Update about using ionizing radiological investigations in pregnancy: what are the fetal risks?

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Abstract

Imaging investigations can help diagnose a wide range of acute or chronic diseases. The practitioner may face uncertainty when choosing targeted and rapid diagnosis or therapeutic intervention for pathologies associated to pregnancy. Also, mothers undergoing unintentionally, early in pregnancy, chest radiograph or dental X-ray may be anxious about the negative effect of radiation on the infant. In this article, we aim to update: 1) the fetal radiation exposure during different radiological investigations procedures; 2) to describe the main consequences of radiation exposure, depending on gestational age. In a justified medical situation, an exposure under 50 mGy used by the standard radiology procedures does not represent a risk for the fetus.

Keywords: *pregnancy, chest radiograph, CT, X-ray, mammography*

Rezumat

Investigațiile imagistice pot ajuta la diagnosticarea unui spectru larg de boli acute sau cronice. Practicianul se poate confrunta cu incertitudini atunci când alege o intervenție diagnostică sau terapeutică rapidă și țintită pentru o afecțiune asociată sarcinii. De asemenea, mamele supuse neintenționat, la începutul sarcinii, radiografiei toracice sau radiografiei dentare pot fi anxioase cu privire la efectul negativ al radiațiilor asupra copilului. În cuprinsul acestui articol, ne propunem să actualizăm: 1) noțiuni legate de expunerea la radiația fetală în timpul diferitelor proceduri de investigații radiologice; 2) să descriem principalele consecințe ale expunerii la radiații, în funcție de vârsta gestațională. Într-o situație medicală justificată, o expunere sub 50 mGy, utilizată de procedurile standard de radiologie, nu reprezintă un risc pentru făt.

Cuvinte-cheie: *sarcină, radiografie toracică, CT, raze X, mamografie*

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Actualizare despre utilizarea investigațiilor radiologice cu raze ionizante în timpul sarcinii: care sunt riscurile fetale?

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Imaging investigations are commonly used methods for the diagnosis or even for therapeutic purposes in a wide range of acute or chronic diseases. Although their usefulness and safety have been proven, there are several situations where practitioners are reluctant to use these methods due to unfavourable risk/benefit trade-offs. In particular, using these diagnosis methods – especially the ionizing ones, such as computed tomography, angiography, fluoroscopy, mammography or radiography – raises the most serious concerns for both doctors and patients when the patient is pregnant or just before the pregnancy has been confirmed.

The results from a study involving questioning family doctors on the usage of imaging methods in pregnancy and their teratogenic consequences showed that 1% of them would recommend abortion if the pregnant woman had undergone an X-ray and 6% if the pregnant woman had a computed tomography examination(1). Consequently, it becomes essential for physicians of various specialities to be aware of the risks associated with these procedures. The specialist may be ensuring that these diagnostic methods are still adequately used in medical situations that could bring substantial benefits in case of the pathology associated to pregnancy.

We aim to update:

1) the fetal radiation exposure during different radiological investigations procedures;

2) to describe the main consequences of radiation exposure, depending on gestational age.

Ionizing radiation generates a large amount of energy, that is capable of disintegrating atoms with the release of electrons. X-rays, which are used in medicine but also in other fields, are electromagnetic waves with high energy and increased capacity of penetration in various structures (bone, soft tissues, paper, metals).

In the human body, X-rays act directly on various intracellular components and can cause damage at the molecular level by altering DNA. The magnitude of processes depends on the type and amount of radiation and also on the type of cells exposed and their ability to regenerate.

To be able to quantify the radiation intensity that a patient is exposed to during a medical investigation, the absorbed dose and the effective dose must be known.

The dose absorbed by an organism exposed to radiation is calculated by reporting the total amount of radiation absorbed per mass unit (body weight) and is expressed in Gray = joule/kg = 100 rad[2]. The effective dose takes into account both the type of radiation and the nature and sensitivity of each irradiated organ or tissue and is expressed in Sievert (Sv) or rem (roentgen equivalents for human), 1 Sv = 100 rem. Since the radiation doses used for medical purposes are small, mGy (1 Gy = 1000 mGy) and mSv (1 Sv = 1000 mSv) are used to quantify them[3].

Radiation can have immediate or distant effects on the exposed tissue or body. The immediate, deterministic effects are secondary to the immediate and destructive action on the exposed cells – necrosis and cell apoptosis. These negative effects arise when going above the threshold critical dose of radiation, and the severity of cell injuries increases with the amount of radiation to which these cells are exposed.

The long-term effects, known as stochastics effects, are caused by the incomplete healing processes of the cellular DNA, which was previously damaged by the radiation.

Although these long-term effects are more difficult to quantify since they no longer depend on going above a quantitative threshold and on a time interval from the moment of exposure, they need to be thoroughly studied due to their highly severe consequences: neoplasms and genetic mutations.

During pregnancy, the concerns about radiation exposure are increased by the risks associated with fetal consequences. It is well known that during pregnancy the fetus receives 0.5-1 mSv of radiation exposure from the environment, and this amount has no consequences[3]. The risks associated with fetal radiation exposure depend on the dose and on the gestational age at which the exposure occurred. The radiation dose refers to the effective dose that the fetus receives, namely the dose absorbed by the maternal uterus during an ionizing imaging investigation. This radiation dose varies depending on the organ examined, in particular on the distance between the examined organ and the uterus. The radiation dose varies depending on the type of imaging used. The higher the distance between the examined organ and the uterine cavity, the smaller the amount of radiation at which the fetus is exposed, since the radiation ends up being mainly dissipated in the maternal organism.

In the following, we present some imaging procedures used in pregnant patients and fetal radiation doses[4,5].

A. Exposures below 0.1 mGy

a) Radiography of the cervical spine (anteroposterior or lateral incidence): <0.001 mGy

b) X-ray of the extremities, except for the coxofemoral joint: <0.001 mGy

c) Chest X-ray (in the first two trimesters of pregnancy): <0.01 mGy

d) Mammography: <0.01 mGy.

B. Exposures between 0.1 and 10 mGy

a) Abdominal radiography: 0.1-3 mGy

b) Radiography of the lumbar spine: 1-10 mGy

c) Cranial or neck CT: 0.1-1 mGy

d) Thoracic CT: 0.5-1.5 mGy

e) Computed tomography of the spine: 2-10 mGy

f) Digital pulmonary angiography with subtraction: 0.5 mGy

g) Urography: 5-10 mGy

h) Perfusion scintigraphy: 0.1-0.5 mGy

i) Bone scintigraphy with Technetium: 4-5 mGy.

C. Exposures between 10 and 50 mGy

a) Abdominal CT: 1.5-35 mGy

b) Pelvic CT: 10-50 mGy

c) PET CT: 10-50 mGy

d) Whole-body scintigraphy: 10-50 mGy

e) Barium enema: 1-20 mGy.

Notice that in the case of commonly used imaging procedures (radiography, CT), that are correctly performed and targeting structures located below the knee joint or above the diaphragm, the amount of radiation at which the uterus is exposed does not exceed 10 mGy. In this case, it is considered that the effects of radiation on the product of conception are negligible[6] and the risk of prenatal death, malformation and for central nervous system injuries does not exceed the risk encountered in the general population[7]. We emphasize in Table 1 the reported fetal risks after different ionizing radiological investigations.

The gestational age represents the essential factor that determines the type (deterministic or stochastic) and the severity of effects caused by fetal radiation exposure.

The most vulnerable period in terms of teratogenic risk is between 8 and 15 weeks postpartum, although notable effects still have an extremely low probability of occurring at cumulative fetal doses below 100 mGy[7].

Repeated radiological exposures can only reach this threshold: e.g., three abdominal computed tomography examinations or 20 radiographs, or by performing a fluoroscopically guided interventional procedure on the abdomen or pelvis[7].

In the first two weeks after conception, the embryo is very resistant to the malformative effects of radiation. The exposure to ionizing radiation during this period is governed by the "all or nothing" law, which means that either the pregnancy stops spontaneously from evolution, or the development will be without medical consequences because the blastocyst cells can replace any of the destroyed cells. The doses associated with usual imaging procedures, except for fluoroscopic methods, computed tomography or repeated radiographs for the abdomen and pelvis, generally do not exceed 50 mGy[7]. Therefore, performing these imaging procedures immediately after conception does not increase the risk of miscarriage compared to the risk of 10-20% of non-viable pregnancies in the general population[9].

Organogenesis begins immediately after implantation and continues throughout pregnancy, and it is a complex process that goes through several stages.

During this period, the fetus is much more susceptible to the action of radiation. The effects on radiation vary depending on the stage at which the exposure occurs.

In **the embryonic stage** (weeks 2-8 postconception) the process of differentiation and the development of the main organs and systems begin. The fetal exposure to radiation doses above 100-200 mGy is associated with

Table 1 Spontaneous fetal risks and additional risks after exposure to ionizing radiation[8]

Risk	Exposure to environmental radiation	Additional exposure to ionizing radiation <50 mGy
Spontaneous abortion in the first 4 weeks after conception	350000/10^6 pregnancies	0
Spontaneous abortion during another pregnancy	150000/10^6 pregnancies	0
Intrauterine growth restriction	30000/10^6 pregnancies	0
Significant birth defects	30000/10^6 pregnancies	0
Severe mental retardation	5000/10^6 pregnancies	0
Leukemia (<15 years old)/year	40/10^6 pregnancies/year	<1-3/10^6/year

intrauterine growth restriction that persists postnatally, microcephaly and malformations of all the organs, in addition to cell destruction[7]. The imaging procedures involving parts of the body outside the abdomen and pelvis – head, neck, extremities – are not associated with any risks because the level of exposure on the fetus is negligible. Even in cases when the imaging procedures involve the pelvis and abdomen, the fetal dose does not exceed the 100 mGy threshold, which is associated with an increased risk of major malformations.

The fetal stage (weeks 8-15 postconception) is the stage when the differentiation of the neural tube and central nervous system takes place, which makes it the most vulnerable period for the fetus to be exposed to radiation. During this period, fetal exposure causes serious and irreversible damage to the nervous system, leading to cognitive and behavioural disabilities or to various degrees of mental retardation, the incidence and severity of which are proportional to the dose.

The exposure to radiation above the 100 mGy threshold results in the IQ decreasing by 2.5-2.9 points for every 100 mGy[10], and a cumulative fetal dose of 1000 mGy leads to 40% risks of severe mental retardation[7]. However, it is important to keep in mind that the risk of mental retardation, defined as an IQ below 70, is approximately 3% in the general population and that of severe mental retardation is 0.5%, in the absence of any additional radiation exposure[7].

From **week 16 to week 25 postconception**, the risk of malformations or damage to the nervous system is lower compared to the previous stage, and the threshold at which these changes occur is 200 mGy[6]. Nevertheless, radiation exposure during this period is associated with an increased risk of radio-induced cancer, leukaemia or solid tumors that occur in children up to the age of 15 years old. In particular, intrauterine exposure to doses of 10 mGy or 10 mSv increases the risk of leukaemia from 0.2-0.3% to 0.3-0.7%, and at fetal exposure doses of 50 mGy the incidence of radio-induced cancer is approximately 2%[11].

After week 25 postconception, the fetus' sensitivity to the effects of radiation is similar to that of the newborn, and high doses are needed to trigger deterministic effects. However, the risk of stochastic effects remains present.

In conclusion, during pregnancy, the woman may be the subject to complex and urgent medical pathologies. Targeted and rapid diagnosis or therapeutic interventions are essential to reduce maternal morbidity or mortality. The International Committee on Radiation Protection has concluded that cumulative fetal doses below 100 mGy are not associated with deterministic effects[12]. Since the amount of radiation resulting from medical radiological procedures does not exceed 50 mGy except in rare situations, the standard diagnostic methods do not represent a risk for the product of conception. They must be used whenever they are justified by the medical situations. ■

Conflict of interests: The authors declare no conflict of interests.

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