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Assessment of Computed Tomography Dose Index (CTDI) During CT Pelvimetry Using Monte Carlo Simulation

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ABSTRACT

A pelvimetry examination is sometimes prescribed to a pregnant woman at the end of her pregnancy in order to assess the dimensions of her pelvis prior to childbirth. This examination has long been performed by using X-ray, but is now increasingly being replaced by CT-scan The objective of this study is to assess the radiation doses received during a practical CT pelvimetry examination performed using a Hitashi Supria 16-slice CT scanner. The radiation doses were estimated using Monte Carlo (MC)-based simulation with GATE code to model the 16-slice CT scanner machine. The GATE code operates using GEANT4 libraries. A polyymethyl metacrylate (PMMA) acrylic phantom of 32 cm diameter was modeled to represent the patient's body. X-ray energy spectrum generated using the SRS-78 spectrum processor was used for simulation. The simulation was executed with the same exposure parameters as the practical CT pelvimetry examination with dose parameters of 1 mGy, 0.9 mGy, and 36.6 mGy.cm, respectively, for the weighted CT dose index ($CTDI_w$), the volume CT dose index ($CTDI_{vol}$), and dose-length product (DLP). The MC simulation results provide dose parameters of 1.16 mGy, 1.07 mGy, and 43.6 mGy.cm, respectively, for the $CTDI_w$, $CTDI_{vol}$, and DLP. The differences between the simulation and the practical examination were 16 %, 18 %, and 18 %, respectively. These differences are considered in a quite good agreement. The results were also consistent with other similar studies. This work proves that the Monte Carlo simulation with the GATE code is usable to assess the patient doses during a CT pelvimetry examination.

INTRODUCTION

Pregnant women do not always avoid the need for radiographic imaging during pregnancy. When the pelvis is narrow or in case of pregnancy with breech presentation, delivery is prolonged and emergency Caesarean section may be required [1]. Estimates of the birth canal size can be made according to delivery schedule to avoid complications. X-ray pelvimetry has proven to be a reliable method for estimating the birth canal size [2]. Different technologies are used in X-ray pelvimetry. Based on clinical experience, some radiology departments use conventional radiography, while others use computed tomography (CT) and, more recently, use medical device called EOS imaging systems [3]. In addition to being more and more widespread, pelvimetry by CT examination appears as a basis for a more comfortable method and is also easier to operate [4].

CT scanning is generally associated with a high radiation dose [5]. Recently, studies have been conducted to evaluate the radiation dose received from different examinations performed by using CT scanners [6-9]. In this context, studies on the establishment of diagnostic reference levels (DRLs) have been published in order to define for different types of CT examinations an appropriate dose level that, ideally, should not be exceeded [10-12] to keep the dose received by the patient at an acceptable level. So, according to radiation safety principles,

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before deciding that a pregnant woman should undergo pelvic CT, the practitioner should be aware of possible risks involved and then justify whether the diagnostic benefits outweigh the risks.

There are two types of ionizing radiation effect to humans, deterministic and stochastic effects. The deterministic effect causes damage to a large number of cells. This effect is associated with a dose threshold for the occurrence of cell damage. These effects include malformations, growth retardation, mental retardation, and death [13,14]. The stochastic effect causes damage to a small number of cells and can lead to carcinogenesis. There is no dose threshold, but the risk of the effect increases with the increase of radiation dose.

Both effects depend on the level of radiation dose received during the examination. Monte Carlo (MC) simulation methods provide a convenient way to evaluate the radiation dose received during a CT examination [15]. The method consists of numerically calculating random processes based on probabilistic techniques. A set of codes is used in radiation-matter interaction physics, radiation protection, as well as medical physics and nuclear instrumentation. A prior experimental, validation of the used code is usually performed, with cases that are either identical to those being modeled, or similar or deemed quite similar. Among these codes, we can mention MCNP, MCNPX and GEANT4 [16-18]. In this work, GATE code based on the use of GEANT4 libraries was used [19]. These libraries offer the user the ability to run validated physical models, build complex geometries, generate and track particles, visualize volumes and trajectories of particles, as well as other specific modules. The first version of this package has been published in May 2004 [20].

Some previous studies have addressed the topic of dose assessment in CT pelvimetry. For example, maternal doses in the recently introduced low-dose CT pelvimetry protocol were estimated by Shahgeldi et al [24]. An estimate of radiation doses from pelvimetry performed using different CT methods has been discussed by Phexell et al [25]. Doses delivered during pelvimetry procedures using CT were estimated by Semghouli et al [10]. This current study considers pregnant women who are referred for a CT pelvimetry examination because they are scheduled to undergo a caesarean section. The aim of this study is to assess the dose received during a CT pelvimetry examination using the simulation method on a 16-slice CT scanner.

METHODOLOGY

A CT pelvimetry examination was performed using a Hitachi Supria 16-slice CT Scanner. The CT pelvimetry protocol is applied with a slice thickness of 3.75 mm and a collimation size of 1.25×16 mm. The table pitch, the high voltage, and the tube current were 1.0625, 120Kv, and 11.3 mAs, respectively.

A Monte Carlo simulation was performed with GATE (GEANT4 Application for Tomographic Emission) code with an identical exposure parameters to the practical examination to evaluate the dose to the patient during CT pelvimetry scanning. The GATE Monte Carlo simulation package is an advanced open source software for numerical simulations in medical imaging and radiation therapy. It currently supports emission tomography (Positron Emission Tomography - PET, and Single Photon Emission Tomography - SPECT), and CT simulations. The GATE code has already been validated by several previous studies in radiology [24,25]. The GATE code allows realistic modeling using accurate physics models and time synchronization for detector movement through a script language contained in a macro file. The simulations were performed in photon transport mode with a low energy cut off of 1 keV. In addition, all simulations were performed with 108 particle histories, the tube angle and photon energy were predefined by the SRS-78 spectrum processor and included in the simulation parameters. The splitting (Variance Reduction Technique) was used to improve the photon transport efficiency.

To validate the results of MC simulation, experimental measurements have been undertaken under various conditions by using a 16 cm diameter PMMA acrylic phantom, an electrometer, a calibrated 100 mm long pencil ionization chamber (model 10X6-3CT) and an interface software called Accu-Gold+. The dose received during a CT examination was evaluated by estimating the CTDI in a Hitachi Supria 16-slice scanner. The measurement results were then compared with the simulation results for 80 KVp, 100 and 120 KVp at 100 mAs. An agreement between the simulation and the measurements was obtained. The differences are 9 %, 9 %, and 14 % for 80 KVp, 100 and 120 KVp respectively as shown in Table 1.

An SRS-78 software was used to generate a spectrum energy of X-ray used for simulation. When 0.5 keV energy increments was used, the simulation time was long. To reduce the simulation time, the energy increment was increased to 5 keV [26].

Figure 1 shows the energy spectrum of X-ray generated by the SRS-78 for 120 kVp and 11.3 mAs.

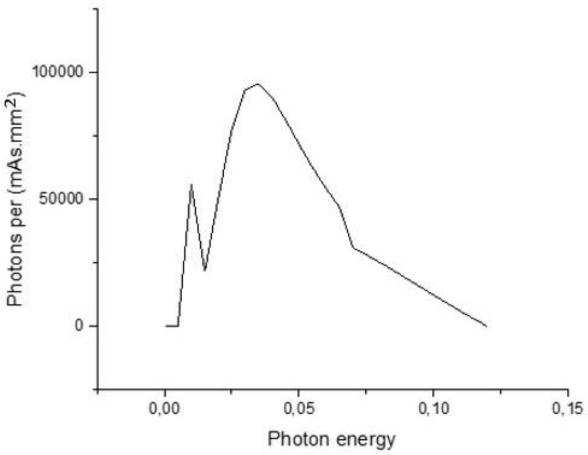


Fig. 1. X-ray spectrum generated by SRS-78 for a tube voltage of 120 kVp and a tube current of 11.3 mAs.

The geometry of the Hitachi Supria 16-slice CT Scan was modeled using the GATE as shown in Fig. 2. In addition, a 32 cm diameter PMMA acrylic phantom was modeled to represent the patient's body. The X-ray beam was modeled along the Z-axis as a pencil beam and then adjusted by a 3.75 mm thick collimator after passing through some filters. The distance from the source to the isocenter was 535 mm.

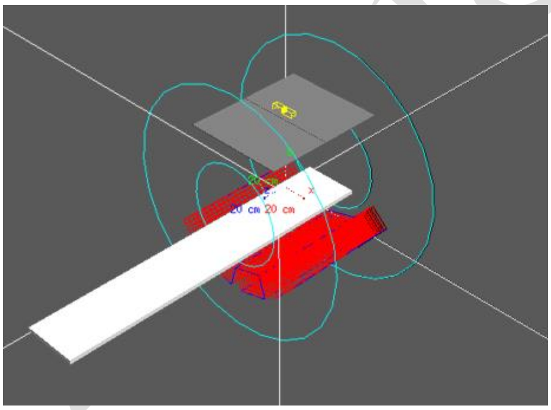


Fig. 2. Geometric diagram of Hitachi Supria 16-slice CT Scan modeled with GATE code.

RESULTS AND DISCUSSION

The CT dose index parameters were evaluated on a Hitachi Supria 16-slice CT scanner. The doses then evaluated by using the GATE code in the MC simulation. Table 1 presents the simulated and measured $CTDI_w$ at 100 mAs for 80 KVp, 100 and 120 kVp.

Table 1. $CTDI_w$ in a Hitachi Supria 16-slice for 80 KVp, 100 and 120 KVp at 100 mAs.

kVp	Simulated $CTDI_w$ (mGy)	Measured $CTDI_w$ (mGy)
80	4.18 ±0.002	3.82
100	6.60 ±0.001	7.25
120	9.60 ±0.001	11.26

A CT pelvimetry examination was performed with a Hitachi Supria 16-slice CT scanner. Dose parameters such as weighted CT dose index ($CTDI_w$), volume CT dose index ($CTDI_{vol}$), and dose-length product (DLP) were recorded. Table 2 summarizes both simulated and measured dose parameters for the protocol of CT pelvimetry.

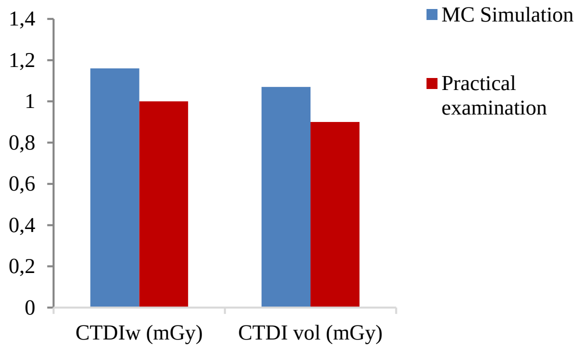
For the protocol of CT pelvimetry examination, the $CTDI_w$ was 1 mGy, the $CTDI_{vol}$ was 0.9 mGy, and the DLP was 36.6 mGy.cm. This examination was then simulated under almost the same conditions using the GATE code. As the results, the dose parameters were 1.16 mGy for the $CTDI_w$, 1.07 mGy for the $CTDI_{vol}$, and 43.6 mGy.cm for the DLP. The difference was 16 %, 18 %, and 18 %, respectively [% Difference = {(|Sm-Ms|/Ms) 100}, where Sm represents simulated CTDI and Ms represents the measured CTDI].

Table 2. Simulated and measured radiation doses for three parameters of the protocol for CT pelvimetry examination.

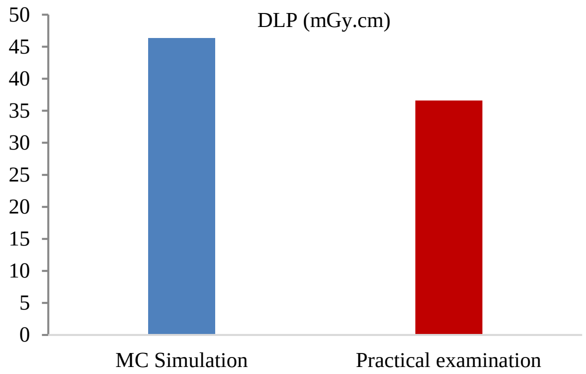
Parameter	Simulation	Measure	Difference(%)
$CTDI_w$ (mGy)	1.16 ±0.01	1	16
$CTDI_{vol}$ (mGy)	1.07 ±0.01	0.9	18
DLP (mGy.cm)	43.60 ±0.40	36.6	18

Differences were found between the results of the practical examination and MC simulation. As summarized in the Table 2, the $CTDI_w$ parameter was about 1 mGy in the practical examination and 1.16 mGy in the MC simulation. For $CTDI_{vol}$ parameter, it was 0.9 mGy in the practical examination and 1.07 in the MC simulation. For the DLP parameter, it was 36.6 mGy.cm in the practical examination and 43.6 in the MC simulation. Nevertheless, the differences of 16 %, 18 %, and 18 % for three parameters considered in close agreement between the measured and simulated results. Figures 3(a) and 3(b) show the patient dose parameters obtained by the practical examination and by the MC simulation presented in histogram style.

The differences are caused by several factors. These include the uncertainty of the geometry in the simulation, the spectrum generated by SRS-78 which provides a photon number per mm^2 × mAs at 75 cm while the distance between the source and the detector of the geometry is 535 cm, the measurement uncertainty and the accuracy of the measured values.



(a)



(b)

Fig. 3. (a) $CTDI_w$ and $CTDI_{vol}$ obtained by practical CT examination and Monte Carlo simulation, and (b) Dose-length product obtained by practical CT examination and MC simulation.

In this study, the $CTDI_{vol}$ obtained based on the MC simulation was 1.07 mGy. This value is more than double the $CTDI_{vol}$ reported by Shahgeldi et al. which was 0.5 mGy [21], slightly higher than the value reported by Phexell et al. which was 0.83 mGy [22], lower than 2.15 mGy, which is the value of $CTDI_{vol}$ for CT pelvimetry reported by Semghouli et al. [23].

Therefore, the result of this study remains comparable to the similar studies performed previously as illustrated in Fig. 4.

The differences are due to particularities of the examination setup parameters and techniques used in the CT pelvimetry examination. It is important to note that the MC simulation results obtained by this study are comparable to the dose parameters used in the practical pelvimetry examination. This results indicate that the MC simulation is reliable to a certain extent and can be used to evaluate the doses received by each organ of the patient's body by each organ of the patient's body.

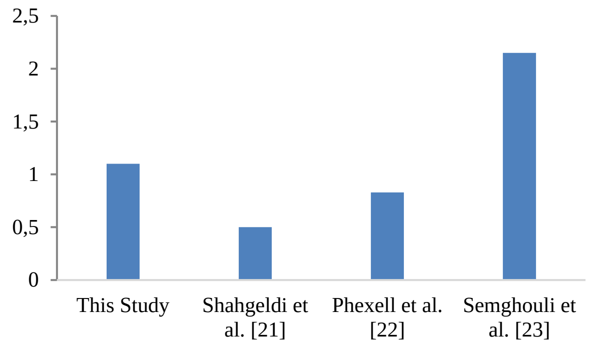


Fig. 4. $CTDI_{vol}$ for the CT pelvimetry examination in this and other previous studies undertaken by Shahgeldi et al. [21], Phexell et al.[22] and Semghouli et al.[23].

CONCLUSION

In this study, the radiation doses received during CT pelvimetry examination performed using a Hitashi Supria 16-slice CT scanner was about 44 mGy. Generally, the results were consistent to a reasonable extent. Furthermore, they were comparable to other similar previous studies. It indicates that the MC simulation is reliable to the extent that it can be used to assess patient doses during pratical CT pelvimetry examination. The Monte Carlo method is today an essential tool and plays a very important role in the simulation of the radiation transport and the evaluation of the dose received by the patient. This simulation model can be used as a source of radiation protection to estimate the dose distribution in the patient's body and also the dose to the fetus in case of a pregnant patient, using an appropriate phantom model.

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AUTHOR CONTRIBUTION

M. Aabid and S. Semghouli equally contributed as the main contributors of this paper. All authors read and approved the final version of the paper.

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