UNINTENTIONAL IRRADIATION OF CONCEPTUS BY DIAGNOSTIC IMAGING EXAMINATIONS IN TURKEY

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Exposure of the fetus with 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 examinations of the women who were unaware of their pregnancies 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 were found to be over the literature for both the range and the average values. Some risks so-called childhood cancer induction, hereditary effects, decline in IQ and severe mental retardation were calculated for the range of each protocol. It was found that accidental exposure to the fetus in abdominal x-ray examinations, even without targeting the uterus, might increase the likelihood of childhood cancer development and severe mental retardation up to ~3-4 times and ~2-3 times respectively.

INTRODUCTION

Ionizing radiation has been widely used for diagnosis and treatment of many diseases in the medical field since 1895, the date 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 former diagnostic methods. These results have led to an increase in the use of ionizing 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 due to low-level radiation dose on living organisms and in particular to the developing conceptus.

Harmful results of ionizing radiation on living organisms can be evaluated in two groups as deterministic and stochastic effects. Main deterministic effects of ionizing radiation exposure on fetus are fetal malformation and/or death, inhibition of growth, and mental retardation. Congenital abnormalities and childhood cancers may occur on 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].

The prescriber and the practitioner of the imaging study with radiation should inquire pregnancy and give a special attention to protect of both expectant mother and the unborn child against ionizing rays for women of childbearing age [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 ionizing radiation and its detrimental biological effects on developing embryo or fetus in uterus can be observed. In some cases, consequence of radiological examinations applying without awareness of patient's pregnancy, 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 ionizing 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 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 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 effect of radiation, including induction of childhood cancer and hereditary effects were estimated and results were discussed at the end.

MATERIALS AND METHODS

Since 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 by law. 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 of the radiology departments of the hospitals by calculating fetal (uterus) doses within two days. Pregnant patients, who 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 hospitals can reach to the application form online, 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 (CD) 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 relted to abdominal CT and conventional x-rays 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. In addition to calculations of doses, fetal radiation risks were also calculated by the following formula [1]:

$$R = D_f \; x \; RC \qquad (1)$$

where D_f is the fetal dose in mSv and RC is the risk coefficient. In the calculation, dose coefficients were taken as 8 x 10^{-5} per mSv for childhood cancer induction, 0.5 x 10^{-5} per mSv for hereditary effects, 25 x 10^{-3} per mSv for decline in IQ and 43 x 10^{-5} per mSv for severe mental retardation [1][11][12][13]. These coefficients are used primarily in high doses and dose rates and not confirmed in low dose and dose rates. However, many researchers are considered linear no threshold model is the most appropriate model matching with the data and form the basis of radiation protection [1].

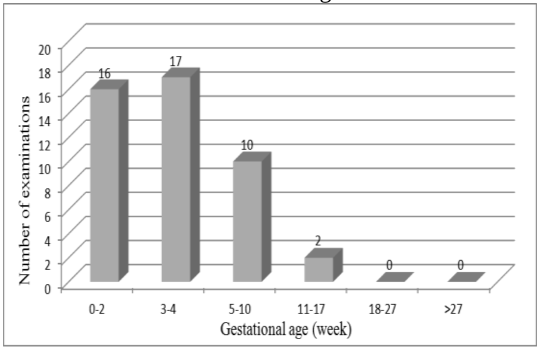
Table 1. Some examination parameters and patients’ specifications

	Conventional x-ray(33 examinations)		Computed Tomography(12 examinations)	
	Range	Mean	Range	Mean
Maternal age (year)	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

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 us 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 3.8 weeks for forty-five examinations. Maternal age of patients varied between 20 years to 39 years (average 29.2 years).

Table 2. Gestational age intervals



Deterministic effects of radiation on fetus depend on the fetal dose and gestational age. Developing baby is more sensitive to radiation in comparison to the children and adult [14]. Development stages can be classified as blastogenesis, organogenesis and fetogenesis. In blastogenesis stage that the fetus is the most sensitive to radiation, spontaneous abortion might occur when fetus exposed to radiation dose over the 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 Table 2. According to the information of the patient application forms, sixteen 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).

RESULTS AND DISCUSSIONS

Estimated Effective Doses and Fetal Doses

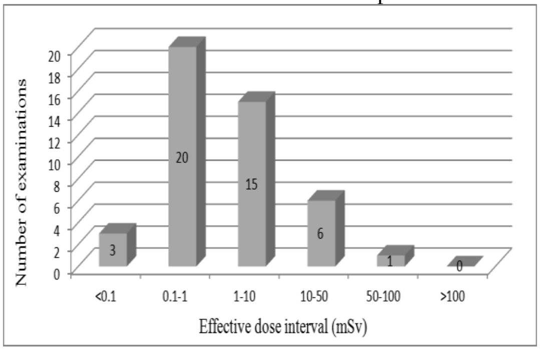
There is no need to discuss the positive impacts of medical imaging techniques. However, the radiologist or physicians have to make a benefit-risk assessment since there is not any foresight on the possible harms of some radiological protocols comparing to the benefits. The effective dose, which is the most important indicator for evaluating the harmful effects of ionizing radiation, is also useful in determining the appropriate design of medical imaging techniques [15]. Effective doses were calculated by the aforementioned software and the results were given in Table 3.

Table 3. 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*	-	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 *: upper abdomen, lower abdomen, and kidney protocoles are given as abdomen protocols.

Table 4. Effective dose interval-number of examination relationship



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 24,5 mSv. Adult effective doses encountered in literature for abdominal CT protocols were ranged from 3,5 to 25 mSv with an average 8 mSv [15]. Both the range and the average values investigated were found to be over the values from 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 was given in Table 4. It was found to be only one examination over the 50 mSv value. Approximately 51% of examinations were calculated to be less than 1 mSv.

Fetal equivalent doses calculated by related software explained before was given in Table 5. 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 28 mSv. The average value and the maximum value for fetal dose encountered in literature are 8 and 49 mSv respectively [16]. For abdominal CT examinations, the mean fetal dose was 3,5 times and also maximum fetal dose was 2 times higher than 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 were found to be 5.4 times higher than the literature given in Table 6. The maximum fetal dose value were determined to be 3,3 times higher than maximum value of literature.

Table 5. The mean and range of fetal equivalent doses for CT and conventional x-ray examinations

Equipment	Region	Projection	Number of examination	Fetal Eq.D. range (mSv)	Mean Fetal Eq.D (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

Eq.D.: equivalent dose, AP: anteroposterior, PA: posteroanterior, Up: upper

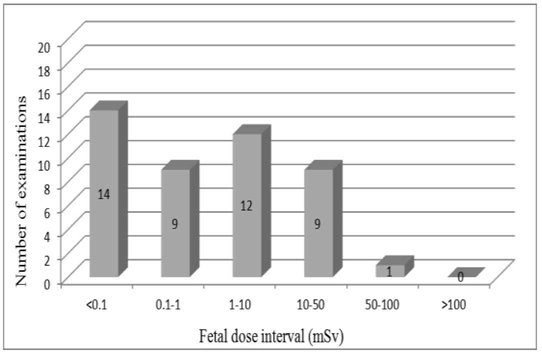
Spontaneous abortion occurred in only two of pregnant patients underwent imaging examination for inspected cases. Every healthy pregnant woman, without any problem or family history, has a risk of miscarriage by 1 in 7 (~15%) [1]. Therefore, it is not scientifically possible to express that spontaneous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

Correlation between fetal dose interval and number of examinations were presented in Table 7. For 78% (35) of examinations, fetal doses were calculated as smaller than 10 mSv value.

Table 6. Approximate fetal exposures from common diagnostic procedures [16]

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

Table 7. Fetal dose interval for examinations



Radiation-Related Effects and Risk Assessments

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

The most radiosensitive period for conceptus is in first two weeks of gestation (0-9 days) and exposure above 100 mSv dose can result in fetal death since embryo has limited number cell [16]. It is considered that fetal irradiation lower than 100 mSv dose during this stage, so-called pre-implantation, does not cause malformations in surviving gestation [14]. However, some studies carried out in mice showed that, even if the fetus is in the early stage, doses above 0.25 Sv has led to many type of malformations [17][18].

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 [14]. In 2007, International Commission on Radiation Protection (ICRP) repeated that harmful tissue reaction, malformation, and deterministic effects of prenatal irradiation are not expected for human in less than 100mSv [19].

Basic risks originated from prenatal radiation dose of studied imaging examinations were calculated and given in Table 8 and Table 9. For children of 0-15 years old, risk of childhood cancer and leukemia, without radiation exposure above background radiation, is ~2-3 per 1000 [16][20]. In this study, risk of childhood cancer ranged from 1 in 1.712 to 1 in 128 for abdomen CT protocols. For abdominal conventional x-ray applications, highest childhood cancer risk were found to be 1 in 983. Calculations reweal that radiation exposure of fetus in abdominal examinations may increase likelihood of childhood cancer up to ~3-4 times for this study.

The highest risk of hereditary effect was calculated as 1 in 2.041 for abdominal CT imaging examinations. The natural frequency of genetic diseases, including congenital abnormalities, has been estimated to be 5-6% [21]. It was found that risk of genetic effects of fetal irradiation is smaller than literature for this study. The highest risks of decline in IQ and severe mental retardations were found to be 1 in 0,4 and 1 in 24 respectively. In this study, decline in IQ is most probably expected for her child of pregnant woman whose uterus exposed to radiation in organogenesis stage. The rate of severe mental retardation originated from natural events in adolescence is about 4-5 per 1000 in the United Kingdom [22]. The highest fetal dose arising from abdominal CT imaging examinations were found to be

27 mSv between 8-15 weeks of gestation when the neural system developed. The maximum risk of severe mental retardation was found to be 1 in 86. It was found that radiation exposure of fetus in the later stage of organogenesis (8-15 week) may increase the likelihood of severe mental retardation up to ~2-3 times for this study.

Table 8. Risk of chilhood cancer and hereditary effect of examinations

Equipment	Region	Projection	Number of examination	Childhood cancer risk (1 in / min. – max.)	Hereditary effect (1 in / min. – max.)
CT	Abdomen	-	10	1.712-128	27.397 – 2.041
	Chest	-	2	480.769-223.214	7.692.308 - 3.571.429
X-ray	Abdomen	AP	2	10.365-893	165.837 - 14.289
	Chest	AP	7	17.857.143-1.435	285.714.286 - 22.962
	Hip joint	AP	1	4.733	75.729
	Hip joint	Lateral	1	43.103	689.655
	Lumbar spine	AP	3	29.070-2.363	465.116 - 37.807
	Lumbar spine	Lateral	4	34.916-2.363	558.659 - 90.909
	Cervical vertebra	AP	4	-	-
	Cervical vertebra	PA	1	-	-
	Cervical vertebra	Lateral	3	-	-
	Pelvis	AP	2	18.519-4.346	296.296 - 69.541
	Up. abdomen	AP	4	9.164-1.397	146.628 - 22.346
	Up. abdomen	Lateral	1	19.841	317.460

AP: anteroposterior, PA: posteroanterior, Up: upper

Table 9. Risk of decline in IQ and mental retardation of examinations

Equipment	Region	Projection	Number of examination	Decline in IQ (1 in /min. – max.)	Mental Retardation (1 in / min. – max.)
CT	Abdomen	-	10	5 - 0,4	319 - 24
	Chest	-	2	1.538 - 714	89.445 - 41.428
X-ray	Abdomen	AP	2	33 - 3	1.928 - 166
	Chest	AP	7	57.143 - 5	3.322.259 - 267
	Hip joint	AP	1	15	881
	Hip joint	Lateral	1	138	8.019
	Lumbar spine	AP	3	93 - 8	5.408 - 440
	Lumbar spine	Lateral	4	112 - 18	6.496 - 1.057
	Cervical vertebra	AP	4	-	-
	Cervical vertebra	PA	1	-	-
	Cervical vertebra	Lateral	3	-	-
	Pelvis	AP	2	59 - 14	3.445 - 809
	Up. abdomen	AP	4	29 - 4	1.705 - 260
	Up. abdomen	Lateral	1	63	3.691

AP: anteroposterior, PA: posteroanterior, Up: upper

CONCLUSION

Forty-five radiological imaging applications of women who were unaware of their pregnancies were radiologically evaluated by calculating their radiation doses and risks. The values of effective doses and fetal doses were found to be higher than literature values for majority of the examinations. Calculation results revealed that decline in IQ is most probably expected for the child of woman whose fetus exposed to radiation in later stage of organogenesis. Especially for abdominal CT imaging examinations, the highest risk of childhood cancers was found to be ~3-4 times higher than the risk of children without radiation exposure above background radiation at the early stage of gestations. Likewise highest risk of severe mental retardation was calculated to be ~2-3 times higher than the risk given in the literature. In this study, it is clearly seen that some of the radiological risks may increase because of medical radiation applications. However, it should be noted that these risks are still very small when compared with the total risks. Medical radiological applications are raising its importance as one of the most significant tolls to use for diagnosis and treatment of diseases.

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 and risks 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-optimized 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 optimization 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. Before being applied radiological imaging tests delivering radiation, possibility of pregnancy for each patient in reproductive age should be questioned properly. Especially in abdomen and pelvis 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 below the 1.5 tesla on fetus [23]. 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 organizations such as ICRP and International Atomic Energy Agency (IAEA).

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