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UNINTENTIONAL IRRADIATION OF CONCEPTUS BY DIAGNOSTIC IMAGING EXAMINATIONS IN TURKEY

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Exposure of the fetus to medical radiation sources during the diagnostic procedures without intention is one of the most significant concerns in the medical community. In this study, 45 conventional X-ray and computed tomography (CT) examinations of the women who were unaware of their pregnancy were investigated. Effective doses and fetal doses were calculated for each application by using PCXMC and ImPACT CT scan software. The exposure of abdominal CT and abdominal conventional X-ray examinations was found to be over the literature for both the range and the average values. Average effective dose for abdominal CT examinations was calculated to be ∼3.1 times higher than that in the literature. For abdominal CT and conventional X-ray examinations, the mean fetal doses were found to be ∼3.5 times and ∼5.4 times higher than those in the literature, respectively.

INTRODUCTION

Ionising radiation has been widely used for the diagnosis and treatment of many diseases in the medical field since 1895, the year of discovery of X rays. Especially over the last decades, medical imaging techniques developed by interdisciplinary scientific studies have found more accurate diagnostic results compared with the former diagnostic methods. These results have led to an increase in the use of ionising radiation for diagnostic purposes in the medical field but also increased some radiological risk concerns in the scientific community. The most important concerns of many researchers are detrimental biological effects caused by low-level radiation dose on living organisms and in particular to the developing conceptus.

Harmful results of ionising radiation on living organisms can be evaluated in two groups as deterministic and stochastic effects. Main deterministic effects of ionising radiation exposure on fetus are fetal malformation and/or death, inhibition of growth and mental retardation. Congenital abnormalities and childhood cancers may occur in a developing baby as the most important effects of X rays on genetic material after exposing to radiation[(1)]. Therefore, the necessity of the imaging procedure using radiation should be evaluated and justified thoroughly before protective measures were taken for the protection of patient and fetus[(2)].

For women of childbearing age, the prescriber and the practitioner of the imaging study with radiation should inquire pregnancy and give a special attention to the protection of both expectant mother and the unborn child against ionising rays[(3)]. In case of emergencies, especially when the mother's life is in danger, possibility of pregnancy dose not reduces the need for the intentional exposure of patients. Expected benefits of X-ray imaging to the parent should be considered to outweigh the potential risks of the fetus[(4)]. If it is necessary to perform imaging techniques of radiation to the pregnant patients, dose reduction techniques should be applied.

Due to unnecessary or inaccurate diagnostic X-ray examinations, patients or expectant mothers could be exposed to ionising radiation and its detrimental biological effects on developing embryo or fetus in uterus can be observed. In some cases, consequence of applying radiological examinations without awareness of patient's pregnancy or fetus may acquire damages from radiation if it is in a radiosensitive period and radiation may cause fetal death. Even in a situation with no or insignificant risk, patients may feel unnecessary anxiety or even decided to terminate their pregnancies in some cases due to the lack of adequate information about possible harms[(5)]. In order to avoid undesirable results, clinicians also must know for sure the spectrum of harmful biological effects of ionising radiation on living organisms and decide to order the convenient radiological examination by estimating the undesired effects of radiation on the embryo or fetus along with other decision parameters[(6)].

This retrospective study is an assessment of the magnitude of radiation burden to unintentionally exposed conceptus of pregnant women from conventional X-ray and computed tomography (CT) applications in Turkey. For the forty-five diagnostic imaging applications of pregnant women who were exposed to radiation without being aware of their

pregnancy, effective and fetal doses were calculated by using two well-known Monte Carlo dose estimation software. Risks of harmful effects of radiation, including induction of childhood cancer and hereditary effects, were discussed at the end.

MATERIALS AND METHODS

Although it is not obligatory to hire medical physicists in radiology departments in Turkey, it is obligatory to hire at least one for radiation oncology departments of the hospitals. Hospitals without radiation oncology sections have some difficulties to answer the needs of radiology staff for patient dose calculation. Health Physics Department of Sarayköy Nuclear Research and Training Center of Turkish Atomic Energy Authority (TAEA) gives rapid information about these situations for compensation of stressful experiences of patients and supports the radiology departments of the hospitals by calculating fetal (uterus) doses within 2 d. Pregnant patients, who are admitted to different hospitals for various health complaints and underwent imaging examinations without being aware of their pregnancy or responsible staff of the radiology departments in which those examinations performed, can make applications to TAEA for fetal dose calculation after discovering the previously unknown pregnancy situation. In case of emergency, people can also directly communicate to the related department by phone in daytimes except weekends.

This study period covers the years between 2008 and 2013. Patients or staff of the hospitals can reach to the application form on-line, named 'whole-body effective dose and organ doses calculation form', at the TAEA official website. The application form contains patients' specifications (age, gestation week, imaging modality, height, weight, etc.) and examination parameters (kVp, mAs, projection, protocol name, etc.).

It was observed that especially the CT information and parameters are not filled correctly in the application forms usually by patients or sometimes by technologists. Therefore, compact discs containing real parameters of examinations were asked mostly, obtained from hospitals, and opened with MicroDicom viewer software (MicroDicom, Sofia, Bulgaria) in many cases to overcome the risk of miscalculation depending on incorrect information delivered by applicants[7]. Majority of the incidents, reported via forms, were related to abdominal CT and conventional X ray examinations to torso and needed risk assessment of pregnancy by calculating fetal doses. Dose calculations were performed by latest version of ImPACT CT scan (ImPACT, St. George's Healthcare NHS Trust, London, UK) and PCXMC (STUK, Helsinki, Finland) software for CT and X-ray examinations, respectively. They are commercially available computer programs, and both are performing Monte Carlo simulation for calculating patients' organ doses and effective doses in medical applications[8, 9]. Detailed information about these simulation programs and fetal dose calculation methods using them were not given in this work, since they are widely used software and can be found elsewhere[8, 10].

Ethical committee approval was obtained before this retrospective study was prepared to conduct.

Forty-five of them were selected within sixty-one examinations. The rest of the patients who had exposures to the body from collected application forms had insufficient data on their forms and did not allow the authors for reliable calculation or they had exposure to the other parts like cranium, dental or periphery of the extremities (forearm, elbow, knee, etc.).

Information of the parameters used for dose calculations and patients' specifications are given in Table 1. Gestational ages of patients ranged from 1 to 12 weeks with an average of 3.8 weeks for forty-five examinations. Maternal age of patients varied from 20 to 39 y (average 29.2 y).

Deterministic effects of radiation on fetus depend on the fetal dose and gestational age. Developing baby is more sensitive to radiation in comparison with the children and adult[11]. Development stages can be classified as blastogenesis, organogenesis and fetogenesis. In blastogenesis stage where the fetus is the most sensitive to radiation, spontaneous abortion might occur when fetus is exposed to radiation dose of >100 mSv. In this stage, X-ray damage to relatively low numbers of the cell in conceptus may cause a miscarriage.

Gestational age intervals and number of examinations correlation are given in Figure 1. According to the information of the patient application forms, 16 imaging examinations were performed in the blastogenesis stage and it corresponds to 36 % of the total examinations. Percentages of radiation exposure of conceptus in organogenesis stage were calculated as 64 % (29 examinations).

Table 1. Some examination parameters and patients' specifications.

	Conventional X-ray (33 examinations)		Computed tomography (12 examinations)	
	Range	Mean	Range	Mean
Maternal age (y)	22–35	29.2	20–39	29.2
Gestational age (week)	1–8	3.3	2–12	5.2
Patient height (cm)	155–180	167.2	160–172	166.5
Patient weight (cm)	42–85	63.2	55–85	65.2
Applied kV	20–140	75.7	110–140	123.3
Applied mAs	3–320	42.8	48–240	96.4

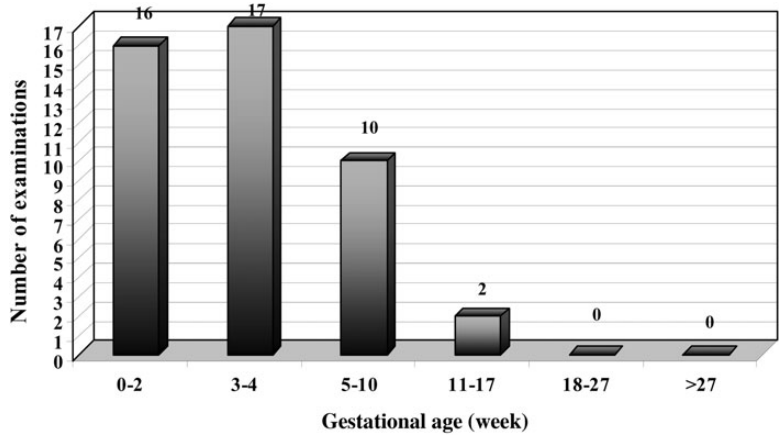

Figure 1. Gestational age intervals.

Table 2. Estimated mean and range of effective doses to pregnant patients.

Equipment	Region	Projection	Number of examination	Range of ED (mSv)	Mean of ED (mSv)
CT	Abdomen[a]	–	10	4.3–86.0	24.5
	Chest	–	2	2.3–5.4	3.9
X-ray	Abdomen	AP	2	0.6–8.5	4.5
	Chest	AP	7	0.1–4.3	1.4
	Hip joint	AP	1	1.3	1.3
	Hip joint	Lateral	1	0.2	0.2
	Lumbar spine	AP	3	0.2–1.3	0.9
	Lumbar spine	Lateral	4	0.2–0.8	0.4
	Cervical vertebra	AP	4	0.01–0.3	0.1
	Cervical vertebra	PA	1	0.3	0.3
	Cervical vertebra	Lateral	3	0.007–0.2	0.1
	Pelvis	AP	2	0.4–1.5	1.0
	Up. abdomen	AP	4	0.4–4.3	1.6
	Up. abdomen	Lateral	1	0.6	0.6

ED, effective dose; AP, anteroposterior; PA, posteroanterior; Up, upper.
[a]Upper abdomen, lower abdomen and kidney protocols are given as abdomen protocols.

RESULTS AND DISCUSSIONS

Estimated effective doses and fetal doses

There is no need to discuss the positive impacts of medical imaging techniques. However, the radiologist or physicians have to make a benefit-risk assessment since there is not any foresight on the possible harms of some radiological protocols comparing with the benefits. The effective dose, which is the most important indicator for evaluating the harmful effects of ionising radiation, is also useful in determining the appropriate design of medical imaging techniques[12]. Effective doses were calculated by the aforementioned software, and the results are given in Table 2.

Results indicated that maximum exposure from investigated imaging examinations comes from abdominal CT and abdominal conventional X-ray protocols. Effective dose value of abdominal CT examinations ranged from 4.3 to 86.0 mSv with an average of 24.5 mSv. Adult effective doses encountered in the literature for abdominal CT protocols ranged from 3.5 to 25 mSv with an average of 8 mSv[12]. Both the range and the average values investigated were found to be over the values from the literature. A similar situation was observed in the chest protocol of conventional X-ray applications. Cervical vertebra applications were found to have the lowest dose exposed to patients undergone conventional X-ray examinations. Applications varied between 0.007 and 0.3 mSv.

Effective dose interval-number of examination relationship is given in Figure 2. It was found to be only one examination over the 50 mSv value. Approximately 51 % of examinations were calculated to be <1 mSv.

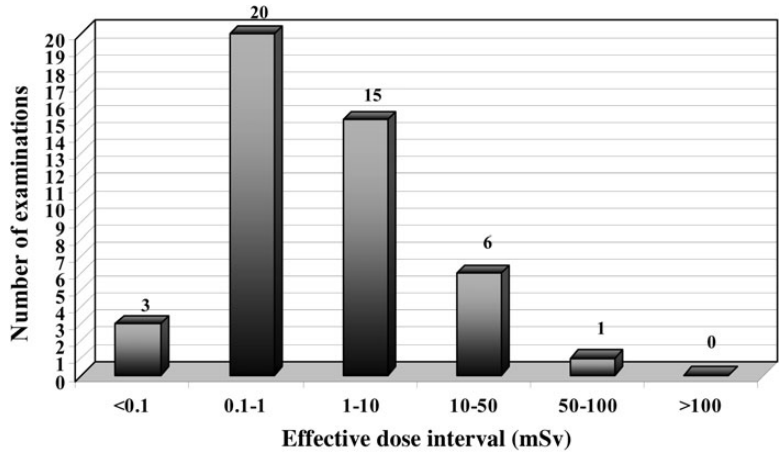

Figure 2. Effective dose interval-number of examination relationship.

Table 3. The mean and range of fetal equivalent doses for CT and conventional X-ray examinations.

Equipment	Region	Projection	Number of examination	Fetal EqD range (mSv)	Mean fetal EqD (mSv)
CT	Abdomen	–	10	7.3–98.0	28.0
	Chest	–	2	0.03–0.06	0.04
X ray	Abdomen	AP	2	1.2–14.0	7.6
	Chest	AP	7	0.001–8.7	1.4
	Hip joint	AP	1	2.6	2.6
	Hip joint	Lateral	1	0.3	0.3
	Lumbar spine	AP	3	0.4–5.3	2.7
	Lumbar spine	Lateral	4	0.4–2.2	0.9
	Cervical vertebra	AP	4	0	0
	Cervical vertebra	PA	1	0	0
	Cervical vertebra	Lateral	3	0	0
	Pelvis	AP	2	0.7–2.9	1.8
	Up. abdomen	AP	4	1.4–9.0	3.5
	Up. abdomen	Lateral	1	0.6	0.6

EqD, equivalent dose; AP, anteroposterior; PA, posteroanterior; Up, upper.

Fetal equivalent doses calculated by related software explained before is given in Table 3. The calculations reveal quite remarkable results, in particular abdomen protocols for both CT and conventional X-ray examinations. In this study, abdominal CT examinations ranged from 7.3 to 98.0 mSv with an average of 28 mSv. The average value and the maximum value for fetal dose encountered in the literature are 8 and 49 mSv, respectively[13]. For abdominal CT examinations, the mean fetal dose was 3.5 times and also maximum fetal dose was 2 times higher than that in the literature.

Likewise, similar high dose exposures were calculated for conventional X-ray abdomen protocols for those patients. Average fetal dose for abdominal conventional X-ray examinations was found to be 5.4 times higher than that in the literature given in Table 4. The maximum fetal dose value was determined to be 3.3 times higher than the maximum value in the literature.

Spontaneous abortion occurred in only two of pregnant patients underwent imaging examination for inspected cases. Every healthy pregnant woman, without any problem or family history, has a risk of miscarriage by 1 in 7 (~15 %)[1]. Therefore, it is not scientifically possible to express that spontaneous abortions were developed after fetal irradiation since smaller radiation doses of <100 mSv were delivered.

Correlation between fetal dose interval and number of examinations are presented in Figure 3. For 78 % (35) of examinations, fetal doses were calculated as smaller than 10 mSv value.

Radiation-related effects and risk assessments

There is no consensus in the scientific community about the magnitude of the risk of radiation-related effects as a result of exposure to low-dose radiation of uterus literally. Based on previous studies made by the survivors of the atomic bombs, it can be said that the risk increases proportionally with the radiation dose according to 'linear no threshold' model. Even some studies were made by using conversion coefficients to calculate the radiation risks from radiation doses[1]. However, these coefficients are used primarily in high doses and dose rates and not confirmed in low doses and dose rates.

Biological response of the cell or tissue to the radiation is quite different from each other in high and low radiation fields. Natural biological defence mechanism, which is called 'adaptive response' by United Nation Scientific Committee on Effect of Atomic Radiation, protects living organisms against radiation-induced damages especially in low doses[14].

Scientific studies carried out with mice in recent years revealed that the measures taken by the immune system increase in low radiation doses. Radiation stimulates the immune system and subsequently the immune system destroys cells that persistent DNA damage, to protect the development of cancer. For low radiation doses, it was monitored that PFC and MLC reaction test results, NK and ADCC activity test results and reaction to Con A 191 test results were increased depending on the dose increment[15].

Cell killing and DNA damage are the basic harmful effects of radiation on living organism and are not generally seen because of low radiation level of the performed examinations in clinical practice. In general, living tissues are capable of repairing the radiation damages. But in higher doses above the threshold, cancer and hereditary effects are possible to be seen due to unrepaired or misrepaired DNA damages.

The most radiosensitive period for conceptus is the first two weeks of gestation (0–9 d), and exposure of >100 mSv dose can result in fetal death since embryo has limited number cell[13]. It is considered that fetal irradiation of <100 mSv dose during this stage, so-called pre-implantation, does not cause malformations in surviving gestation[11]. Some studies carried out in mice showed that, even if the fetus is in the early stage, doses of >0.25 Sv have led to many type of malformations[16, 17].

In the early stage of organogenesis (2–8 week), fetal dose of 100–200 mSv can cause gross malformations. At the later stage of organogenesis (8–15 week), central nervous system of conceptus is highly radiosensitive and mental retardations can be observed for over the 120-mSv radiation exposure[11].

Table 4. Approximate fetal exposures from common diagnostic procedures[13].

Examination	Mean (mGy)	Maximum (mGy)
CT		
Abdomen	8.0	49
Chest	0.06	0.96
Head	<0.005	<0.005
Lumbar spine	2.4	8.6
Pelvis	25	79
Conventional X ray		
Abdomen	1.4	4.2
Chest	<0.01	<0.01
Intravenous urogram	1.7	10
Lumbar spine	1.7	10
Pelvis	1.1	4
Skull	<0.01	<0.01
Thoracic spine	<0.01	<0.01

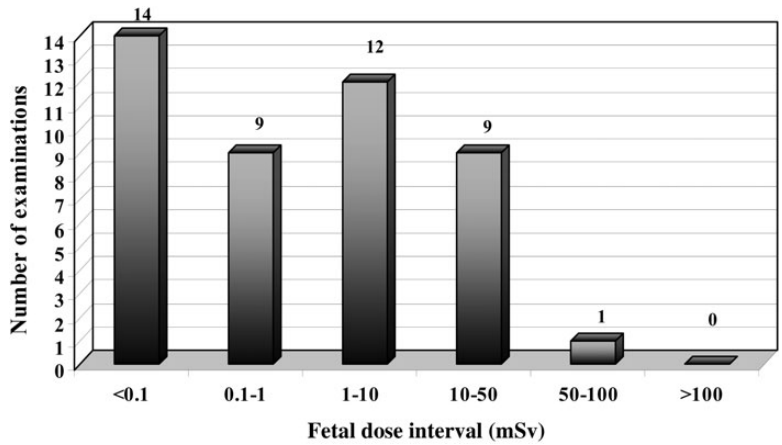

Figure 3. Fetal dose interval for examinations.

In 2007, International Commission on Radiation Protection (ICRP) repeated that harmful tissue reaction, malformation and deterministic effects of prenatal irradiation are not expected in humans exposed to radiation doses of <100 mSv[18]. According to the latest report published by NCRP (National Council on Radiation Protection & Measurements), radiation-induce adverse effects (including hereditary effects and cancer induction) are not expected in a fetus, which has been exposed to radiation doses of <100 mSv[19]. Based on the reports of the ICRP and NCRP, due to the calculated fetal radiation doses remain under the dose threshold of 100 mSv, it can be expressed that radiation-induced childhood cancer and leukaemia, congenital abnormalities, severe mental retardations, etc. are not expected for this study.

CONCLUSION

Forty-five radiological imaging applications of women who were unaware of their pregnancy were radiologically evaluated by calculating their radiation doses. The values of effective doses and fetal doses were found to be higher than the literature values for majority of the examinations. Average effective dose for abdominal CT examinations was calculated to be $\sim$3.1 times higher than that in the literature. For abdominal CT and conventional X-ray examinations, the mean fetal doses were found to be $\sim$3.5 times and $\sim$5.4 times higher than those in the literature, respectively. Dose calculation results showed that cancer induction and hereditary effects are not expected in the fetuses exposed to radiation in all stages of gestation period based on the latest reports of NCRP and ICRP.

These results also revealed that some of the radiological tests might be done improperly in related radiological units. Misuse or non-calibrated devices may cause these kinds of improprieties. The imaging examinations were performed by using general adult parameters because technicians were not having information about pregnancy of patients. Many of radiological imaging applications including X rays may cause negligible effect on conceptus. However, in examinations directed to abdomen or pelvis, it was found that conceptus exposed to remarkable radiation dose from aforementioned imaging tests.

The small number of the cases for the estimation of effective doses is the main limitation of this study. However, in comparison with the literature, mean and maximum exposure parameters applied in radiological tests such as kV and mAs values, calculated effective doses and fetal doses are also giving a hint of non-optimised imaging protocols of the related radiology departments in which those imaging examinations were performed. These results indirectly show a need for education and increase of awareness for stakeholders about basic patient protection procedures including optimisation of the imaging protocols in all around the country.

Primarily, to avoid undesired radiological problems, related imaging tests, maintenance and performance testing should be made on time and well-calibrated devices should be used by well-trained staff. Possibility of pregnancy for each patient in reproductive age should be questioned properly before being applied to radiological imaging tests delivering radiation. Especially in abdominal and pelvic imaging examinations, pregnancy tests should be used before applications. It is not forgotten that ailments of patients admitted to hospitals may be directly originated from pregnancy-related complications such as nausea, vomiting, abdominal pain, back pain, etc. In case of suspicious of pregnancy, ultrasounds and MRI should be used as first-line modality. There is not a report or investigation about harmful biological effects of MRI of <1.5 Tesla on fetus[20]. If there is not a medical necessity, a posterior-anterior projection should be preferred instead of anterior-posterior projection because of the location distance of fetus for abdominal or pelvis radiograph. For the protection of the health of mother and the developing fetus, appropriate precautions should be implemented in accordance with the recommendations of international organisations such as ICRP and International Atomic Energy Agency (IAEA)[21].

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