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ORIGINAL ARTICLE

Determination of Embryo/Fetus Doses of Pregnants in Thorax Computed Tomography Scan

Mustafa DEMİR,[1] Nazenin İpek IŞIKCI[2]

[1]Department of Nuclear Medicine, İstanbul University-Cerrahpaşa, Cerrahpaşa Faculty of Medicine, İstanbul-*Türkiye*
[2]Department of Electrical and Electronics, Nişantaşı University Faculty of Engineering and Architecture, İstanbul-*Türkiye*

OBJECTIVE

The aim of this retrospective study was to experimentally estimate the embryo/fetal dose from non-conformal collimation computed tomography (CT) scans of pregnant women during thorax computed tomography (CCT) scans.

METHODS

The study involved 22 pregnant women who underwent CCT scans unintentionally during 2015–2022. Embryo/fetal absorbed doses were calculated by FetDose V4 software and compared with experimental measures using Alderson Rando Phantom and thermoluminescent dosimeters (TLDs).

RESULTS

The CCT of 6 patients (27%) showed the thorax region in the scanned area only; whereas 16 patients (73%) exhibited a wider scan length involving the thorax and abdomen. The average embryo/fetal dose was found to be 1.54±0.71 mGy for 6 patients who had only the thorax area in the CCT, whereas the mean embryo/fetal dose of the 16 patients with thorax and abdomen CCT was calculated as 5.31±1.67 mGy.

CONCLUSION

As a result, non-conformal collimation was observed in the abdomen and thorax in CCT scans leading to a relative increase in the embryo/fetal dose.

Keywords: Embryo/fetus dose; fetus dose; pregnant women; radiation dose; thorax computed tomography.

INTRODUCTION

Thorax computed tomography (CCT) is an important diagnostic method that is frequently used for the diagnosis of lung diseases. CCT can be performed for those who are unaware of their pregnancy or who have a false positive pregnancy test.[1] While the targeted area in CCT is exposed to primary radiation, the fetus is mostly exposed to only scattered radiation. The biological effects of radiation are divided into two groups as deterministic and stochastic effects.[2] Tissue damage, cataracts, alopecia, and infertility are associated with deterministic effects caused by exposure to certain radiation doses. On the other hand, teratogenic and carcinogenic developments are stochastic effects that can increase in proportion to the radiation dose level. In diagnostic imaging, fetal radiation exposure is accidental, but exposure time and radiation intensity determine the magnitude of the embryo/fetal absorbed dose.

The most harmful biological effects of ionizing radiation came from long-term studies of atomic bomb survivors in Hiroshima and Nagasaki. It has been reported

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Dr. Mustafa DEMİR
İstanbul Üniversitesi-Cerrahpaşa,
Cerrahpaşa Tıp Fakültesi,
Nükleer Tıp Anabilim Dalı,
İstanbul-Türkiye
E-mail: demirm@istanbul.edu.tr

that 2800 pregnant women survived radiation doses above 10 mGy. International Commission on Radiological Protection (ICRP), in its 84th report, states that if the fetus is exposed to >10 mGy, the risk of leukemia and cancer may increase by 40%, however, in the 0–15 age group, the cancer risk is around 1/1700.[3,4] Whereas, therapeutic abortion is considered significant at an exposure above 100 mGy. On the other hand, the FETDose V4 code is a computer code dedicated to calculating the absorbed dose and risk to the fetus from computed tomography (CT) using the uterine dose at an average fetal depth normalized to the airborne free entry surface dose. In addition, anthropomorphic Alderson Rando phantom Alderson Radiation Therapy (ART) and TLDs are widely used in the experimental evaluation of embryo/fetal radiation dose.[5,6] The female Rando Phantom is 155 cm tall and weighs 50 kg. It is made of 0.985 g/cm^3 density, 32 plates, and 2.5 cm thick tissue-simulating plastic resembling the female body geometry.

Since radiation damage is dependent on the developmental period of the fetus, the critical periods in pregnancy are classified into: pre-implantation or blastogenesis (0–2 weeks), organogenesis (3–8 weeks), and embryo/fetal development from the 9th week until birth. The all-or-none rule is valid when the embryo is exposed to radiation before implantation and radiation-induced spontaneous abortion is accordingly expected.[7,8] However, the increasing risk of malformation is a matter of concern when the radiation dose exceeds 100 mGy.[2] This study, it was aimed to investigate the embryo/fetal radiation doses of pregnant women who had CCT examined from the thorax and to draw attention to possible technical errors in CCT imaging.

MATERIALS AND METHODS

The study was approved by the Istanbul University-Cerrahpasa, Cerrahpasa Faculty of Medicine Ethics Committee (No: 219488, Date: July 09, 2015). In Türkiye, the Genetic Research and Teratology Counseling Center (GETAM) at Istanbul University-Cerrahpasa, Cerrahpasa Medical Faculty is dedicated to providing the necessary assessment to pregnant patients. Female patients who underwent CCT and learned to be pregnant applied to teratological counseling services. A group of 9 pregnant patients with symptomatic coronavirus during the Covid-19 pandemic were referred to GETAM because they were accidentally exposed to CCT. The screening and exposure techniques of CCT including make, model, peak kilo-voltage, mAs, number of slices, tube rotation (sec), pitch, CTDIvol (mGy), and dose length product (mGy×cm) were retrospectively gathered. In particular, CT images of Covid-19 patients (6/9 patients) revealed an excessive scan length covering the thorax and abdomen. In addition to the patient study, a phantom study was performed to measure embryo/fetal site dose from both thorax and thorax + abdominal CCT scans using anthropomorphic Alderson Rando phantom (ART) and TLD-100. Ethics committee approval numbered 219488 was obtained from Cerrahpaşa Medical Faculty for this study. The consent of the participants was obtained using an assigned form.

Patient Population

Twenty-two pregnant patients who had an accidental CCT performed between March 2015 and December 2022 were included in this study. CCT of 9/22 (41%) patients were done during the Covid-19 outbreak. The mean number of pregnancies per patient was 2.36±0.8, the mean height of the patients was 162.2±4.48 cm, and the mean weight of the patients was 71.9±15.08 kg.

CT Examination and Calculation of Embryo/Fetal Doses

Diagnostic CT scans were performed using various CT devices from different manufacturers (6, 16, 128, and 640 slices). Pregnant women who applied to GETAM were routinely referred to the medical physics department for the estimation of embryo/fetal radiation doses. Detailed information was obtained about the procedure, CT images, and exposure techniques. Information about the patients and CT scan parameters were obtained from a backup site called e-pulse or from CDs brought with the patients. FetDose V4 computer software was used to calculate the dose absorbed by the fetus. Embryo/fetal dose absorbed during CT examination was calculated with the following formula.

$$Df = (NUDV \times CTDI_{soft\ tissue} \times [mAs/100])/Pitch$$

Where Df refers to embryo/fetal absorbed dose, $CTDI_{soft\ tissue}$ (mGy/100 mAs) is the $CTDI_{air}$ to the ICRU muscle ($CTDI_{soft\ tissue} = CTDI_{air} \times 1.07$) used as approximations for the dose to soft tissue and NUDV is the sum of the normalized uterus doses for all 5 mm slabs lying within the scan volume.[9–11]

Phantom Study

The anthropomorphic Alderson Rando Phantom is broadly used to simulate the human body. A tissue-simulating plastic with a density of 0.985 cm^3 is the basic composition of a female Rando Phantom with 32 slices. The Phantom is designed to match a female human body type of 155 cm in height and 55 kg in weight.

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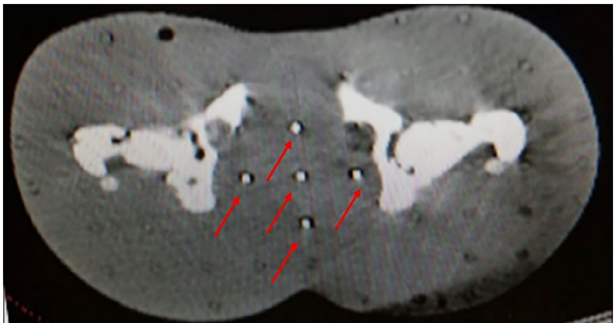

Fig. 1. Axial pelvic image of the anthropomorphic phantom showing the inserted TLDs, (red arrows).
TLDs: Thermoluminescent dosimeters.

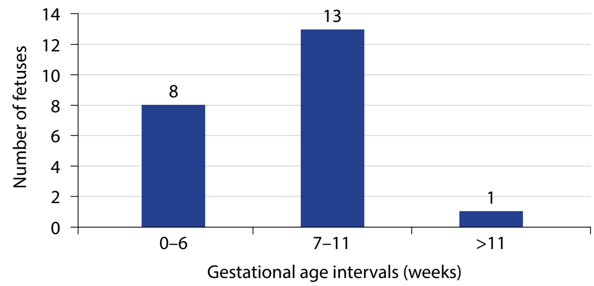

Fig. 2. Number of CCT examinations according to gestational age of pregnant women.
CCT: Thorax computed tomography.

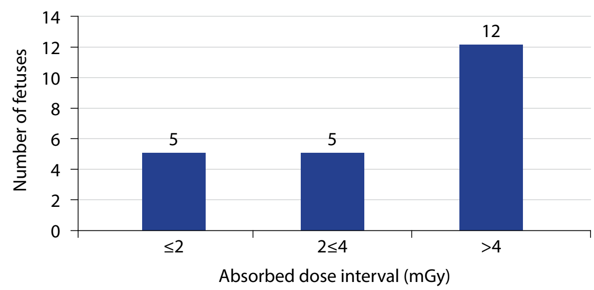

Fig. 3. Number of embryos/fetus by absorbed doses following thorax CT examination of pregnant women.
CT: Computed tomography.

The Rando Phantom is equipped with many holes in the slabs that allow the placement of TLDs. TLD calibration and post-irradiation reading were done in the Secondary Standard Dosimetry Laboratory (SSDL). The SSDL has a Harshaw 4500 model reader that connects a computer with WinREMS software, which can read the TLD card and chip. The TLD heating process is carried out by hot nitrogen gas. The TLD chips are specially designed with doped lithium fluoride (LiF: Mg, Ti) crystals by Harshaw. The reader calibration factor for the TLD and the element correction coefficients of the TLD chips were determined using the standard Cs-137 gamma source in the SSDL according to the manual of WinREMS software. Dose measurements were made on the transverse planes of the phantoms corresponding to the embryo/fetal position, and the dose was measured at 5 locations for each plane (Fig. 1). The Rando Phantom represents the location of the uterus and the approximate location of a developing conceptus. This position was 7.5 cm from the anterior and 14.5 cm from the posterior side of the Phantom. TLDs were placed in various slots in the embryo/fetal slice. The imaging protocols were likely set as determined by the hospital. After exposure, the dose readings were obtained from the TLD detectors at the Cekmece Nuclear Research Center. Measurements were made once and then the average of the measurements was taken.

RESULTS

Patients Study

Pregnant women who underwent CCT scans were sent to GETAM for teratogenic counseling. Embryo/fetal radiation doses were calculated in the department of medical physics. The gestational ages of those who underwent CCT scans were recorded as 6–21 weeks. Of 22 women, 21 (95%) were in the first trimester and one patient (5%) was in the second trimester. The frequency of pregnant women as a function of gestational age ranges is shown in Figure 2. The mean number of pregnancies was 2.36±0.8 and ranged from 1 to 3. The mean height was 162.2±4.48 cm and the mean weight was 71.9±15.08 kg. Only 6 patients showed thorax area on CCT, whereas thorax + abdomen area was shown on CCT of 16 patients. As a result, it was determined that the mean embryo/fetal dose of all participants varied between 0.62 and 8.84 mGy (mean 4.28±2.25 mGy). However, the mean embryo/fetal dose in women with CCT involving one breast is 1.54±0.71 mGy, ranging from 0.62 to 2.48 mGy (Fig. 3). In addition, the mean dose was as high as 5.31±1.67 mGy (range 3.01–8.84 mGy) in those with CCT covering the thorax+abdomen (Table 1) as summarized and the amount of radiation dose received by fetal participants is shown 100.

Phantom Study

On the Rando Phantom (female), 5 TLDs were placed at various points along the embryo/fetal slices. The imaging setup and protocols were most likely used as determined by the hospital, as shown in Figure 4. Phantom

Table 1 Pregnant female information and embryo/fetus doses

Patient no	Stage of gestation (week+day)	Number of pregnancies	Height (cm)	Weight (kg)	Scanning zone	Fetus dose (mGy)
1	6w+4d	3	160	80	C+A	3.79
2	7w+1d	3	165	95	C	0.93
3	21w+3d	3	165	78	C+A	3.01
4	7w+7d	2	157	60	C+A	4.2
5	10w+3d	4	160	105	C+A	3.85
6	6w+1d	1	160	62	C+A	3.02
7	7w+4d	3	158	58	C+A	5.32
8	6w+4d	2	165	85	C+A	6.41
9	10w+0d	3	165	70	C+A	5.56
10	10w+5d	3	160	65	C	2.0
11	9w+3d	2	163	65	C	2.48
12	6w+4d	2	169	78	C	0.62
13	6w+1d	1	158	47	C	1.96
14	6w+2d	2	162	63	C+A	6.92
15	8w+3d	3	160	71	C+A	4.52
16	8w+0d	3	158	105	C	1.26
17	7w+1d	1	171	65	C+A	8.84
18	8w+3d	2	169	52	C+A	7.76
19	6w+2d	2	158	74	C+A	6.42
20	6w+6d	3	163	65	C+A	5.77
21	7w+4d	3	155	68	C+A	5.39
22	8w+4d	1	169	71	C+A	4.2
Mean±SD	7.95w±3.22d	2.36±0.8	162.2±4.48	71.9±15.08		4.28±2.25

C: Thorax; A: Abdomen; w: Week; d: Day; SD: Standard deviation

CT examinations were performed separately according to the two protocols: thorax CT only and thorax+abdomen. Screening parameters and measured embryo/fetal doses are reported in Table 2. As expected, the embryo/fetal absorbed doses were 6, 16, 128, and 640 sliced CT in patients with thorax CT only. The mean embryo/fetal dose was also calculated as 0.173±0.018 mGy. However, thorax + abdominal CT scans showed higher embryo/fetal doses up to 5.05 mGy, 4.91 mGy, 4.85 mGy, and 5.27 mGy corresponding to the same slice count, with a mean of 5.05±0.18 mGy.

DISCUSSION

Excess collimation was observed in thorax CT scans of Covid-19 patients compared to previously scanned pregnant women. In general, embryo/fetal radiation doses obtained from thorax CTs have been previously reported as 1.0 and 1.4 mGy [9]. In another study, the average dose absorbed by the fetus was 1.2 mGy in thorax CT scans, whereas it was 11.1 mGy in abdominal CT scans.[12] More importantly, Xie et al.[13] pointed out the importance of CTDIvol and mAs on embryo/fetal absorbed dose through a Monte Carlo simulation (MCS) study. Accordingly, the mean embryo/fetal dose per mAs was found to be 22.60 mGy/100 mAs, and the calculated embryo/fetal dose ranged between 0.013 and 0.026 mGy in the first trimester.[12] Globally, the ICRP has published average embryo/fetal doses for different radiological studies. The approximate mean embryo/fetal dose obtained from thorax CT has been reported as 0.06 mGy for single detector sequential helix CT.[3] On CT scanners with automatic exposure control, mean mA is used to calculate CTDIvol for embryo/fetal dose determination. The CTDIvol values reported at the end of the CT examinations of the patients were 40% higher than the values displayed in the study panel.[14]

When the fetus is exposed to a dose of 1.04–3.65 mGy, the risk of childhood cancer is 1 in 12500 and 1 in 3300, the hereditary risk is 1 in 200000 and 1 in 5000 based on long-term data. In addition, after CCT with an embryo/fetal dose of 0.02 mGy, the fetus is expected to have a childhood cancer risk of 1 in 500,000 and a he-

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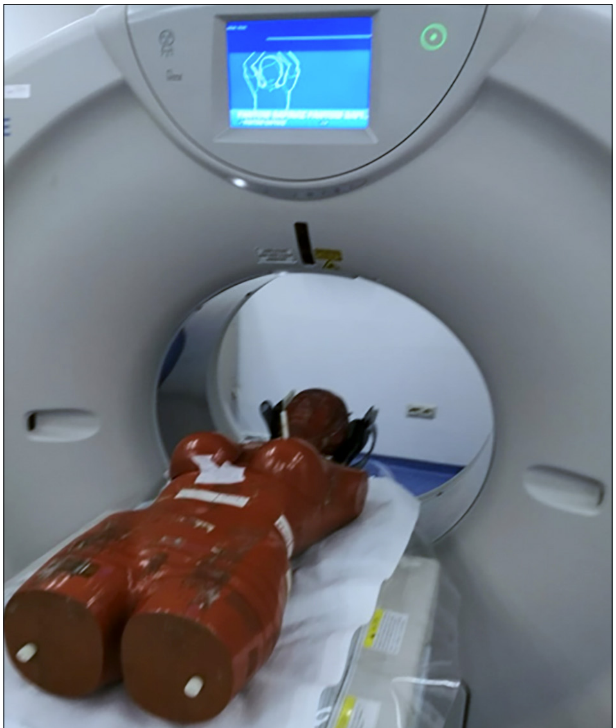

Fig. 4. Phantom positioning for CT scans.
CT: Computed tomography.

reditary risk of 1 in 1000,000, and if the dose of the fetus is increased 10 times, the risk increases 1000 times.[11] On the other hand, the American College of Radiology announced that the accreditation reference CTDIvol value in abdominal CT was 25 mGy and increased to 35 mGy for a 70 kg patient. It has also been reported that the upper embryo/fetal dose limit is 100 mGy, which cannot be exceeded in most CT examinations. However, it is stated that it may be possible for pregnant patients to use a direct measurement technique (or equivalent) to estimate embryo/fetus doses. As mentioned above, embryo/fetal absorbed doses from thorax CT scans range from 0.02 mGy to 2.0 mGy. The current Phantom study showed that the mean embryo/fetal dose was 0.173±0.018 mGy. However, the Phantom doses appear to be considerably lower than the calculated doses (1.54±0.71 mGy) for Covid-19 patients with thorax CT only. The mean fetal dose was calculated as 5.31±1.67 mGy, and the mean embryo/fetal dose of the phantom was 5.05±0.18 mGy in patients who underwent thorax + abdominal CT. Using the same calculation software, Ozbayrak et al.[1] the mean embryo/fetal dose was 1.53 mGy (range: 0.4–2.3 mGy), which is 3.47 times less than the embryo/fetal doses calculated for patients in the current study. MCS study showed that normalized fetal dose estimates ranged from 7.3 to 14.3 mGy/100 mAs, with a mean of 10.8 mGy/100 mAs.[15] In contrast, there was one study that reported the mean percent difference between TLD measurements and MCS as −4.9% and a standard deviation of 8.7%. MCS using digital voxelized phantoms instead of stylized phantoms is the most accurate dose estimation method, but the computation time and complexity of MCS slow down to produce patient-specific estimates.[16] The risk of childhood cancer due to embryo/fetal radiation exposure from thorax CT is 1 in 200,000 and the risk of disease is 1 in 500,000.[11] In addition, 1 in 33 healthy women (3.3%) had birth defects without specific or family history, and 1 in 7 women (15%) had a potential risk of miscarriage following CCT.[17] It is clear that embryo/fetal dose values are quite low to increase the risks of deterministic effects in thorax CT scans. However, the occurrence of the risk of many stochastic effects increases with increasing doses absorbed. Overall, the risk of infection was extremely high during the ongoing coronavirus era. Therefore, the study team in the radiology department faced a lot of stress and rapid performance overhead by wearing protective coveralls, which likely caused nonconformal collimation and abdominal involvement on CCT scans and consequently higher embryo/fetal doses.

Table 2 Thorax+upper abdomen scan parameters in Alderson Rando Phantom

Parameters	6 Slice-CT (mGy)	16 Slice-CT (mGy)	128 Slice-CT (mGy)	640 Slice-CT (mGy)
Embryo/fetal dose mAs	5.05	4.91	4.85	5.27
	39	49	55	55
kVp	139	120	120	120
$CTDI_{vol}$	4.2	4.5	3.84	4.6
Time (s)	16.2	13.62	9.81	7.3
DLP	–	210	177	–
Pitch	1.35	1.37	1.25	1.48

CT: Computed tomography; mAs: Milliampere-seconds; kVp: Peak kilovoltage; $CTDI_{vol}$: CT dose index volume; DLP: Dose length product

CONCLUSION

Embryo/fetus absorbed dose of pregnant women increased significantly from thorax CT scans when the abdomen was frequently included. This increase in embryo/fetal dose is still small to cause a determinant effect, but thorax CT scans should be limited to the lung region to reduce dose and related stochastic effects.

Peer-review: Externally peer-reviewed.

Conflict of Interest: All authors declared no conflict of interest.

Ethics Committee Approval: The study was approved by the Istanbul University-Cerrahpasa, Cerrahpasa Faculty of Medicine Ethics Committee (no: 219488, date: 09/07/2015).

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REFERENCES

1. Ozbayrak M, Cavdar I, Seven M, Uslu L, Yeyin N, Tanyildizi H, et al. Determining and managing fetal radiation dose from diagnostic radiology procedures in Turkey. Korean J Radiol 2015;16(6):1276–82.
2. Hall EJ, Giaccia AJ. Radiobiology for the radiologist. 6th ed. Philadelphia: Lippincott Williams and Wilkins; 2006.
3. International Commission on Radiological Protection. Pregnancy and medical radiation. Ann ICRP 2000;30(1):iii–viii, 1–43.
4. Busby C, Lengfelder E, Pflugbeil S, Schmitz-Feuerhake I. The evidence of radiation effects in embryos and fetuses exposed to Chernobyl fallout and the question of dose response. Med Confl Surviv 2009;25(1):20–40.
5. Damilakis J, Perisinakis K, Voloudaki A, Gourtsoyiannis N. Estimation of fetal radiation dose from computed tomography scanning in late pregnancy: depth-dose data from routine examinations. Invest Radiol 2000;35(9):527–33.
6. Dietrich MF, Miller KL, King SH. Determination of potential uterine (conceptus) doses from axial and helical CT scans. Health Phys 2005;88(2 Suppl):S10–3.
7. Brent RL. Saving lives and changing family histories: appropriate counseling of pregnant women and men and women of reproductive age, concerning the risk of diagnostic radiation exposures during and before pregnancy. Am J Obstet Gynecol 2009;200(1):4–24.
8. Roux C, Horvath C, Dupuis R. Effects of pre-implantation low-dose radiation on rat embryos. Health Phys 1983;45(5):993–9.
9. Osei EK, Faulkner K. Fetal doses from radiological examinations. Br J Radiol 1999;72(860):773–80.
10. Osei EK, Darko JB, Faulkner K, Kotre CJ. Software for the estimation of foetal radiation dose to patients and staff in diagnostic radiology. J Radiol Prot 2003;23(2):183–94.
11. Osei EK, Darko J. Foetal radiation dose and risk from diagnostic radiology procedures: a multinational study. ISRN Radiol 2012;2013:318425.
12. Damilakis J, Tzedakis A, Perisinakis K, Papadakis AE. A method of estimating conceptus doses resulting from multidetector CT examinations during all stages of gestation. Med Phys 2010;37(12):6411–20.
13. Xie T, Poletti PA, Platon A, Becker CD, Zaidi H. Assessment of CT dose to the fetus and pregnant female patient using patient-specific computational models. Eur Radiol 2018;28(3):1054–65
14. Huda W, Randazzo W, Tipnis S, Frey GD, Mah E. Embryo dose estimates in body CT. AJR Am J Roentgenol 2010;194(4):874–80.
15. Rehani MM, Yang K, Melick ER, Heil J, Šalát D, Sensakovic WF, et al. Patients undergoing recurrent CT scans: assessing the magnitude. Eur Radiol 2020;30(4):1828–36.
16. Bostani M, Mueller JW, McMillan K, Cody DD, Cagnon CH, DeMarco JJ, et al. Accuracy of Monte Carlo simulations compared to *in-vivo* MDCT dosimetry. Med Phys 2015;42(2):1080–6.
17. Brent RL. Utilization of developmental basic science principles in the evaluation of reproductive risks from pre- and postconception environmental radiation exposures. Teratology 1999;59(4):182–204.