RADIATION DOSES TO THE UNBORN CHILD AT DIAGNOSTIC EXAMINATIONS IN SWEDEN

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SUMMARY

This report describes methods to estimate fetal radiation doses from radiation diagnostic examinations, based on survey data from 3 hospitals in southern Sweden.

The fetal dose has been calculated with available computer programs and verified by dose measurements inside a female human phantom for conventional X-ray and computed tomography (CT) examinations. Measured fetal doses have been correlated to the DAP (Dose Area Product) value or the CTDI (Computer Tomography Dose Index) and DLP (Dose Length Product) values and conversion factors have been evaluated.

For nuclear medicine examinations tables for the calculations of fetal doses by administered activity are presented together with information of administered activity for normal and pregnant women in Sweden.

For X-ray examinations where the uterus is outside the primary radiation fields the fetal dose is generally below 1-2 mSv. In order to calculate fetal doses documentation of fluoroscopy time and number of X-ray images, scanning parameters for the CT and administered activity for nuclear medicine examinations are necessary.

INTRODUCTION

With increasing knowledge and awareness of risks associated with prenatal ionising radiation exposure there is a need for standardised methods for estimating and documenting fetal radiation doses. The use of ionising radiation in a medical examination of a woman caring a child is not always possible to avoid. The following situations can occur:

1. The pregnancy of the patient is known and the examination has to be performed due to medical reason
2. The pregnancy of the patient is unknown at the time of examination

The medical situation for the patient normally determines which type of examination should be performed. The risk with an X-ray examination has to be compared to the medical benefit for the patient and for pregnant women the radiation risk to the unborn child also need to be evaluated.

Methods to identify pregnant women at radiological departments in Sweden are already in use, but national rules and methods to calculate the individual dose to the unborn child for different examinations are less evaluated. These calculations and estimates are normally very time consuming since examination methods and X-ray equipment varies between different

hospitals. Uniform calculation methods would also facilitate comparisons of radiation doses between different hospitals.

According to directives from the European Commission (EUR 16260 En, 1995 and EUR 16262 EN, 1998), every X-ray examination has to be justified and optimised. Knowledge of the dose levels for different radiation fields can be used in this optimisation and gives possibilities to design an examination with a minimum of radiation dose to the unborn child. Even if the absorbed dose to the fetus is low the patient has the right to know the dose level.

The aim of this study is to determine the absorbed dose to the unborn child for common radiation diagnostic examinations used in Sweden and to find a standardised method for dose calculations.

MATERIALS AND METHODS

Conventional X-ray

The absorbed dose to fetus has been calculated for the following examinations: chest, bedside chest, lumbar spine, abdomen, hip, pelvis, urography, and barium enema at Linköping University Hospital and County Hospital Ryhov. The absorbed dose to the uterus has been used for simulation of the dose to the fetus. This approximation can be used for a fetus smaller than 12 weeks (3 months). The fetus size is starting to change more rapidly in the weeks 16-20 (after 4-5 months) (ICRP/22/136/01 Draft Report, 2001). In the calculations two available calculation programs have been used WinODS (Rados ODS-60 (WinODS) User guide, 1996 and Servomaa et al, 1989) and PCXMC (Tapiovaara, 1997 and Servomaa and Tapiovaara, 1998). WinODS is a computer program that calculates absorbed dose to the organs in the body based on depth and profile dose curves. Calculations can be made for organs with given tissue weighting factors defined by ICRP 60 added with eyes and salivary gland by using the DAP value for the used radiation field. A phantom model of an adult person adapted to gender, weight and length is used. PCXMC is a computer program based on Monte Carlo calculated organ doses defined in ICRP 60 added with gallbladder and heart. The phantom is defined for 6 different ages: newborn, 1, 5, 10, 15 years and adult. The model can be adapted to gender, weight and length. The organ doses are calculated in relation to the entrance surface dose or DAP value.

In order to verify the calculated doses a female human phantom (CIRS ATOM female phantom, Model # 702-004, 2002) was used to simulate the examinations of the patient. The phantom weight (55 kg) and length (160 cm) have been used in the calculations. The phantom consists of 38 slices of each 25mm thickness made from tissue equivalent materials. The phantom has been loaded with TL-dosimeters ($Li_2B_4O_7$) in order to measure the radiation dose in uterus. The dosimeters have been calibrated in known radiation fields at different energies. For some examinations measurements were done for single views and for some for full examinations. Tube voltage, total filtration, focus to surface distance, radiation field size and DAP value were documented at each exposure. The X-ray images were used to determine field size and location. In this study the following X-ray units have been used: Siemens Pendex, Philips Pendla Modul and Siemens Siregraph.

Computed tomography

The following examinations are included in this study: chest, abdomen and trauma, both sequence and multislice spiral examinations at County Hospital Ryhov. The same phantom was used. Methods described by Nagel (Nagel et al, COCIR 2000) using $CTDI_w$ (weighted CTDI) values have been used for dose calculations. According to Verdun et al (Verdun et al, 2000) the $CTDI_w$ value is a value of absorbed dose suitable to use in the comparison of image quality. The $CTDI_w$ values give the average absorbed dose in a slice (Nagel et al, COCIR 2000). A computer program (WinDose, Kalander et al, 1999) has also been used in comparative calculations of organ doses. This program uses $CTDI_{air}$ (CTDI free-in-air) values and makes no corrections for variations in length and weight of the patients, but it is possible to choose between gender. The following CT units have been used in this study: Siemens Somatom Plus S and Somatom Plus 4 VZ.

Nuclear medicine

To calculate the fetal dose at nuclear medicine examinations data given in the Fetal dose calculation workbook, RIDIC (Stabin, 1998), ICRP 53 (ICRP 53, 1988) and ICRP 80 (ICRP 80, 1998) have been used. Data on administered activities were obtained from the Linköping University Hospital. Administered activity can show great variation between different hospitals (Mattsson et al, 1998). Reference activities given in European Commission publications (European Commission, Radiation Protection 109, 1999) are not generally used in Sweden. The choice of activity level is a compromise between used equipment, available resources and need of image quality, given by type of examination and patient. The type of radiopharmaceutical and the possibility of placenta transfer also influence the fetal dose (ICRP 84, 2000).

RESULTS

Conventional X-ray

Table 1 (a and b) shows the results of calculated and measured fetal doses. Since the DAP value is used as a reference dose value of an examination (European Commission, Radiation Protection 109, 1999) the fetal doses are in this report given in relation to this value as a conversion factor. The value of this factor mainly depends on used parameter settings and the view of the used radiation field. The extent of uterus inclusion in the radiation field is also of great importance. Variation in equipment and methods make general evaluations uncertain. However, by using the DAP value some of the uncertainties due to differences in equipment, methods and patient size are corrected for and thus gives more reliable results.
This study gives the following conversion factors $C_{conv.} = D_{uterus}/DAP$ ($mGy/Gycm^2$).

1. $C_{conv.}$ is < 0.01 if the radiation fields does not include the uterus
2. C_{conv} is approximately equal to 0.5 when the uterus is only partly included
3. C_{conv} is approximately equal to 1.3 if all radiation fields include uterus.

The uncertainty in the evaluation of the conversion factor is less than ± 30 %.

If the fetal dose is expected to be more than 10 mSv a dose simulation of the examination is recommended, especially if the DAP value is not documented. Then documented fluoroscopy times and number of images are helpful information in the

simulation. For examinations where the fetus is not included in the primary examination fields a simplified general estimation can be done. The fetal dose is then expected to be less than 1-2 mSv.

In comparison with values of fetal doses for some common examinations in United Kingdom (ICRP 84, 2000) (Table 2), this study show lower values for abdomen and pelvis examinations, probably depending on different sensitivity of film screen system. The higher value for barium meal in this study must depend on different examination procedures. Otherwise the dose levels were similar.

A comparison between the used computer programs and the measured values shows that the PCXMC slightly underestimate the dose when the uterus is outside the radiation field, while WinODS slightly overestimate the dose. When the uterus is included in the radiation field both programs overestimate the dose. However, both programs can be used for dose calculations for dose ranges where very accurate estimations are not needed.

Computed tomography

Table 3 shows the results of calculated and measured fetal doses for CT examinations. The $CTDI_w$ value gives the most reliable correlation to fetal dose. If the uterus is included in the examined part of the body the fetal dose is very close to the $CTDI_w$ value. In this study the following conversion factors $C_{CT} = D_{uterus}/CTDI_w$ (mGy/mGy) have been estimated:

1. C_{CT} is < 0.01 if the examined volume does not include the uterus
2. C_{CT} is approximately 1.0 for examinations where the examined volume includes the uterus

The uncertainty in the evaluation of the conversion factor is less than ± 20 %.

If the fetal dose is expected to be greater than 10 mSv a verification of the used $CTDI_w$ value is suggested when a tabulated value is used. Agreements between calculations and measurements are also shown.

The dose levels given by ICRP 84 (ICRP 84, 2000) (Table 4) for common CT examinations in United Kingdom are in agreement with measured values in this study.

Nuclear medicine

The results of dose calculations for the most common examinations of pregnant patients at the Linköping University Hospital are shown in Table 5. The dose was calculated for different ages of the fetus. For one examination placenta transfer is included. For pregnant patients lower activity is normally administered.

Comparison with values given in ICRP(ICRP 84, 2000) (Table 6) shows that administered activities in this study are generally lower, which also gives lower fetal dose.

DISCUSSIONS

Independent of the level of the fetal dose, the patient has the right to know the radiation dose. It is therefore of great important to make a reliable estimation of the fetal dose. The knowledge of doses from different radiation fields and radiopharmaceuticals also gives the opportunity to optimise the examination of a pregnant patient, and the radiation diagnostic examination can then be done with low risk to the unborn child.

For dose estimates later in the pregnancy (after 3 months) other organs than uterus should be included, for example the GI-tract. More measurements and simulations are therefore needed in order to determine more exact conversion factors.

Conventional X-ray examinations where the fetal doses can show great variation are barium meal, barium enema and urography, depending on type of patient, equipment and examination methods. Individual documentation of DAP values and simulation ought to be done for these examinations. Fetal doses at CT and nuclear medicine examinations are more easily calculated since examination parameters and administered activities are often documented for these types of examinations.

DAP and CTDI values and administered activity are values, which easily can be registered and of great use in the calculation of the radiation dose to the patient. The DAP and CTDI values can, together with the conversion factors in this study, also be used to easily estimate the fetal dose.

The DAP dose meter need to be regularly calibrated and the CTDI values regularly checked in order to obtain reliability estimations.

The fetal dose can easily be manipulated in conventional X-ray examinations by changing views, field size and number of images in order to avoid direct exposure of the uterus. The same situation can be valid for CT examinations. For nuclear medicine examinations careful choice of radiopharmaceutical and use of lower administrate activity can substantially lower the absorbed dose to the fetus. The examination time then normally has to be increased to obtain sufficient image quality.

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REFERENCES

ATOM Adult Female Phantom, Handling Instruktions, CIRIS Tissue Simulation Technology, 2428 Almeda Avenue, Suite 212, Norfolk, Virgina 23513, USA. www.cirsinc.com, admin@cirsinc.com, 2002.

European Commission, Radiation Protection 109. European guidelines on diagnostic reference levels (DRLs) for medical exposures, 1999.

EUR 16260 EN. European Commission, European guidelines on quality criteria for diagnostic radiographic images., 1995.

EUR 16262 EN. European Commission, European guidelines on quality criteria for computed tomography, 1998.

ICRP/22/136/01 Draft Report: Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values. http://www.icrp.org, 2001.

ICRP 53, Radiation Dose to Patients from Radiopharmaceuticals. Vol.18 No 1-4, 1988.

ICRP 80, Radiation Dose to Patients from Radiopharmaceuticals. Vol.28 No 3, 1998

ICRP 84, Valentin J. Pregnacy and Medical Radiation. Volume 30 No.1 2000.

Kalander WA, Scmidt B, Zankl M, Schmidt M. A PC program for estimating organ dose and effektive dose values in computed tomography. European Radiology 1999; 9: 555 – 562.

Mattsson S, Jacobsson L, Vestergren E. The Basic Principles in Assessment and Selection of Reference Doses: Consideration in Nuclear Medicine. Radiation Protection Dosimetry, Vol. 80, pp 23-27, 1998.

Nagel H. D. Radiation Exposure in Computed Tomography. COCIR, october 2000.

Rados ODS-60 (WinODS) Userguide doc no 2092 3914 ver 1.0, RTI Electronics Möndal, 1996

Servomaa A., Rannikko S., Nikitin V., Golikov V., Ermakov I., Masarskyi L. and Saltukova L.. A topographically and anatomically unified phantom model for organ dose determination in radiation hygiene STUK-A87, august 1989.

Servomaa A., Tapiovaara M.. Organ dose calculationin medical x-ray examinations by the program PCXMC. Radiation Protecktion Dosimetry, Vol 80, pp213-219, 1998.

Stabin M. G.. Fetal dose calculation workbook. RIDIC, Radiation Internal Dose Information Center Oak Ridge Institute for Science and Education P.O. Box 117, Oak Ridge.ORISE 97-0961. 1998.

Tapiovaara M, Lakkisto M, Servomaa A. PCXMC, APC-based Monte Carlo program for calculatingpatient doses in medical x-ray examinations. STUK-A139, february 1997.

Verdun F R, Meuli R A, Bucher G, Noel A, Stines J, Schnyder P, and Valley J-F. Dose and Image Quality Characterisation of CT Units. Radiation Protection Dosimetry, Vol. 90, Nos 1-2, pp 193-196, 2000.

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Tables

Table 1a

Calculations and measurements of the absorbed dose to the fetus for conventional X-ray examinations at Linköping University Hospital. Measured uterus dose values are used in the calculation of the conversion factors $C_{conv.} = D_{uterus}/DAP$ (mGy/(Gycm^2)).

Examination/ view	**Uterus in the radiation field**	**DAP value Gycm^2**	**PCXMC calculated dose to uterus mGy**	**WinODS calculated dose to uterus mGy**	**Measured dose to uterus mGy**	**$C_{conv.}$ factor mGy/(Gycm^2)**
Hip frontal	can be	0.43	0.019	0.3	0.12	0.28
Pelvis frontal	yes	1.219	0.67	0.9	0.72	0.59
Pelvis partly frontal	no	0.083	0.007	0.08	0.02	0.24
Pelvis lateral	partly	2.448	0.91	0.95	0.60	0.25
Passage	yes	0.359	0.41	0.33	0.26	0.72
Bedside chest	no	0.028	< 0.001	< 0.001	0	0
Lumbar spine frontal	yes	0.460	0.78	0.65	0.24	0.52
Lumbar spine lat.	partly	0.739	0.074	0.2	0.06	0.08
L5 frontal	can be	0.682	0.54	1.01/0.31*	0.91	1.33
L5 laterally	yes	0.831	0.1	0.22	0.17	0.20
Totals:		**2.712**	**1.49**	**2.08/1.38***	**1.38**	**0.51**
Abdomen upper part frontal	no	0.311	0.01	0.01	0.01	0.03
Abdomen lower part frontal	yes	0.254	0.25	0.31	0.31	1.22
Abdomen horizontally	yes	0.224	0.14	0.06	0.12	0.54
Totals:		**0.789**	**0.40**	**0.38**	**0.44**	**0.56**

*A small change in the calculation of the position of the radiation field gives large change in fetal dose value.

Table 1b

Calculations and measurements of the absorbed dose to fetus for conventional X-ray examinations at County Hospital Ryhov. Measured uterus dose values are used in the calculation of the conversion factor $C_{conv.} = D_{uterus}/DAP$ (mGy/(Gycm^2)).

Examination/ view	Uterus in the radiation field	DAP value Gycm^2	PCXMC calculated dose to uterus mGy	WinODS Calculated dose to uterus mGy	Measured dose to uterus mGy	Conversion factor $C_{conv.}$ mGy/(Gycm^2)
Chest PA frontal	no	0.024	<0.001	< 0.001		
Chest lateral	no	0.062	<0.001	<0.001		
Totals:		**0.086**	**<0.001**	**<0.001**	**0.001**	**0.01**
Lumbar spine frontal	yes	0.537	0.66	0.58		
Lumbar spine lateral	partly	0.691	0.074	0.19		
L5 frontal	partly	0.650	0.87	0.31		
L5 lateral	partly	2.274	0.41	0.43		
Totals:		**4.152**	**2.01**	**1.51**	**1.75**	**0.42**
Pelvis	yes	1.275	0.85	1.06	0.66	0.52
Abdomen						
lower frontal	yes	0.939	0.65	0.77		
upper frontal	no	0.151	0.003	0.01		
lower frontal standing	yes	0.136	0.18	0.14		
upper frontal standing	no	0.053	0.004	<0.01		
Totals:		**1.279**	**0.84**	**0.92**	**0.63**	**0.49**
5. Barium meal fluoro + 13 images	yes	20.15	12.3*	13.0*	7.79	0.39
6. Urography 10 images	yes	6.012	4.0	4.6	2.84	0.47

*Uncertain simulation

Table 2

Conventional X-ray examinations: comparison with values from ICRP 84 (ICRP 84, 2000)

Examination	Fetal dose mean (United Kingdom) mGy	Fetal dose max (United Kingdom) mGy	Fetal dose this study mGy
Abdomen	1.4	4.2	0.44/0.63
Chest	< 0.01	< 0.01	0.001
Urography	1.7	10	2.8
Lumber spine	1.7	10	1.38/1.75
Pelvis	1.1	4	0.72/0.66
Barium enema	1.1	5.8	7.8

Table 3
Calculations and measurements of the absorbed dose to fetus for computed tomography examinations at county hospital Ryhov. In the calculation of the conversion factor C_{CT} = $D_{uterus}/CTDI_w$ (mGy/mGy) measured uterus dose values are used. Tabulated $CTDI_w$ values are used in the calculations with Somatom Plus S and measured with Somatom Plus 4 VZ.

Examination	Uterus in the radiation field	$CTDI_w$ mGy	DLP mGycm	WinDose calculated dose to uterus mGy	COCIR calculated dose to uterus mGy	Measured dose to uterus mGy	Conversion factor C_{CT} mGy/mGy	Dose to uterus per DLP mGy/(Gycm)
CT abdomen. Somatom Plus S								
Sequence 1: upper abdomen	no	12	288	1.1	1.0			
Sequence 2: lower abdomen	yes	12	240	13.7	14.1		1.15	58.8
Totals:			**528**	**14.8**	**15.1**	**13.8**		**26.1**
CT chest. Somatom Plus S								
Sequence 1: chest	no	12	288	0.022	0.5	0.21	0.02	0.3
CT trauma Somatom Plus 4 VZ								
Sequence 1: head	no	79.5	1115	0	0			
Sequence 2: neck	no	11.4	185	0	0.0024			
Sequence 3: chest	no	13.7	445	0.3	0.57			
Sequence 4: abdomen	yes	14.9	464	18.2	14.9		1.06	34.1
Totals:			**2209**	**18.5**	**15.5**	**15.8**		**7.2**
CT abdomen. Somatom Plus 4 VZ								
Sequence 1: abdomen	yes	15.5	658	24.8	15.6	15.6	1.01	23.7

Table 4
Computed tomography examinations: comparison with values from ICRP 84 (ICRP 84, 2000)

Examination	Fetal dose mean (United Kingdom) mGy	Fetal dose max (United Kingdom) mGy	Fetal dose this study mGy
Abdomen	8.0	49	13.8/15.6/15.8
Chest	0.06	0.96	0.21

Table 5
Common nuclear medicine examinations used for pregnant women at Linköping University Hospital. Values in brackets are administered activity used if the pregnancy in known. Shaded area include placenta transfer in the calculation

Examination	Kit/nuclide	Activity MBq	Pregnancy			
			early dose mGy	3 months dose mGy	6 months dose mGy	9 months dose mGy
Leucocyte scan	HMPAO/^{99m}Tc	200	1.74	1.34	0.96	0.72
Bone scan	HDP/^{99m}Tc	600	3.12	3.24	1.80	1.50
Renography	MAG3/^{99m}Tc	75	1.35	1.05	0.41	0.39
Lung perfusion	MAA/^{99m}Tc	75 (50)	0,21 (0.14)	0.30 (0.20)	0.38 (0.25)	0.30 (0.20)
Lung ventilation	Technegas/^{99m}Tc	120	Uterus: 0.04			

Table 6
Nuclear medicine examinations: comparison with values from ICRP 84 (ICRP 84, 2000). Values in brackets are administered activity used if the pregnancy in known.

Examination	Nuclide	Administered activity ICRP 84 MBq	Administered activity this study MBq	ICRP 84 early preg. dose mGy	This study early preg. dose mGy	ICRP 84 9 months preg. dose mGy	This study 9 months preg. dose mGy
Bone scan	^{99m}Tc	750	600	4.6-4.7	3.12	1.8	1.5
Lung perfusion (MAA)	^{99m}Tc	200	75 (50)	0.4-0.6	0.21 (0.14)	0.8	0.30 (0.20)
Thyroid scint	^{99m}Tc	400	80	3.2-4.4	0.88	3.7	0.74
Liver colloid	^{99m}Tc	300	200	0.5-0.6	1.04	1.1	0.5
Kidney DTPA	^{99m}Tc	750	200	5.9-9.0	2.4	3.5	0.94