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Fetal organ dose assessment during pelvic CT examination using Monte Carlo/GATE simulation and pregnancy voxelized phantom Katja

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Abstract. In certain situations where there is a risk of fetal-pelvis disproportion (risk that the baby will not be able to pass through the pelvis), pelvic scan examination may be prescribed to the mother at the end of pregnancy. This examination assesses the dimensions of the pelvis by measuring various bone diameters. It also provides details information about pelvis morphology.

Patients are routinely worried about the risk of unwanted effects on the fetus from radiation exposure. Accepting the possibility of adverse effects from fetal exposure and the inability to measure directly in vivo [1]. Medical physicists have developed several techniques to determine the amount of radiation that reaches the fetus. Physicians need to understand these methods and how the numbers they produce relate to possible biological effects on the fetus.

In this study A 16 helical multi-slice CT scanner was simulated. Full technical specifications were obtained from the constructor and simulated in GATE to produce single x-ray beams. Katja voxelized patient phantom, pregnant in 24 weeks, was scanned with pelvis protocol.

The code was used to estimate the absorbed and effective doses in the important organs of the fetus as a consequence of the scanning parameters.

The purpose of this study was to use patient voxelized phantom Katja to assessed fetal organ dose, effective dose and evaluate the risk related to radiation due to pelvis CT examination using Monte Carlo/ Gate platform.

Fetal effective doses were 4.8, 6.3 and 8.2 mSv for 80, 110 and 130 kV respectively. Fetal dose in heart, eye lens, brain was 1.61, 1.6 and 0.8 mGy for 80 kV.

Since the dose to the fetus from a pelvic scan is lower than 50 mGy, when exposed to a single scan teratogenic effects on the fetus are not significant concern [2].

1 Introduction

CT pelvimetry has been recognized and used in daily practice for several years [3-4], although the classical radiographic pelvimetry technique is still used in a number of centers; the argument given in this case is that radiography provides richer anatomical information on the shape of the pelvis than CT. Sometimes it may simply be a continuation of old technical habits. In practice, pelvimetry by radiography [5,6] has not been completely replaced by pelvimetry by CT, despite the many advantages of the latter technique. In particular, the extreme precision of the measurements should be noted, the speed of acquisition of the slice, on the other hand, the pregnant woman stays lying, without moving, without setting up a real particular position.

2 Materials and Methods

2.1 CT scanner

A 16 helical multi-slice CT scanner was simulated. Full technical specifications were obtained from the constructor and simulated in GATE to produce single x-ray beams, (Fig. 1).

The energy spectrum of the source was produced using the SRS78 application and then inserted into GATE versus General Particle Source (GPS).

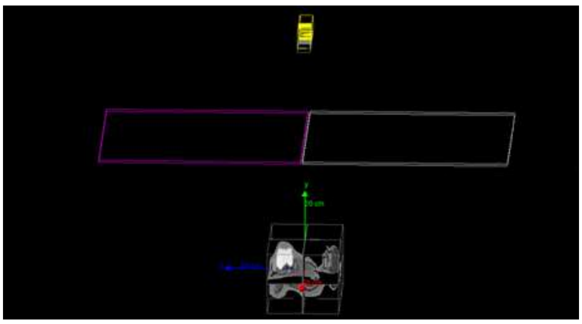

Fig.1. GATE visualization of geometry and katja phantom

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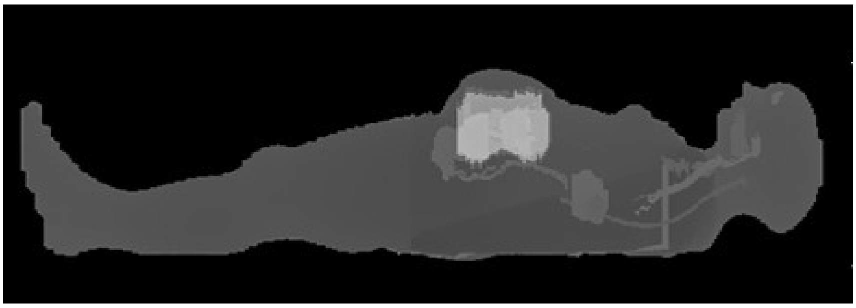

Fig. 2. Katja phantom

To validate the simulated CT geometry, a CTDI 100 data set was simulated for body and head CTDI phantoms with diameters of 32 and 16 cm, respectively [7].

2.2 Monte Carlo

Monte Carlo [8] methods are based on a microscopic modeling of the transport of particles leading to a simulation in 1D, 2D and 3D: it is no longer a question of distribution function but of probability of occurrence of each interaction also called event. The trajectories of the particles are simulated individually from a series of random numbers and cross sections in charge of reproducing physical process.

The solution is derived from the statistical average of quantities obtained from the simulation of a very high number of primary particles (also called "stories" or "events").

In order to simulate the histories of the particles, it is necessary to have a scattering model consisting mainly of a set of differential cross sections that determine the probability distributions of the random variables representing a trajectory.

2.3 GATE

GATE [9] (Geant4 Application for Tomographic Emission) is a simulator developed in C++ and based on the Geant4 [10] development environment. The basic physics consists in simulating all the physical processes involved in particle-matter reactions. The question of random number generators, fundamental in the domain of calculation by Monte Carlo technique, is taken care by the CLHEP library, also developed at CERN.

The package allows to define simulations for any type of imaging modality by emission tomography (nuclear imaging) and transmission tomography (X-ray scanner). Since 2008, GATE has been used to simulate conventional radiotherapy examinations (photon-electron) as well as the future of radiotherapy, namely hadrontherapy. One of the specificities of GATE is its ability to integrate and manage temporal and motion aspects in the simulations.

One of the specificities of GATE is its ability to integrate and manage temporal and motion aspects in the simulations, thus allowing the integration of tracer kinetics, patient or detector motion, or even an irradiation protocol that integrates variations in beam kinematics and conformation during a treatment session.

The development and validation of GATE is done within an international collaboration, the OpenGATE collaboration, set up in 2002 by the Ecole Polytechnique de Lausanne team. This collaboration includes 20 laboratories. In France, the collaboration brings together teams from INSERM, CNRS and CEA [11].

The use of Monte Carlo simulations requires very high computing capacity.

2.4 Characteristic of the phantom

For Katja phantom (Fig. 2) a fetus was segmented from an MRI scan data of a patient's abdomen and pelvis region at 24 weeks of pregnancy. The pelvis and abdomen of the standard female voxel phantom were changed to allow for the segmented fetus. This was accomplished by lowering the amount of the bladder contents, restricting and shifting the intestines posteriorly and properly lengthening the body circumference. Katja includes 136 segmented objects, as well as the placenta, amniotic fluid, umbilical cord, and 16 tissues from the fetus.

3 RESULT

In this work the simulation was run using a new package "Dose by region" which can calculate dose for each organ then effective dose [12] [13].

A pelvic scan was simulated using the parameters reported in table 1.

10^8 primary photons were performed in a High-Performance Computing with the following characteristics: 64 cores, 256 GB RAM, 8T storage.

Table 1. The scan parameters of pelvic CT examination.

kVp	mAs	Pitch	Bowtie filter	KATJA phantom scan length (cm)
80	100	1	Body	13
110				
130				

Effect of tube voltage

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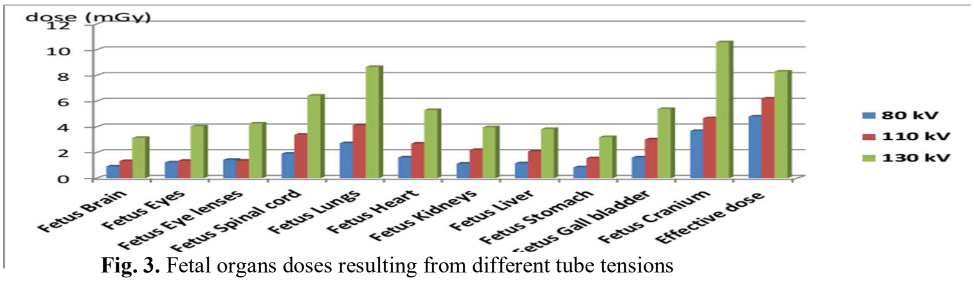

Fig. 3. Fetal organs doses resulting from different tube tensions

(Fig. 3) shows organ dose for eleven tissues for different values tube voltages.
Fetal organ dose was increased linearly with tube voltages in all organs, the cranium received the maximum of dose because of high density.
Although the fetal organ dose reduced by 31.5%, 9.6% ,40.1% and 17,6% for brain, eyes, heart and eye lenses between 80-110 kV and reduced by 70.9%, 69.8%, 68.4% and 66.5% respectively between 80-130 kV. The effective dose was 4.8, 6.2 and 8.3 mGy for 80, 110 and 130 kV.

4 DISCUSSION

The purpose of this study is to use patient voxelized phantom Katja to assess fetal organs doses, effective dose and evaluate the risk related to radiation due to pelvic CT examination using Monte Carlo/ Gate platform and measure of diameter of pelvis.
Teratogenic consequences in the fetus include prenatal mortality, small head size, mental impairment, microcephaly, and organ malformation. These teratogenic effects do not occur below a threshold of 50 mGy to 100 mGy and occur exclusively during the first 15 weeks following conception [14,15].
Comparing of our results, show a good agreement fit, effective fetal dose is lower than 50 mGy for all value tube voltages. So, using the parameter showing in Table 1 can keep the baby safe.
In pelvic scan we usually use a pitch higher than 0.8, because when we increase the pitch we increase the speed movement of table, thus reducing the irradiation time, which reduces the dose to the fetus.
The effective doses for pelvic CT estimated was compared with Semghouli et al. [16] study. Which consisted of examining a total of 30 patients, the data collected for each selected diagnostic pelvic exam included CT acquisition parameters. It has been found that difference between our study and Semghouli et al. is 52% for the effective dose.
This difference is probably due to uncertainties in the X-ray spectrum (filtration), geometry modeled, phantom size, age of the fetus, and density of organs.

5 CONCLUSION

Larger doses of radiation can have significant bioeffects on the fetus.
Although it is critical to only expose the fetus to radiation when absolutely required, Routine CT scans conducted in a single session do not often produce a dose high enough to cause major bioeffects.
A qualified medical physicist can estimate fetal exposure if many imaging investigations are conducted with the fetus in the field of vision. The methods for estimating fetal dose are generally in agreement.
In this paper, Gate has shown their ability to calculate the organ dose and to quantify the risk to the fetus.

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