the solid angle specified by the field size and focal distance.

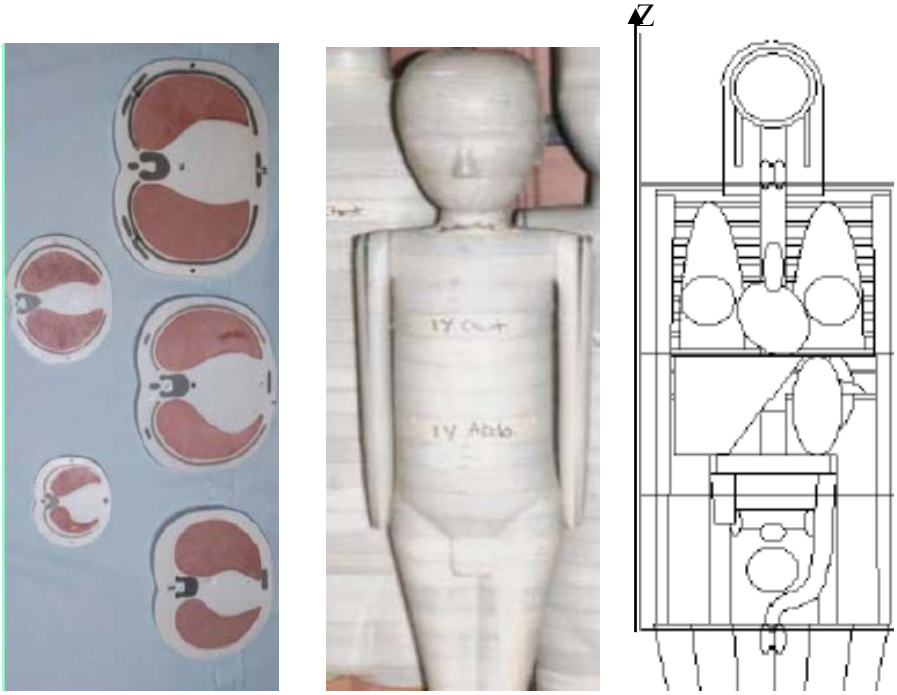


Figure 2. One year old phantom which is used in urography and lung investigations (Willis et al, 2005)

The interaction probability depends on the photon energy and the interacting material. By simulation of a limited number of photon histories, e.g. 50.000 photons in an x-ray field, a mean value of the absorbed energy in a specific organ and the effective dose can be calculated. The limited amount of simulated photons can cause some variation in the effective dose.

The accuracy of both the dose estimate and its error depends on the number of simulated interactions in the organ. The error expresses only the statistical error related to the finite amount of simulated photons. The program calculates the Monte Carlo data in ten different batches. The statistical error of the results is estimated as the standard deviation in those results. Some examples are shown in Table 5.

Table 5. Error (%) in calculation of organ dose using PCXMC

	Lungs	Uterus	Breast	Testes
Cardiac procedure	0.7	67.1	3.1	NA*
Lungs examination	0.5**	60.1	1.7	90***
Urography	3.6	9.8	54.1	11

* NA (not applicable) is used when the precision estimate could not be done because the dose is nil or very close to it.
** The statistical error is low because the dose in the organ is high and the organ is large.
*** When the number of interactions is small (the testes is small and dose is low), which is indicated by a high value of the statistical error, the estimate has a skewed non-normal distribution and the actual statistical errors may be higher than expected on the basis of the standard deviation (STUK, 2002)

x-ray spectra are calculated according to the theory of Birch and Marshall (Birch & Marshall, 1979) and are specified in terms of the x- ray tube (kV), filtration, and the angle of the tungsten target of the x-ray tube. The DAP is used as input data for effective dose calculation in this study.

Unlike ARP, which has a fixed size, several phantom models are available for representing a human body in MC calculations. The basic phantom is selected from six mathematical hermaphrodite phantoms (adult, 15, 10, 5 or 1-year old, newborn) by Cristy (Cristy,1980) but PCXMC has done some changes, e.g. the arms of the phantoms can be removed, and the breast material is taken to be a 50:50 mixture of fat and water. The principal body dimensions of these phantoms are given in Table 6.

Table 6. Principal dimensions of the mathematical phantoms. In the calculation, the user can specify whether the arms of the phantom are included at the sides of the trunk or whether they are removed (which may simulate the real situation better, e.g. for lateral projections). Trunk width is given for both of these conditions (Tapiovaara et al, 1999).

	Weight	Total height (cm)	Trunk height (cm)	Trunk thickness (cm)	Trunk width* (cm)	Trunk width** (cm)	Leg length (cm)
Newborn	3.51	51.5	21.6	9.8	10.9	12.7	16.8
1 year old	9.36	75.0	30.7	13.0	15.1	17.6	26.5
5 year old	19.1	109.0	40.8	15.0	19.6	22.9	48.0
10 year old	32.1	138.6	50.8	16.8	23.8	27.8	66.0
15 year old	54.5	164.0	63.1	19.6	29.7	34.5	78.0
Adult	71.1	174.0	70.0	20.0	34.4	40.0	80.0

* excluding arms
** including arms

2.3. Thermoluminescense Dosimetry

The TLDs used in this study are TLD-100 (in the form of chips about 3mm^2 square and 0.9 mm thick) manufactured by the Harshaw Chemical Company. This phosphor contains lithium in its natural isotopic ratio (92.5% ^{7}Li and 7.5% ^{6}Li by weight), approximately 100-200 parts per million magnesium and about 15 parts per million titanium by weight. To keep the dosimeters clean from dirt and touch by hand, which will reduce the TL sensitivity, the dosimeters were washed in methanol with a compound of 12 mmole HCl/l before every irradiation. Since LiF has an effective atomic number (Z_{eff}) of 8.2 (muscle Z_{eff} =7.4, air Z_{eff} =7.6) the TL response as a function of absorbed dose in the phantom is only slightly dependent on energy which makes lithium fluoride suitable for fluoroscopic procedures. Some of specific advantages and disadvantages for LiF (TLD 100) are shown in Table 7.

Table 7. Principal advantages and disadvantage for LiF (TLD 100).

Advantage	Disadvantage
Wide useful dose range	Fading
Dose rate independence	Light sensitivity
Passive dosimeter-no cables required	Loss of reading. A measurement erases the stored information.
Small crystals. Can be used in inaccessible areas.	Spurious TL. Sensitive to surface contamination and dirt.

A Harshaw Automatic TLD Reader, Model 5500 is used to heat up the dosimeters and register their emitted light as shown in Fig 3.

The reader reported the TLD dose measurements as charge values in nanocoulombs (nC), which were then converted into dose values by multiplying the measurements by a calibration

factor. The calibration factor was determined by means of parallel exposure of a set of TLDs and a calibrated ionization chamber using the same x-ray beam qualities as in the phantom studies for each investigation.

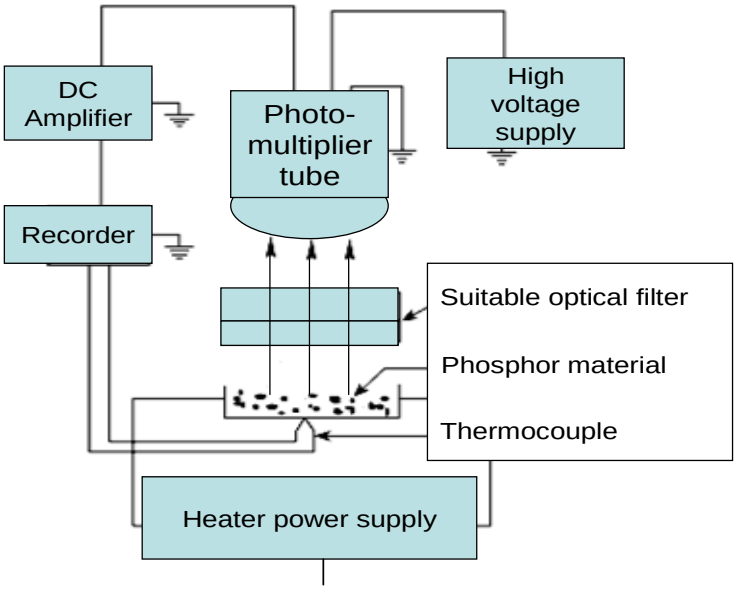


Figure 3. Reader Principle

2.4. Dose-area product

The Dose-area product, a quantity easily measured in the x-ray room, has been proposed for use as a dose index for patient exposure in diagnostic radiology. DAP is defined as the integral of dose across the x-ray beam and the simplest method to compute it, is to place a transmission full-field ionization chamber in the beam between the final collimators and the patient. The reading from a DAP meter is changed by varying the x-ray technique factors (kVp, filtration, mA, or time), changing the area of the field, or both. The portable DAP meters (Dose Guard, RTI, Mölndal, Sweden) were calibrated at the factory with an uncertainty of 5% at 70 kVp and 3.5 mm Al.

Deriving of the effective dose using conversion factor with DAP as foundation, is more accurate than using entrance surface dose measurements since the DAP measurements include a field size component. This is in agreement with Le Heron (Le Heron, 1992), who reported that ”dose area product best mirrored effective dose”, and the National Radiological Protection Board statement that”it is likely that dose–area product is more closely related to effective dose, since it takes into account the x-ray beam area which affects the number of organs irradiated ” (Hart et al, 1994).

On the other side, estimation of radiation risk from DAP value has limitations, since the patient size, beam positioning and the effect of scattered radiation are not taken into consideration.

There is also a disadvantage with DAP value. The arrangement of the DAP meter may bring in a prejudice to the DAP value. For example, if undercouch tube and overcouch intensifier system is used as in cardiac procedure, the patient will receive less than what is implied by the displayed DAP value. In the same circumstances DAP is used as input data in order to calculate the effective dose through Monte Carlo simulation, demands correction for table attenuation.

It should also be noted that the relation between maximum entrance skin dose and DAP varies depending on the type of cardiac procedure and operator. A threshold DAP value should therefore preferably be established for each procedure/operator (Karambatsakidou et al, 2005).

2.5. The work stages

The fluoroscopic exposures during cardiac procedure as shown in Fig 4 were categorized into three types on the basis of beam direction.

1. GHPA (Groin to the Heart exposure Anterior Posterior), connecting fluoroscopy in the PA (Posterior Anterior) projection required for placing and advancing the catheter from the groin to the heart, and PA cardiac fluoroscopic exposure.
2. RAO (Right Anterior Oblique) cardiac fluoroscopic exposure.
3. LAO (Left Anterior Oblique) cardiac fluoroscopic exposure.

Organ dose data was obtained in three identified fluoroscopic projections involved in catheter ablation procedures from direct dose measurements on a Rando anthropomorphic phantom. The percentage irradiation time to fluoroscopy was 60 % for GHPA and PA, 20 % for RAO, and 20 % for LAO. This examination was performed on a single-arm Integris H3000 undercouch tube and overcouch intensifier system (Philips Medical Systems).

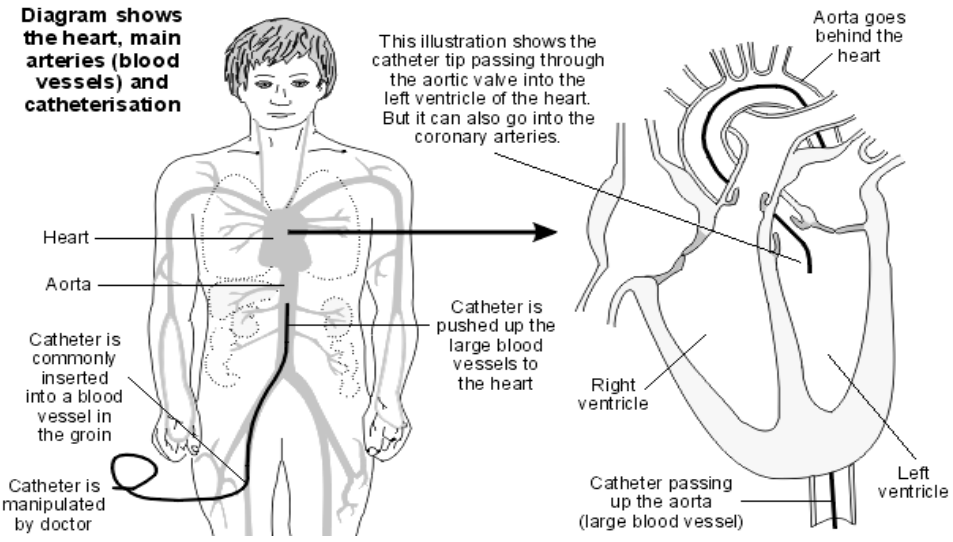


Figure 4. Diagram illustrating location of catheter in cardiac procedure (Patient UK, 2006)

The conventional lung examinations in paediatrics were categorized into two types on the basis of beam direction: (1) AP (Anterior Posterior), (2) LAT (left lateral).

In urography investigation only AP was used in a one year old phantom. The same projections were used in both TLD and MC. The examinations were done on a standard Bucky table (Digital diagnost; Philips medical systems)

Only the upper body of the phantoms was used and TLDs were placed in various organs in the abdomen and thorax for calculation of the effective dose according to ICRP 60. The outlines and position of various organs inside the male ARP and the child phantom were drawn to simulate actual human organs which are influenced directly or indirectly by irradiation beam. Sex-related differences in radiation doses in male and female patients were taken into account. The radiation dose to the testicles accounted for the male-specific gonad dose, whereas doses to the ovaries were used to measure radiation doses for female.
The absorbed dose in the gonads which is used in the effective dose calculation was taken as the mean value of the absorbed dose to the ovaries and testes.

The dose corresponding to the TLD positions that are inside the organs are summed and averaged over the total number of TLD positions included in the organ. Linear regression performed on the data in Figure 6 by fitting a straight line through origin. The coefficient of simple determination (R^2) value was used to measure the strength of relationship between organs dose according to TLD and MC.

Unlike the other organs, the calculation of the dose in the bone marrow was difficult. This is because there is no distinct marrow volume in the phantom. The two kinds of bone marrow are yellow and red. The yellow bone marrow consists of fat tissues and is not relevant in effective dose calculation while the red bone marrow (RBM) has a large tissue weighting factor in effective dose calculation. The positions of these two types differ in different regions of skeleton and for age. Data on the distribution of RBM as function of age in different organs were taken from Cristy (Cristy, 1981).

For each x-ray examination and projection the data recorded in order to be used in MC simulation as input data, and TLD calibration were:

1. focus to patient entrance surface distance(FSD).
2. tube voltage (kV) and tube loading (mAs).
3. DAP measurements.
4. total filtration.
5. anatomical area examined.

In the MC simulation and TLD methods, the arms were removed from the phantom both in cardiac procedures, urography and lung investigation simulating the normal clinical practice in which the patients have to move their arms along their head so as not to hinder the lateral projection. A single-arm Integris H3000 undercouch tube and overcouch intensifier system was used. The patient table was also included in the model to compensate for additional attenuation in cardiac procedures. For this the DAP value was corrected for this effect when the undercouch tube was used. In order to set up this attenuation value an ionization chamber was used to measure radiation dose above and below the board. The correction for absorption in the patient couch was 0.71 for PA and 0.64 for LAO and RAO.

Finally, for each procedure, the phantoms were exposed to higher tube loading (mAs) in total to increase TLD signal and thus reduce the statistical error of the measurements.

3. Results

A total of 436 TLD dosimeters were used in all investigations. The number of TLD dosimeters taken during one examination varied. The variation of used TLD depended on the kind of investigation, projections and considered organs.

3.1. Cardiac procedure

For the cardiac procedure, the total number was 145. The concentration points were in the thorax and upper abdomen. The equivalent dose (H_T) calculation was performed cumulative in the TLD method (exposure of three projections was made consecutively which means one reading in the TLD was performed), but H_T was calculated for PA, LOA and ROA separately when using of MC simulation. The results of the equivalent dose and conversion factor are shown in the Tables 8 and 9.

Table 8. Dose to the organs which are taken into account for calculation of effective dose in cardiac procedure measures in both TLD and MC.

Organ		H_T (mSv) TLD	H_T (mSv) MC	Active red bone marrow %	Weighting factor (w_T**)	$w_T H_T$ TLD (mSv)	$w_T H_T$ MC (mSv)
Lungs		3.80	4.240		0.12	0.456	0.509
Thyroid		0.23	0.081		0.05	0.011	0.004
Stomach		1.15	0.425		0.12	0.138	0.051
Liver		0.86	0.751		0.05	0.043	0.038
RBM	T. vertebrae	4.97	1.082	0.161	0.12	0.133	0.130
	Lumber vertebrae	0.21		0.123			
	Ribs	1.49		0.161			
	Sternum	1.52		0.031			
Ovaries***		0.03	0.006		0.20	0.006	0.001
Oesophagus		3.58	3.023		0.05	0.179	0.151
Testes***		0.02	0.000		0.20	0.004	0.000
Breast		1.55	0.453		0.05	0.077	0.023
Thymus		1.31	1.240		r	0.065	0.062
Heart*		5.72	4.843		r	0.286	0.242
Adrenal		0.51	1.662		r	0.025	0.083
Pancreas		0.65	0.774		r	0.033	0.039

* Included for calculating the effective dose.
** The effective dose was calculated using tissue weighting factors from ICRP Publication 60 (ICRP 60,1990)
*** A restricted number of dosimeters were used for measurements in lower abdomen since the dose in these regions is relatively small.
r The remainder is composed of the following additional tissues and organs: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus. In those special cases in which one of the remainder tissues or organs receives an equivalent dose in excess of the highest dose in any of the organs for which a weighting factor is specified, a weighting factor of 0.025 is applied to that tissue or organ and the rest of the weighting factor, 0.025, is applied to the mass averaged dose in the other remainder organs and tissues. Otherwise, all ten remainders shared the 0.05.

Table 9. Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dose and DAP for cardiac

	MC	TLD	Tube voltage(kV)	Filtration(mm)	Field size(cm^2)	Time(s)
PA	0.16	-	84	7 Al	95	115
RAO	0.21	-	89		79	30
LAO	0.18	-	86		95	30
Averge	0.18	0.19	-		-	-

3.2 Lungs

The organ dose and effective dose were calculated for each projection for LAT and AP to lung examination. The number of used TLD for both projections was 200. The concentration points were in the thorax and upper abdomen. The results of the equivalent dose and conversion factor are shown in the Tables 10 and 11.

Table 10 a. Dose to the organs which are taken into account for calculation of effective dose for lung examination (AP) in both TLD and MC.

Organ		H_T (mSv) TLD	H_T (mSv) MC	Active red bone marrow %	Weighting factor w_T	$w_T H_T$ TLD (mSv)		$w_T H_T$ MC (mSv)
Lungs		6.30	5.73		0.12	0.756		0.687
Stomach		7.09	6.28		0.12	0.850		0.754
Liver		5.30	5.64		0.05	0.265		0.282
Testes		0.07	0.17		0.20	0.015		0.034
Breast		9.71	6.64		0.05	0.485		0.332
RBM	ribs	6.40	1.05	7.6	0.12	0.058	0.10	0.126
	Sternum	10.49		1.5	0.12	0.016		
	Vertebra	2.61		7.7	0.05	0.024		
Oesophagus		6.35	3.22		0.05	0.317		0.161
Thyroid		0.83	0.61		0.12	0.041		0.073
Ovaries		0.24	0.30		0.20	0.048		0.059
Kidneys		2.11	2.06		r	0.105		0.103
S. intestine		0.40	1.68		r	0.048		0.084

Table 10 b. Dose to the organs which are taken into account for calculation of effective dose for lung examination (LAT) in both TLD and MC.

Organ		H_T (mSv) TLD	H_T (mSv) MC	Active red bone marrow %	Weighting factor w_T	$w_T H_T$ TLD (mSv)		$w_T H_T$ MC (mSv)
Lungs		3.08	2.92		0.12	0.370		0.350
Stomach		2.33	2.13		0.12	0.280		0.255
Liver		1.78	1.39		0.05	0.089		0.070
Thyroid		0.35	0.66		0.12	0.042		0.079
Breast		4.72	4.11		0.05	0.236		0.206
RBM	ribs	2.78	0.48	7.6	0.12	0.025	0.059	0.058
	Sternum	3.32		1.5	0.12	0.006		
	Vertebra	3.07		7.7	0.05	0.028		
Oesophagus		1.86	1.34		0.05	0.093		0.067
Testes		0.04	0.00		0.20	0.008		0.000
Ovaries		0.09	0.13		0.20	0.018		0.026
Kidneys		0.64	0.47		r	0.032		0.024
S. intestine		0.16	0.19		r	0.008		0.010

Table 11. Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dose and DAP for lung examination.

	TLD	MC	Tube voltage(kV)	Filtration (mm)	Field size (cm^2)	mAs
LAT	1.39	1.29	117	2.22 Al + 0.1 Cu	220	100
AP	2.12	1.95			320	
Average	1.75	1.62			-	

3.3. Urography

For the urinary tract investigation the number of used TLD was 91 and the concentration points were in the lower abdomen. Like the other investigations a gonad dose was calculated as the mean of the doses to the ovaries and testes for calculating effective dose and thereby conversion factor. The results of the equivalent dose and conversion factor are shown in the Tables 12 and 13.

Table 12. Dose to the organs which are taken into account for calculation of effective dose for urography examination in both TLD and MC.

Organ		H_T (mSv) TLD	H_T (mSv) MC	Active red bone marrow %	Weighting factor w_T	$w_T H_T$ TLD (mSv)		$w_T H_T$ MC (mSv)
Lungs		0.33	0.03		0.12	0.039		0.004
Stomach		1.44	1.62		0.12	0.172		0.195
Liver		1.42	1.44		0.05	0.071		0.072
Testicles		2.81	3.07		0.20	0.562		0.614
Ovaries		1.27	1.51		0.20	0.255		0.302
RBM	ribs	0.16	0.21	7.6	0.12	0.001	0.013	0.026
	femur	1.05		3.9	0.12	0.005		
	vertebra	0.44		7.7	0.12	0.004		
	sacrum	0.54		4.7	0.12	0.003		
Oesophagus		0.14	0.16		0.05	0.007		0.008
Thyroid		0.08	0.01		0.05	0.004		0.001
Kidneys		0.53	0.49		r	0.027		0.024
Pancreas		0.93	1.04		r	0.047		0.052
S. intestine		1. 58	1.81		r	0.079		0.091
Bladder		2.04	1.74		r	0.102		0.087
Gallbladder		1.82	1.87		r	0.091		0.093
Spleen		0.75	0.68		r	0.037		0.034
Uterus		1.41	1.40		r	0.073		0.070

Table 13 Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dos and DAP for urography.

	TLD	MC	Tube voltage(kV)	Filtration (mm)	Field size (cm^2)	mAs
Conversion factor	1.34	1.48	70	3.35 Al	304	100

4. Discussion

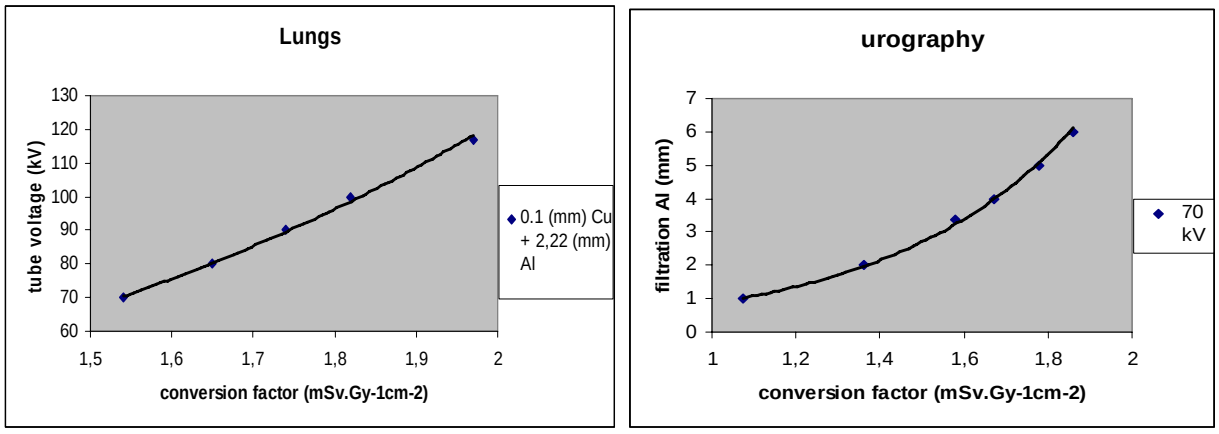
4.1 Discussion of results

The conversion factor which is used for derivation of the effective dose from DAP for a particular radiographic examination, is dependent on beam quality and is dependent on the field size in a specific anatomic area. From one point of view this value is going to be influenced by any difference in the field size or organ position in different phantoms and this sensitivity is much higher for children. From another point of view uncertainties in the effective dose estimated by conversion factor may be introduced due to that the standard conditions of exposure when deriving the conversion factor will surely not be met completely in the investigation room since every case is unique.

The calculation of conversion factor for all investigations is made for standard-sized phantom. In practice, this will not be the case. For the same tube voltage, field size and filtration (which mean the same DAP value) thicker patients will have smaller conversion factor because the organ doses are smaller compared with the phantom. In practice, thicker patients can have larger tube voltage values (A higher tube voltage can combine with lower mAs).

The conversion factor increases with the increase of tube voltage. The reason for this increase is increased penetration ability of the photons in turn will decrease the effective dose (on expense of the picture's contrast) however the DAP value decreases more than effective dose because the DAP-meter is thinner than phantom. Figure 5 shows the relationships between the voltage/filtration and the conversion factor value for the urography and lungs (AP) investigation.

Figure 5. The relationships between the conversion factor and the tube voltage / filtration for the lungs and urography using PCXMC.



The field size and position are important parameters in radiographic technique, especially in paediatrics, because children are more sensitive to exposure of ionising radiation than adults. In addition the children's motion under examination makes the correct positioning of the radiation field difficult at this age. Because of this, it is sometimes practical to use large fields which will not only impair image contrast and resolution by the increasing amount of scattered radiation, but most importantly the result is an increase in effective dose. At the same time any decreasing in the field size will immediately degrade the anatomical information.

The organ dose to stomach mirrors this complication. The absorbed dose during ***lung*** investigations with AP projection decreases from 0.754 mSv to 0.303 mSv (a decrease with 60 %), if the field length decreases with one cm using MC simulation in positive Z-axis direction. The same reduction in the field length of the positive Z-axis has almost negligible effect on the effective dose in the adult phantom. This is because the stomach, which has a relatively high weight factor, is so close to the lungs in a one year old child. Besides that, the stomach is small so minor change in a field size will highly influence the organ and then the effective dose.

The difference in the organ position between the ARP and the mathematical phantom used in MC simulation in ***cardiac catheter ablation*** indicates a similar tendency in the organ dose, particularly the edge organs. Table 14 shows the effect of a two cm field displacement in negative Z-axis on the edge organ, such as the stomach, and the organs which surround the field such as lungs.

Table 14. Equivalent dose (mSv) to stomach and lungs before and after displacement of irradiation field in negative Z-axis direction using MC simulation in cardiac procedure. Equivalent dose using TLD is considered as reference.

	Equivalent dose* MC	Equivalent dose** MC	Equivalent dose TLD	Different before %	Different after %
Stomach	0.43	0.83	1.15	63	28
Lungs	4.24	4.11	3.80	10	7

* Before field displacement in negative z-axis.
** After field displacement in negative z-axis

In ***urography*** examination the figures show clearly that testicles and ovaries have a big effect on the influence of the conversion factor, because they have a high tissue weighting factor. The dose in testicles stands for 47 % of the total effective dose for a boy using TLD method as shown in Table 12, while this figure is subsided to 31 % for ovaries in a girl with the same method (corresponding figures for MC simulation are 43 %, 23 % for testicles respective ovaries).

In many studies, no difference is made between conversion factors for the female and the male patients. But Table 15 shows that there is a significant difference in conversion factors. For the urography, the position of the gonads is crucial here. The conversion factors for the male patients are higher than those for the female patients. The reason for this difference is that testicles get higher dose than ovaries (0.56 mSv respective 0.26 mSv). This is due to the more regarding the surface anatomical location of the testicle in the scrotum, instead of deeper placement of the ovaries in the pelvis. As a consequence the ovaries exposure is less since the surrounding tissues attenuate a proportion of the beam.

It has also been recommended that the tissue-weighting factor for gonads be reduced to 0.08 and be increased to 0.12 for breast (ICRP 103, 2007). It is really necessary in the light of the new recommendation to estimate the effect of this changing on the conversion factors value.

When using the old directives (ICRP 60, 1990) in cardiac procedures, the difference in conversion factor between female/male and the mean value is less than 5 % as shown in Table 15 and Figure 6. This is because the breast weighting factor is relatively low (0.05) and the organ dose in the breast is relatively small (PA projection). However, there is a higher difference between male/female- mean value concerning the lungs investigation, because the

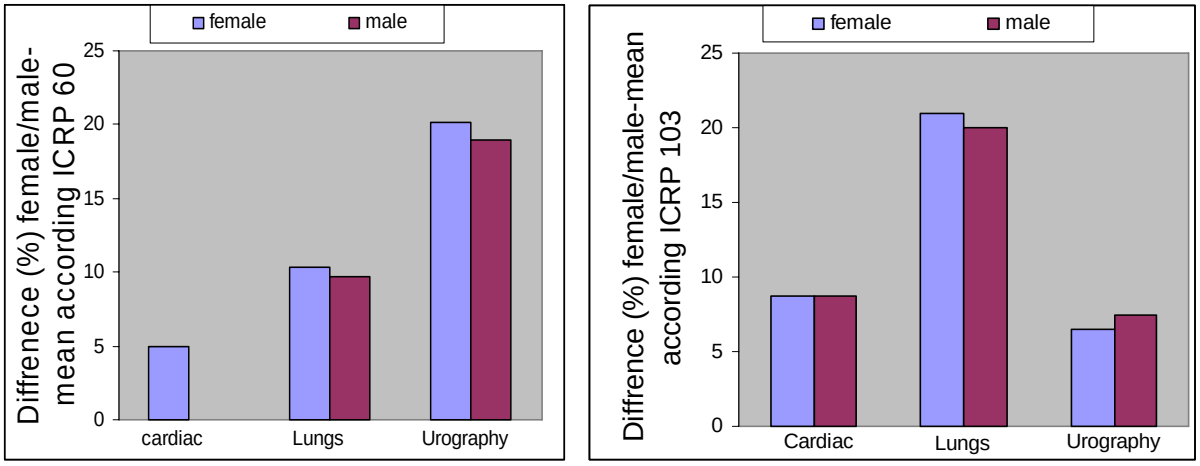
breast is in the primary field (AP projection). The same difference can be noticed in the urography, which is due to the fact that the testicles with high weighting factor are positioned in the primary field.

When using the new directives from ICRP 103, the difference in conversion factor between female/male and the mean value for both the cardiac producers and the lungs are greater since breast weighting factor has increased to 0.12, while it becomes smaller for the urography. This is due to changes in weight factors for the gonads.

Table 15 Effect of ICRP 60 and ICRP 103 weighting factors in conversion factor ($mSv.Gy^{-1}\ cm^{-2}$) value.

	Cardiac procedures			Lungs			Urography		
	female	male	mean	female	male	Mean	female	male	mean
ICRP 60	0.20	0.19	0.19	1.93	1.58	1.75	1.06	1.60	1.34
ICRP 103	0.25	0.21	0.23	2.43	1.62	2.02	1.00	1.15	1.07

Figure 6. Difference (%) in conversion factor between female/male and mean value according to ICRP 60 respective ICRP 103.



From ***lung*** examination the effective dose in the AP projection is higher than the corresponding value for the LAT projection by 15 %, because almost all radiosensitive organs such as breast, lungs and gonads are located in the anterior of the human body. This consequence reflects in conversion factor value between these projections, where conversion factor in the AP projection is 2.12 $mSv.Gy^{-1}cm^{-2}$ while corresponding value in the LAT is 1.39 $mSv.Gy^{-1}cm^{-2}$ using TLD method. The same tendency is noticed in MC simulation.

The amount of absorbed radiation dose to various organs in the ***catheter ablation*** procedures which are represented in Table 8 show, the organs receiving the greatest amount of radiation are the lungs which are identified as critical organs. Significant doses are received by oesophagus, stomach, and red bone marrow. Values which are represented in table 8 assumed that the conversion factor is similar for both male and female, and this approximation must be considered particularly after ICRP new recommendation (ICRP103, 2007) coming into use which means that the risk factor for females will ascend.

As expected, the conversion factor varies between projections even in cardiac procedures. The results show that the conversion factor varied according to the location of the field. Some of this variation is connected to tube voltage increasing in LAO and RAO direction where

deeper organs get higher absorbed dose in relation to DAP value. But the most important reason is the position of irradiation field, where increasing tube voltage with 3 %, or decreasing total filtration with the same amount, cannot explain this variation in conversion factor value between projections as shown in Table 9. The location of irradiation field around the heart and position of the heart in the lung results in higher dose to the heart in AP than LAO and RAO, but less dose to the lungs and the breast. Since the heart is considered as a remainder organ, the effect of lungs and breast to influence effective dose is much more.

The average effective dose for a typical ***cardiac catheter ablation*** by using conversion factor value from this study and DAP from from McFadden et al (2002) is 23 mSv, if ICRP 60 is used in effective dose calculation. This value will increase to 28 mSv by using ICRP's new recommendation for tissue-weighting factor. The mean effective dose of 23 or 28 mSv can be put into perspective by comparing it with the figures in Table 16 and the effective dose of 0.11 mSv from an average lung investigation (Leitz, 2001). When all these figures are taken into account, there is a strong need to evaluate the doses delivered not only to adults of different sex where majority of patients who undergo catheter ablation procedures are young with a mean age of 36 years (Damilakis et al, 2001), but also to paediatric, because 7 % of all cardiac angiography procedures are children 0 to 15 years of age (Klaus, 2005). Moreover, in children with congenital heart disease, there is often a need to perform multiple examinations, further increase radiation risks (Schueler et al, 1994).

Table16. Doses received by the population of cosmic radiation, radon and x-ray examination in Sweden. (Andersson et al, 2007)

Exposure	Effective dose(mSv)
Cosmic radiation	0.3 (mSv/year)
Radon*	1.2-2.7 (mSv/year)
Lungs	0.11
Urography	4.0
Lumbar Spine	1.8
Barium enema	10
Pelvis	0.7

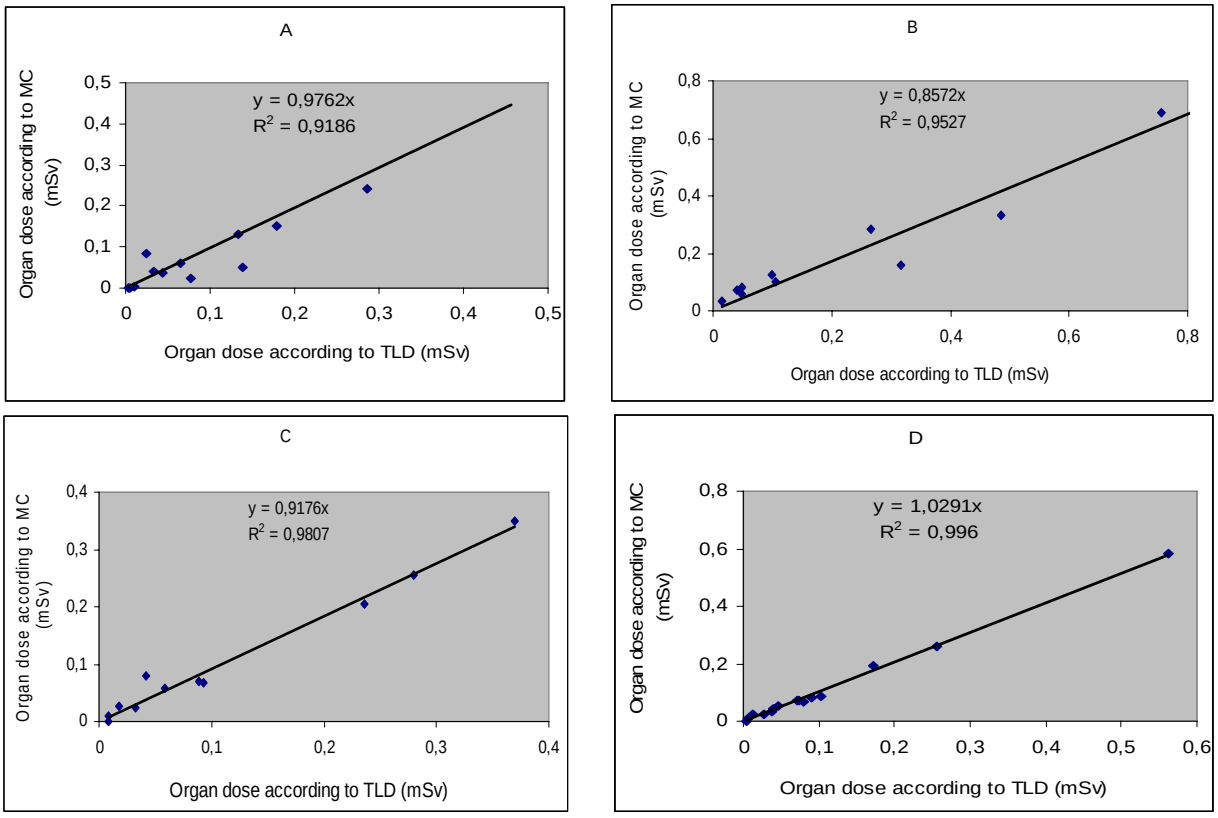
* Average effective annual dose received by the population broken down between no-smokers and smokers.

The agreement between the results of TLD and MC simulation for all investigations is good as demonstrated in Figure 7 and Tables 8, 10, 12 and 17. The values of the R^2 show that there is a strong linear statistical relation between organs dose from TLD and the organ dose from MC simulation.

Table 17. Slope and R^2 for all investigations.

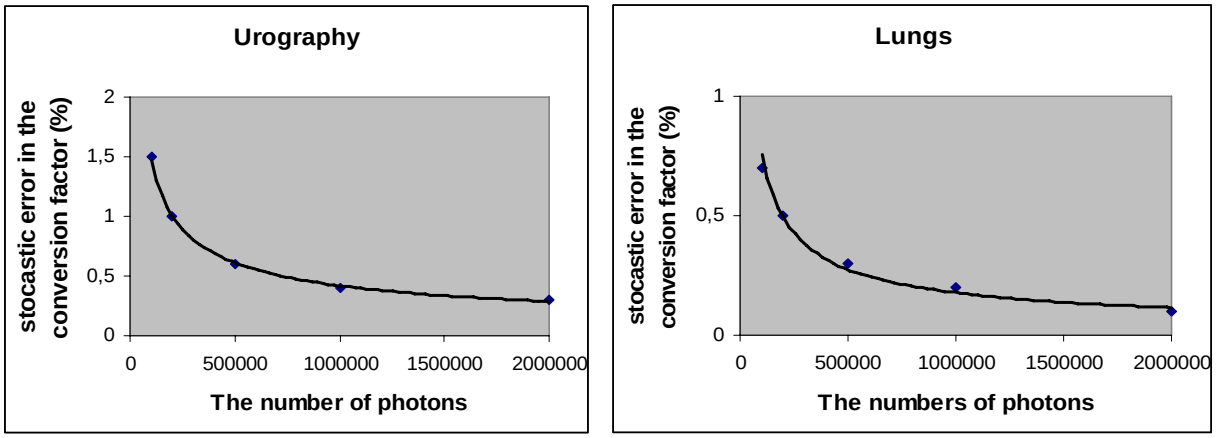
	Cardiac procedure	Lungs (AP)	Lungs (LAT)	Urography
Slope	0.98	0.86	0.92	1.03
R^2	0.92	0.95	0.98	1.00

Figure 7. The organ dose by the TLD as function of organ dose by MC simulation. (A) Cardiac procedure. (B) Lung examination AP. (C) Lung examination LAT. (D) Urography.



The same difference between them can be related to the statistical error that is caused by the finite amount of simulated photons in MC. Increasing the number of photons decrease stochastic errors in the data. But, there is a limit to the number of photons that can be used in simulation, set by the CPU (Central Processing Unit) speed. The calculation time can be shortened by specifying a lower value for energy levels, or the number of photons. In this study, 100 000 photons were used per projection of an examination, which reduced the stochastic errors for organs located inside the field to less than 2%. For organs located at the outside the field, the stochastic errors can be up to 30%. Another difference is connected to the dissimilar position of the organs in the phantoms. The relationship between the error in the conversion factor and the number of photons for urography and lungs is shown in Figure 8.

Figure 8. The relationship between the error in the conversion factor and the number of photons for urography and lungs.



Comparison with other works in paediatric cases is a problem due to scarce studies. There is a difference in conversion factor value between this study and Almén study as shown in Table 20 in urography. The wide interval in the children's weight between 0-1 years makes DAP determination a difficult process in Almén work (Almén, 1996). This difficulty will reflect in the conversion factor value. Some of the differences can also be related to the different irradiation parameters such as tube filtreation. The agreement for lung investigation between this work and Almén work is good as shown in Table 19.

The model of irradiation in cardiac procedure is depending on several factors, such as the number of projections used, the geometry of each projection and the field size. These factors explain some difference in conversion factor between current study and other works. Mostly, the difference in conversion factor value for cardiac procedure as shown in Table 18 is less than 8% and not significant for practical conversion factor evaluation purpose. The conversion factor is strongly related to the age of the patient (mass of the phantom). It is less dependent on the irradiation projection but showed some decrease in the PA projection as shown in Table 18.

Table 18. Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dose and DAP for cardiac procedure and comparison with paediatric for the same procedure.

	MC*	TLD*	Adult (Broadhead ,1997)	Adult (Wilde et al, 2001)	Adult (Betsou et al,1998)	Paediatric (Axelsson et al, 1999)		Paediatric (Bacher et al, 2005)
						7-11 kg	15-26 kg	
PA	0.16	-	0.15**	-	-	0.9	1.8	-
ROA	0.21	-	0.21	-	-	-	-	-
LOA	0.18	-	0.18	-	-	-	-	-
mean	0.18	0.19	0.18	0.18	0.18	-	-	1.30
Filtration (mm)	70 Al		7 Al	3 Al	4 Al	3 Al		6.5 Al
Voltage (kV)	86*		80	80	70	58-62		80

* Average

Table 19. Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dos and DAP for paediatric lung examination, and comparison with adults.

	TLD*	MC*	Paediatric (Almén,1996)	Adult (Leitz and Jönsson, 2001)	Adult (Einarsson et al, 1998)
LAT	1.39	1.29	1.62	-	-
AP	2.12	1.95	2.18	-	-
mean	1.75	1.62	1.90	0. 18**	0. 16
Filtration (mm)	2.22 Al + 0.1 Cu			6 Al	
Voltage (kV)	117			150	122

* This study

** Karolinska hospital Thorax 2.

Table 20. Conversion factor ($mSv.Gy^{-1}cm^{-2}$) between effective dos and DAP for paediatric urography, and comparison with adults.

	TLD*	MC*	Paediatric (Almén,1996)	Adult (Leitz and Jönsson, 2001)	Adult (Einarsson et al, 1998)
AP	1.34	1.48	1.80 (1.53)**	0.17****	0. 19
Filtration (mm)	3.35 Al		3.7 Al	5 Al	
Tube voltage (kV)	70		70	67	72

* This study
** at maximum DAP value
*** Karolinska hospital

4.2 Risk estimation

The radiation –induced cancer can be determined by multiplying the effective dose by a suitable risk factor. The reason behind risk estimation in this study is to illustrate effect of ICRP new recommendation (ICRP103, 2007) for different examinations. The attributable lifetime risk for fatal cancer per absorbed dose is 16 % per Sv for exposure between ages 0 and 9 years compared with 4% per Sv at the age of 30 years as given by ICRP 60 (ICRP 60, 1990).

The International Commission on Radiological Protection (ICRP 103, 2007) notes that collective effective dose is an instrument for optimisation and for comparing radiological technologies. The calculation of the number of cancer deaths based on collective effective doses from trivial individual doses should be avoided.

4.2.1. Cardiac procedures

To estimate the potential risk for stochastic effects, the effective dose should be calculated. Unluckily, determining the effective dose in cardiac procedures is complicated, because of the complexity of the beam direction. Using 4% per Sv at the age of 30 years as given by ICRP 60 (ICRP, 1990) and 23 mSv effective dose value which have been determined, the excess risk of developing fatal cancer from this dose is calculated to be approximately 1 to 1000 (9.7×10^{-4} female, 9.2×10^{-4} male). This is similar to results from other studies (Perisinakis et al, 2001 Efstathios et al, 2006). The maximum effective dose received by cardiac catheter ablation using conversion factor value from this study and maximum DAP from Br J Radiol (Fadden, 2002) is 357 $Gycm^2$ and the excess risk for developing a fatal cancer from this DAP using conversion factor in this study is approximately 1 to 370 . This value will be increased to 1 to 300, if ICRP 103 is used for effective dose calculation. The risk of radiation induced cancer is shown in Table 21.

Variation in radiation-induced cancer risk between male and female is understandable in cardiac procedures since the breast is lying in the prime field. This variation is supported by the fact that the women who received pulmonary tuberculosis treatment suffered substantial increase in the frequency of breast cancer (Mackenzie, 1965).

4.2.2. Urography and lung examination

The estimation of the effective dose is performed by use of conversion factor from the present study, and DAP value from Almén (Almén, 1996) for both urography and lung examination. The risk of radiation induced cancer is shown in Table 21.

Table 21. Risk of radiation induced cancer per 10 000 for urography, lung and cardiac procedure.

	Risk (ICRP 60)		Risk (ICRP 103)	
	female	Male	female	male
Urography	0.16	0.24	0.15	0.17
Lungs (mean AP, LAT)	0.06	0.05	0.08	0.05
Cardiac	9.7	9.8	12.3	10.3

The risk from different examinations shows that the risk involved in urography (male) is approximately 5 times higher than the lung investigation using ICRP 60 recommendations. This value will be decreased to 3 times, if ICRP 103 is used for both investigations as a consequence of decreasing of gonads tissue-weighting factor. The same argument can explain the increase in risk for lung investigation between ICRP 60 and ICRP 103, where breast weighting factors are changed.

4.3. Limitations of the study

No direct radiation dose estimates were available in the examined phantoms in the radiation risk estimation. The DAP values for all investigations were derived from other works. For an accurate risk estimation, a patient-specific DAP value must be measured in all investigations.

There were uncertainties related to the use of TLDs. A total uncertainty ranging from 5 to 20 % was measured at a confidence level of 95 %. There are inaccuracies due to the deficiency of direct dose measurements during cardiac procedure performed in patients. Thus organ doses of patient undergoing cardiac procedure may differ from those measured in the ARP because of the different body dimensions. Because the amount of tissue is greater in patients of larger size compared with ARP, overweight patients may require increased tube voltage and current. The consequential inaccuracy in effective dose and risk determination is expected to be higher in those patients. The fluoroscopic exposures during a patient study in cardiac procedure may perform with angulations that are rather different from the corresponding phantom exposure.

The determination of organ position in the Alderson Rando phantom is a difficult process. In this study the problem has minimized by taking the advice of expert radiologist and anatomical literatures. The large number of TLD measurements to estimate the equivalent dose to the large and extensive organs such as lungs and edge organs relative high weighted factor such stomach, lead also to considerable reduction of this effect.

The uncertainties related to use of two different phantom materials (ARP-child phantom and MC phantom). The differences in the effective atomic number in these phantoms lead to different attenuation property. In PCXMC, the limitation in the number of photons causes some statistical error i.e. uncertainty in organ dose (0.7% - 90%), despite that this uncertainty in effective dose is limited.

What also must be emphasized is the importance of the calibration of the DAP-meters. The inherent calibration must be checked or separately calibrated DAP-meters must be used as in this work. In addition, the conversion factors found here are strictly valid for the geometry/projections used in the examinations investigated here only. Different geometry (field size, distances, and radiation beam directions) can give different conversion factors. It is therefore important to have this in mind when using conversion factors taken from the literature.

5. Recommendations and conclusion.

5.1. Recommendations.

Because effective dose in cardiac procedures and children sensitivity to the radiation is high, dose reduction techniques should be useful to keep the effective dose as low as reasonably realizable and to reduce the stochastic and deterministic risk. Techniques that do not worsen image quality are of particular interest. Today, several principles are available and the basic principles of minimizing radiation exposure in cardiac procedures include:

1. **Use pulsed fluoroscopy.** Using of appropriate pulsed fluoroscopy can reduce radiation exposure rate of 30 to 50 % (Bacher et al, 2005).
2. **Minimize beam-on time.** The fluoroscopy ray should be on only when new information is needed. The last image can be used for investigate many anatomical details without need for a new exposure.
3. **Vary the beam direction.** Because procedures need long fluoroscopy time, changing the radiographic projection will decrease deterministic effects. A variation in angle of incidence by ±10 degrees produce a deviation in effective dose <5%. But at the same time this variation in beam direction can be very important in deterministic risk determination. All patients with estimated skin doses higher of 2 Gy should be followed up after exposure.

Due to the anatomic position of testicles, the use of testicles shields will be good measure to reduce effective dose in urography. To reduce effective dose in lung investigations, reduction of organ dose to the breast is a necessary step (especially after ICRP new recommendation). The use of one projection (if the case allows) will be a step in the right direction. Separate conversion factors for AP and LAT projections in lung investigation are recommended. Based on the results of this study, conversion factors of 2.12 $mSv.Gy^{-1}cm^{-2}$ and 1.39 $mSv.Gy^{-1}cm^{-2}$ should be used for AP and LAT views respectively

The need to minimize patient exposure requires that the dose be reduced to the minimum level that will generate an image with an acceptable degree of noise and contrast. For example, an image would be perfectly acquired using a low tube voltage exposure to take advantage of image contrast and a large dose rate to minimize image noise. Increasing tube voltage reduces patient exposure but decreases image contrast. Decreasing tube current reduces patient exposure but increases image noise. Therefore there is an optimal compromise set of exposure parameters that save diagnostic quality image contrast at an acceptable image noise level as well as minimizing patient dose. In some investigations the objective can be reached by an added copper filtration. This can be a better filter for high energy radiation instead of very thick Al-filters. Many studies have shown that there exist possibilities to reduce effective dose without any significant deterioration of image quality (Persliden et al, 1997. Okka et al, 2005)

5.2. Conclusions

1. In the light of the changes which have been carried out on weighting factors, it is of utmost importance to recalculate the conversion factors since the study shows a difference which hardly can be ignored, especially concerning breast examinations.

2. The experience possessed by the medical profession is necessary in order to reduce the effective dose and skine dose in cardiac procedures.

3. Several parameters, such as field size, field position, patient thickness, tube voltage and filtration are known to affect the conversion factors. For an accurate calculation of effective dose, one should investigate if there are large deviations in those parameters between the actual investigation and the reference parameters for which the conversion coefficients were calculated.

4. Both the present study (Table 18) and other (Axelsson et al, 1999) have shown that the conversion factors are strongly related to the age of the patient (mass of the phantom) and they are less dependent on the projection direction.

Appendix

Weighting factors

Two types of weighting factors are needed in order to compute effective dose: a radiation weighting factor and a tissue weighting factor. The value of the radiation weighting factor (w_R) is a characteristic of each specific kind of radiation. What makes it easy is that the radiation that is used in medical diagnosis (x-ray, gamma, electron, and positron) all has radiation weighting factor (w_R) values of one. Tissue weighting factor (w_T), a value recommended by ICRP to indicate the probability that a unit dose of radiation to the tissue will result in a cancer in the exposed person. Different probabilities exist for stochastic radiation effects in different organs and tissues. The new values that apply for the tissue weighting factors are listed in Table 21.

Table 21. ICRP 60 (1991) and ICRP 103 (2007) weighting factors (w_T). The changes between the two schemes are evidenced using bold fonts.

ICRP 60 (1991)		ICRP 103 (2007)	
Organ	Weighting factors (w_T)	Organ	Weighting factors (w_T)
Gonads	**0.20**	**Gonads**	**0.08**
Breast	**0.05**	**Breast**	**0.12**
Active marrow	0.12	Active marrow	0.12
Colon	0.12	Colon	0.12
Lungs	0.12	Lungs	0.12
Stomach	0.12	Stomach	0.12
Bladder	**0.05**	**Bladder**	**0.04**
Liver	**0.05**	**Liver**	**0.04**
Oesophagus	**0.05**	**Oesophagus**	**0.04**
Thyroid	0.05	**Thyroid**	**0.04**
Skin	0.01	Skin	0.01
Bone surface	0.01	Bone surface	0.01
Brain	**0.05**	**Brine**	**0.04**
Remainder: adrenals, brain, upper large intestine, small intestine, **kidney,** muscle, pancreas, spleen, thymus, and uterus	**0.05**	**Remainder:** adipose tissue, adrenals, connective tissue, extrathoracic airways, gall bladder, heart wall, **kidney,** lymphatic nodes, muscle, pancreas, prostate, small intestine wall, spleen, thymus, and uterus/cervix.	**0.12**

Radiation protection quantities

When tissue is irradiated by ionising radiation, adverse effects are possible. Depending on the radiation quality different radiation modalities have different efficiencies in producing biological effects. In radiation protection, this is handled by multiplying the absorbed dose D, with a radiation weighting factor, w_R. Then a new quantity, *Equivalent dose*, H_T is obtained.

$$H_T = D.w_R \qquad \text{Unit: Sv (sievert)}$$

When only a part of the body is irradiated the risk for radiation effect is smaller compared to a whole body radiation. This is taken into account by introducing another quantity, Effective dose, E. The effective dose is obtained by multiplying the equivalent dose with tissue weighting factors w_T.

$$E = \sum H_T.w_T \qquad \text{Unit: Sv (sievert)}$$

Cardiac catheter ablation

Catheter ablation is a non-surgical procedure that uses radiofrequency energy to destroy the electrical pathway causing the arrhythmia (also called irregular heart rhythm). An arrhythmia is an abnormal heartbeat which can involve a change in the rhythm, producing an uneven heartbeat, or a change in the rate, causing a very slow or very fast heartbeat

Mitral valvuloplasty

Mitral valvuloplasty is a procedure carried out under local anesthetic, in which a balloon is passed from the right femoral vein, up the inferior vena cava and into the right atrium.

Dry Desquamation

Dry desquamation is the second phase of radiation skin toxicity. It is characterized by dry, peeling skin that is usually itchy.

Telangiectasia

Telangiectasia are small enlarged blood vessels near the surface of the skin usually they measure only a few millimeters. Telangiectasia is a common problem in breast cancer treatment.

Transient erythema

Erythema is redness of the skin caused by capillary congestion which is defined as the blocking of the capillaries. Transient erythema is a common side effect of radiotherapy treatment due to patient exposure to ionizing radiation.

Effective atomic number

Among the most important substation structure parameters, one should specially note the effective atomic number Z_{eff}. In fact, it approximately determines the chemical composition of a material. Higher $Z_{eff} \geq 20$ correspond to inorganic compounds and metals, lower $Z_{eff} \leq 10$

correspond to organic substances. The formula for the effective atomic number, $Z_{eff,}$ is as follows:

$$Z_{eff} = \left[\sum_{k=1}^{P} a_k A_k Z_k^{2} \Big/ \sum_{k=1}^{P} a_k A_k Z_k\right]^{1/2}$$

Where A_k and Z_k are the atomic mass and atomic number of simple elements, P is the total quantity of simple elements, a_k - relative atomic (molar) concentrations, i.e., the number of atoms of each kind in one molecule.

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