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# ABOUT THE FETAL RISKS FROM DIAGNOSTIC USE OF RADIATION DURING PREGNANCY: A SYSTEMATIC REVIEW AND PROPOSAL OF A CLINICAL PROTOCOL

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**ABOUT THE FETAL RISKS FROM DIAGNOSTIC USE OF RADIATION DURING PREGNANCY: A SYSTEMATIC REVIEW AND PROPOSAL OF A CLINICAL PROTOCOL**

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**ABOUT THE FETAL RISKS FROM DIAGNOSTIC USE OF RADIATION DURING PREGNANCY: A SYSTEMATIC REVIEW AND PROPOSAL OF A CLINICAL PROTOCOL**


**ABSTRACT**

**Aim:** Analyze existing literature about the fetal risks of radiation exposure, producing a clinical protocol to guide radiation exposure in a clinical setting.

**Methods:** An initial query was made on PubMed: "Diagnostic radiography in pregnancy AND radiation", with the limits "published from January 1st 1993 to December 31st 2013, in English or Portuguese". The articles that presented our aim were analyzed according to their MESH terms and created the final query: "((radiation) AND pregnancy) AND diagnostic imaging". Research on April 15th of 2014, with the same limits, on PubMed gathered 688 articles; on SCOPUS 245 additional articles. After reading the title and abstract 298 articles remained. 179 allowed access to full text and were analyzed according to inclusion and exclusion criteria. A total of 103 articles were used and an additional one regarding *In utero* radiation exposure from atomic bombs. The PRISMA statement was followed.

**Results:** Deterministic effects like pregnancy loss, congenital malformations, growth retardation and neurobehavioral abnormalities have threshold doses greater 100-200 mGy, being the risk considered negligible at 50 mGy. No diagnostic exam exceeds this limit. The most crucial time to avoid radiation exposure is from the 8th to the 15th week of gestation. The risk of carcinogenesis is slightly higher than the general population, although very similar. Intravenous contrast is discouraged, except in highly-selected patients.

**Conclusion:** Measures to diminish radiation are essential and affect the fetal outcome. Nonionizing procedures should be considered whenever possible and every radiology center should have its own data on fetal radiation exposure.



**KEYWORDS:** Diagnostic Imaging; Fetal Risks; Pregnancy; Radiation.

## INTRODUCTION

Everyday medical practitioners face the dilemma of exposing pregnant or presumably pregnant patients to radiation from complementary diagnostic exams [1-3]. In fact, irradiation of the fetus is a very common phenomenon [1], but one should be aware of the implicated risks [4].

There are many circumstances for fetal exposure to radiation. The most common one, especially during the first trimester, is accidental as the patient was not aware of the pregnancy [5-11]. To this we add the need for medical diagnosis of the mother (at any given time during gestation) or the fetus (to confirm an abnormality or provide further information, usually after ultrasound during the 2nd and 3rd trimesters). More frequently irradiation during pregnancy derives from diagnostic need for both mother and fetus, if no alternative to ionizing radiation is available [1]. Finally, special consideration should be granted to pregnant radiology staff [6,7,11].

Much of the information regarding radiation exposure of the fetus comes from "opportunistic" accidents in the world's history. Survivors of the atomic bombs of Hiroshima and Nagasaki have shown risks of fetal exposure to radiation, the most common one being microcephaly at 100-200 mSv [5,12-14]. Mental retardation was also observed among survivors (20-30 points per 100 rad; 25-31 points per Gy above 0.1 Gy) [12,13,15,16], as well as growth retardation (permanent above 250 mSv, 25 rad or 0.25 Gy) [5,13], teratogenesis (above 1Gy) and cancer (increased rate of leukemia) [13]. Studies on cancer after intrauterine exposure to the atomic bomb are inconsistent [17]. The Chernobyl reactor accident was also associated with increased rate of cancer [13]. Studies on children exposed to radiation before 15 weeks of gestational age showed a higher susceptibility to these effects [12].

Ionizing radiation is frequently used with the purpose of achieving a medical diagnosis since the discovery of X rays [18] and is still a helpful tool. In recent years there has been a great concern in developing new techniques and methods to decrease the risk of radiation for pregnant women and, just as important, to their fetus [4,19].

Both doctors and patients often have questions about the risks of radiation. Therefore, creating a guideline is not only a useful tool for every medical practitioner but also a necessity [1]. The main objectives of this systematic review are to analyze the existing literature about the risks of radiation exposure and safety of contrast agents. Additionally, a clinical protocol is proposed to guide radiation exposure in a clinical setting.

## METHODS

The present article is a systematic review that aims to analyze the existing literature about the fetal risks from radiation exposure during pregnancy. An initial query was made on PubMed: "Diagnostic radiography in pregnancy AND radiation", with the limits "published from January 1st 1993 to December 31st 2013, in English or Portuguese". This research yielded a total of 381 articles. Those who presented the same objective as intended in this systematic review where analyzed according to their MESH terms. Gathering the most frequent MESH terms the final query was created: "((radiation) AND pregnancy) AND diagnostic imaging". On April 15th 2014, the total of articles retrieved from this research on PubMed was 1462. After applying the same restrictions to publication date and language, 688 articles remained, 261 of them reviews. The same query and research limits were applied on SCOPUS, gathering an additional 245 articles (Fig. 1 – Flowchart of the methods). After reading the title and abstract, when available, 635 were excluded.

The main inclusion criteria considered:

- Radiation doses absorbed by the fetus;
- Risks of radiation from diagnostic exams to the fetus;
- Protection measures for diagnostic radiology exams in pregnant women.

The following excluding criteria were also used:

- Studies on radiotherapy;
- Studies on occupational hazards of radiation;
- Risks of ultrasound;
- Discussion of ethical problems regarding radiation usage;
- Molecular studies of radiation rather than clinical ones;
- Articles with an iconographic purpose;
- Studies on animals other than Humans;
- Studies with the objective of comparing diagnostic exams for specific pathologies regardless of the risks for the fetus (for example: comparison of sensitivity and specificity of two different diagnostic exams).

From the 298 final articles, 179 allowed access to full text and were analyzed according to different variables: dosages of radiation absorbed by the fetus according to the irradiated area of the pregnant woman, effects and safety limits of radiation. A total of 103 articles were used and an additional on regarding *in utero* exposure from atomic bombs (Fig. 1 – Flowchart of the methods). The PRISMA statement was followed for the construction of this systematic review. As a result of our research from the literature, a protocol for medical use was designed.

## DOSAGE OF RADIATION TO THE FETUS

Background radiation is considered to vary across the globe [4] between 1.3-5.8 mSv/year [20], being that the average annual effective dose from it is about 3.6 mSv (0.36 rem) for an adult [3,15,21,22] and 0.5-1 mSv or 1.1-2.5 mGy [23,24] for a fetus during the entire period of gestation [3,25-28]. The fetus is more radiosensitive than the mother [28,29].

If a pregnant woman is in need of medical care and, to achieve diagnosis, requires the use of a diagnostic procedure that will expose her unborn child to radiation, we need to take into account not only the type of energy but also the quantity of photons, size of the patient and vulnerability of irradiated tissues. However, quantifying the dosage delivered to the fetus is not an easy task [21,30].

In radiographic and fluoroscopic examinations, if the uterus is outside the field of view, the fetus is only exposed to scattered radiation in minimal doses [31,32]. Therefore, the fetal exposure increases if the uterus is within the field of view (Table 1). It appears that posteroanterior chest x-rays exposes the fetus to less radiation than the anteroposterior projection [31]. The dosage applied to the fetus in radiography depends on the patient thickness, the direction of projection, the depth of the fetus from the skin surface and x-ray technique factors [25,33] (Table 1).

Maximum exposure of the fetus to radiation comes from abdominal computed tomography (CT) [18,25]. However, the dosage is minimal and the patient can benefit significantly from the exam [25] (Table 1). If the abdomen is not in the field of view, the fetus is only exposed to scatter radiation [24]. The fetal radiation dose from a CT depends on kilovolt peak, milliamperes, slice thickness [34], gestational age, the depth of the fetus and proximity of the uterus to the field of interest [25,35] (Table 1).

The mean effective dose of radiation for each procedure to the mother, the fetal exposure and the fetal equivalent dose (Table 2) and the number of exams needed to reach the accepted cumulative dose of

fetal exposure (Table 3) are presented. The measurements vary extensively, requiring each radiology department to have access to its own data.

## RISKS TO THE FETUS FROM RADIATION OF DIAGNOSTIC EXAMS

When using radiation we have to consider two kinds of effects: deterministic and stochastic. Deterministic effects are those whose severity increases with the dose of radiation, having a threshold dose below which its effect is clinically irrelevant. For them to have an effect on the fetus, the threshold dose must be reached. After this limit, the severity of the effect increases with the dose [3,5,13,16,32,34,36-45]. Stochastic effects are those whose probability of occurring increases with the dose, not caring for a threshold dose because the result is the same (acting on one single cell or a group of them). The severity of the effect is dose-independent [3,5,13,16,21,32,34,37-45].

The effects of radiation on the fetus depend on the stage of the pregnancy, radiation dose [5,8,11,13,15,23,32,46-48] and fetal cellular repair mechanisms [25]; demographic factors (patient age and weight), medical history factors (coexisting diseases, genetic factors, medication use and radiation history) and procedure factors influence as well [3,16,23,28,40,42,49]. We can divide the fetal effects of radiation in:

1. Pregnancy loss;
2. Congenital malformations (teratogenesis) [21,34];
3. Neurobehavioral abnormalities [13];
4. Fetal growth retardation [9,36,50];
5. Carcinogenesis [9,21,34,36,50,51].

### 1. Pregnancy Loss

At the beginning of every pregnancy the risk of spontaneous miscarriage is about 15% [3,16,24,32,36]. After conception and during preimplantation and preorganogenesis, the embryo cells are omnipotential. This means that it is unlikely for malformations to occur by the effects of ionizing radiation during these stages. Other cells can replace adjacent cells that have been deleteriously affected. This period is called “the all-or-none period” [11,13,14,36,49].

If the exposure to radiation exceeds 100 mGy or 100 mSv during the first 2 weeks after conception, the "all-or-none" phenomena can result in spontaneous abortion instead of a completely unaffected embryo [3,5,11,14,16,20,28,34,38,44,45,48,49]. From the fourth to eight week of gestation, the threshold goes up to 150mGy [42], 200 mGy [45] or 250 mGy and 500 mGy [36,52]. After 26 weeks the risk of neonatal or fetal death rises with doses above 1Gy, with a threshold of 100 mGy [34,53,54].

Exposure to less than 5 rad (50 mGy) has not been associated with increased fetal anomalies or pregnancy loss [25,45,46,55]. The exposure to radiation on its own is not an indication for terminating the pregnancy [5,9,13,25,46] and should only be considered if the exposure dose is higher than 100 mGy – "Danish rule" [7,20,24,31,39,49,56]. Some propose a limit dose of 150 mGy [8].

## 2. Congenital Malformations

In every pregnancy the background risk for birth defects is about 3% [3,13,16,24,32,36]. The most sensitive period for malformations is from the 2nd to 8th week of gestation, during organogenesis [13,21,34,50] and during the early fetal period (up to 15th week) [11,14], with a threshold of 100 mGy [15,18,23,28,31,38,48,56-58]. A threshold of 150 mGy [3,8,10,25,41,59,60], 200 mGy [3,11,15,20,36] or 250 mGy [25,45] has been suggested. After 16 weeks, the threshold is about 500 mGy to 700 mGy [11,45,52]. During the last trimester major organ malformations and functional anomalies are unlikely [13,14]. There has been no evidence of congenital malformations at doses below 50 mGy or 5 rad being this value the accepted cumulative dose of ionizing radiation for the entire gestational period [11,16,20,25,31,55,56,61]. No diagnostic exam exceeds this limit [9,13]. The risk of malformations is significantly increased above 150 mGy (15 rad) [13,16,26,46]. When the dose of exposure exceeds 100 mGy the probability of congenital birth defects increases 10% [62].

In the light of current knowledge, diagnostic x-rays, CTs or nuclear medicine procedures cannot be considered a risk for malformations [11,20,25,26,53].

## 3. Neurobehavioral Abnormalities

The background risk for neurological development problems is about 1% [3,24,32] up to 6% [5] The most sensitive stage for mental retardation and microcephaly is from the 8th week to 15th week of the gestational period [3,9,11,13,15,16,36,47,58,63]. Exposure up to 20 weeks of development increases the risk of microcephaly and mental retardation [13,21]. However, from the 16th to the 25th week the

central nervous system is less radiosensitive [3,13-15,63]. After the 25th week it becomes radioresistent [13].

Mental retardation has a threshold of 100 mGy to 250 mGy [3,13,15,16,20,25,28,38,44,45,48,55] or 120 mSv [18] and is not directly linked to microcephaly [13,48].Severe cases occur with higher doses: 350-500 mGy [16,20,36,45] or even 1 Gy [20,34], 120-230 mGy between 8th and 15th weeks, 210 mGy between 16th and 25th weeks [13]. The IQ loss is about 25 to 31 points per 1 Gy beyond 100 mGy of radiation [11,15,41,45,63] or 21-29 IQ points per Gy, 30 points for every Sv [13]. Eight weeks after conception, intellectual damage has not been demonstrated [58]. But others find that at 8 to 15 weeks the incidence of severe mental retardation establishes a linear connection without a threshold dose, with an increased risk of 40% per gray of radiation [9,14,15,50,63] or 40% per 100 mSv to 200 mSv (200 mGy) [5]. After this period, the incidence is lower and doses from 20 mGy to 250 mGy may show cognitive loss [50], although it is more common at high doses (>=200 mGy) [64]. In the 16 to 25 week stage the average IQ loss is approximately 13-21 points per Gy (per 100 rads) at doses above 700 mGy [13,15,63]. Microcephaly occurs at a threshold of 100 mGy [28], 200 mGy [48] or 350 mGy to 500 mGy [31,36].

Based on the evidence seen so far, no diagnostic exam (x-ray, CT or nuclear medicine procedures) can cause neurodevelopment effects [20].

### 4. Fetal Growth Retardation

Growth retardation due to radiation exposure has a risk of 4% in all pregnancies [3,16,24,32]. It occurs mainly during the first trimester, after 14 days of conception [34]. Exposure to radiation up to 20 weeks of development increases the risk of growth retardation [21]. It shows a dose threshold of 100 mGy to 250 mGy [16,25,44,55], in some studies up to 500 mGy [20,36,45,52], 1 Gy [15] or 50-100 mSv [1,15]. Growth retardation usually is not permanent and the fetus will recover [5].

Dental radiography during pregnancy is associated with low birth weight [13,16,65].

## 5. Carcinogenesis

Cancer and hereditary effects after radiation exposure occur without a threshold dose [9,17,24,25,31,49,52,60,66] and appear at the same age as spontaneous ones [50]. The risk of this occurrence is constant throughout the whole pregnancy [15,28,34,48] except for the first two/three weeks of pregnancy when the risk is low [51,58]. After radiation exposure to the fetus there is an increase in risk for all cancers [14,26,30,32,35,67] (including solid tumors [11,16]) and leukemia, especially acute myeloid leukemia. However, this is not statistically significant [67].

After pelvic procedures like barium enema or CT, the carcinogenic risk is similar to the natural incidence of fatal carcinogenic risk before age 15 [14]. If the absorbed dose is 5 rad, the risk of childhood cancer is 0,3% (0.2-0.8%) - the same value as the natural risk for fatal childhood cancer [14-16,47,58]. The risk can be of 0.06% per 10 mSv or 10 mGy [1,28,39] or 0.06% per 1 rad [47], 5% per Sv (100 rem) [5] (Table 3). Others say that 100 mGy of radiation increases the risk for childhood cancer by 0.1% [52]; a dose of 10 mSv during the last trimester increases the risk of leukemia by 40%. 10 mSv at any stage of the pregnancy increases the risk of leukemia by a multiple of 1.5. Doses above 10 mSv increases the risk coefficient 6% per Sv [5]. The most consensual attitude is to consider a risk slightly higher than the general population, but still very similar [45].

Most of the articles included in this review mention leukemia as the most common carcinogenic phenomenon associated with *in utero* radiation [9,32,37,42]. However, leukemia associated with high exposure to radiation is not more severe than a spontaneously occurring leukemia [36]. The background risk is about 3.6 per 10000; after exposure increases to 5 per 10000 [9]. *In utero* exposure to 0.01 Gy increases the risk of cancer in the first and second decades of life from 0.03% to 0.04% [37].

Some studies report that radiation exposure at all gestational ages increase the risk of childhood leukemia [21,68] but others find that there is little evidence of any increased risk of childhood acute lymphoblastic leukemia associated with maternal x-rays during the pregnancy [69]. In some cases it has been recorded an excess of maternal x-ray exposure among children with acute lymphoblastic leukemia but the statistical analyses and experimental data were reassuring and do not support this connection [68].

Although perfusion scanning exams do not pose a risk for deterministic effects they can be linked to cancer or genetic effects, regardless of the dose [62]. Carcinogenesis associated with diagnostic radiation is a dose independent event but the risk seems relatively low with doses less than 10 rad (100 mGy) [3,14,16,37,41,42,70] or 10 mSv [22,70]. A cutoff of 50 mGy has also been proposed [41].

**Complementary use of contrasts**

Intravenous contrast is discouraged during gestation, except in highly-selected patients where there is no other alternative to obtain important diagnostic information [71]. These contrast agents are used in CT and MRI to detect, characterize and stage diseases [72]. There are two main contrast agents: iodine or gadolinium-based.

Radioiodine crosses the placenta and starts to accumulate in the fetal thyroid since the 12th week of gestation, not exceeding the 100 mGy limit [20,23,41,46,66,73]. We have to consider the possible risk of hypothyroidism and thyroid cancer induction to the fetus, so radioiodine is contraindicated during pregnancy [3,20,23,24,26,34,49,74,75]. Internal uptake of iodine occurs mostly during the 16th to 25th week stage [15]. However, there aren't sufficient human studies on fetal thyroid depression due to iodine [46,53] and it has not been observed with the administration during pregnancy [28,39]. It is considered generally safe during pregnancy and therefore iodinated contrast could be used during pregnancy after assessing the risk-benefit ratio [7,8,24,39,49,74,76,77]. If the mother received iodinated contrast material during her pregnancy, the thyroid function of the newborn should be evaluated in his first week of life [23,26,37,41,49,73,75]. Evidence of mutagenic or teratogenic risk does not exist, but there is a lack of human studies [3,23,24,37,48,66,75].

Gadolinium-based contrast cross the placenta, enter the fetal circulation and are excreted into the amniotic fluid, where they remain for some time [3,39,41,66,78,79]. It appears there are no teratogenic or mutagenic effects in humans when using these agents [3,39,41,46,66,72,75,76] but gadolinium's safety has not been established [3,23,34,37,74,79]. Apparently nephrogenic systemic fibrosis and dissociation of toxic-free gadolinium are some of the effects in discussion [46]. At higher doses than the ones used in human studies gadolinium has been associated with growth retardation and congenital anomalies [26]. Gadolinium should be contraindicated during pregnancy, only used when the benefits outweigh the risks, with extreme caution [8,27,28,39,47,49,74,76,80].

Barium sulphate is used during fluoroscopic exams and appears to be safe for the fetus [81].

**Computed Tomography**

Computed Tomography (CT) examinations on pregnant women are usually in areas away from the uterus, so the fetus is not directly exposed to radiation. The risk in these cases is scatter radiation that only hits low levels of radiation, thus carrying a small risk for the fetus [29].

CT of maternal head and chest have negligible fetal exposure. Maternal pelvic CT may increase the risk of cancer [53]. Computed tomography pulmonary angiogram exposes the fetus to similar or lower doses of radiation as V/Q scans [82]. Helical CT has an average fetal exposure dose smaller than ventilation-perfusion lung scanning [83].

**Magnetic Resonance Imaging**

Non ionizing procedures should be considered whenever possible [26,42,43,84-86]. In fact, Magnetic Resonance Imaging (MRI) should be the second line examination, after ultrasound, because it is an expensive, complex and less available exam [6,46,76,80,87-89].

MRI can be performed at any stage of the gestational period, but safety during the first trimester is not yet established [16,46,49,78,79]. The major concerns are heating effects of radiofrequency pulses and effects of acoustic noise on the fetus [6,26,41,47,49,74,89-91]. Thermal heating can cause biologic damage, related to cell migration, proliferation and differentiation, up to and including miscarriage [74,87,91]. The central nervous system is especially sensitive to heat rising. A 2°C rise over 24h can result in abnormalities like neural tube and cranio-facial defects [6,90,91]. Some say that MRI should be avoided in the first trimester to avoid excessive heating and high fetal exposure; however, after 24 weeks (when the fetal hearing is developing) is not easy to give additional protection from acoustic noise to the fetus [3,41,92]. Acoustic damage appears to be a more theoretical risk and not a significant practical issue [8,49].

MRI shows no harmful effects on the fetus under 1.5 Tesla [7,18,26,28,39,41,49,93], considered generally safe for use in pregnant women [46,76,84]. In some radiology centers higher field strengths are used with no apparent risk to the fetus. The use of 3 Tesla equipments is gradually being introduced in clinical practice. Field strengths above 2.5 Tesla should be avoided [3,26,41,92]. Safety of the fetus is overestimated because the effect of heat dissipation by convection in the amniotic fluid is overlooked. There should be more studies on this matter [93].

Until today no evidence of conclusive harmful effects to the fetus from MRI exists [3,8,41,47,78-80,87,89,91].

The risk is considered to be negligible at 50 mGy or less [3,5,8,13,15,16,23,28,38,43,52] and diagnostic exams have lower doses [3,23,24,37,45,48,52,75]. Deterministic effects have thresholds

greater than 100-200 mGy (below are considered safe) [14,32,45,56,64] and the most crucial time to avoid radiation exposure is from the 8th to the 15th week of gestation [86]. Measuring the dosage of exposure is important to determine the risk to the fetus [28,61].

## MEASURES TO DIMINISH THE RISKS OF RADIATION

Accurate imaging helps to achieve a definitive diagnosis, deciding proper treatment, avoid complications and unnecessary interventions [76,80]. Withholding proper diagnostic imaging care can result in significant harm for the mother and therefore to the fetus, considered an irresponsible medical action [64]. Protection in radiology follows some basic principles: there should be no risk without benefit, prescribed limits should not be exceeded and, at all times, the "ALARA" concept (as low as reasonably achievable) should be kept [21,23,26,38,40-42,46,52,77]. Therefore, measures to reduce the dosage to the fetus should be implemented.

### Screening for pregnancy

The first step to take is screening for pregnancy [2,38,40,45,78,79]. The "10 day rule" states that, in women of childbearing potential, non urgent radiography examinations that involve pelvic irradiation should be restricted to the first 10 days of the menstrual cycle [51,54,57,58]. Hence avoiding irradiating the fetus before the mother knows that she is pregnant [51] and the risk of pregnancy loss [57].

Recently, the accepted interpretation is that if the patient's menstruation started less than 10 days, the chance of pregnancy is very low and no cause of concern [54]. Most radiology departments no longer follows this principle [57].

In all situations, informed consent should be acquired, if the patient is stable [38,40,79].

### General measures

Ionizing radiation should be avoided especially during the first trimester but, whenever possible, through the whole pregnancy ultrasound and MRI should be preferred [26,41,76,85,86]. Special care is advised between 10 and 17 weeks because of the risk for central nervous system teratogenesis. In this period, non urgent exams should be postponed [9,47].

Additionally, all radiologic equipment should be well-maintained and periodically inspected for radiation safety [2]. It is important to monitor the radiation dose of every exam [5,40].

For all diagnostic exams is important to minimize exposure time [2,35,44,46,58,61,77,94-96]. In a general way, protraction and fractionation of exposures of ionizing radiation to the embryo decrease the magnitude of the deleterious effects of deterministic effects [36]. Radiography, fluoroscopy and computed tomography share the following measures:

- Lead shielding whenever possible [5,8,14,16,23,24,28,38,40,41,43,61,76,77];
- Collimators [3,5,23,28,41,46,48,61,77,97,98];
- Minimize the number of acquisitions [2,23,41,42,48,55,61];
- Scan the minimum body area needed to provide sufficient guidance [3,24,32,41,42,61,99,100].

Specific technicalities adopted in radiographic, fluoroscopic and CT examinations are detailed in the clinical protocol section.

## CLINICAL PROTOCOL

Every female patient in reproductive age should be screened for pregnancy before undergoing diagnostic radiation exams. If the pregnancy is a possibility or confirmed the risks of radiation to the mother and fetus need to balance with the benefit of the exams.

Deterministic effects like pregnancy loss, congenital malformations, growth retardation and neurobehavioral abnormalities have threshold doses greater 100-200 mGy [14,32,45,56,64] (Table 1 Protocol), being that the is considered to be negligible at 50 mGy or less [3,5,8,13,15,16,23,28,38,43,52]. No diagnostic exam exceeds these values [3,23,24,37,45,48,52,75](Fig. 2 – Comparison of the minimal threshold doses for the deterministic effects of radiation with the accepted cumulative radiation during pregnancy). Moreover, the most crucial time to avoid radiation exposure is from the 8th to the 15th week of gestation [86]. The risk of carcinogenesis is slightly higher than the general population, but still very similar and should be considered during the entire gestational period [45].

Intravenous contrast is discouraged during gestation, except in highly-selected patients where there is no other alternative to obtain important diagnostic information [71].

**For radiography and fluoroscopy:**

- Highest peak kilovoltage possible that results in acceptable image contrast [33];
- Lead shielding whenever the abdomen or pelvis is not being imaged to protect the uterus from external scattered radiation [5,14,16,28,38,40,43,61,76,77]. If a specifically designed shield is not available, lead aprons should be reserved specifically for this task [101];
- Minimize fluoroscopy time [2,44,58,61,77,94,95] and the number of images acquired during digital subtraction angiography and cinematic acquisitions [2,55,61];
- Magnification only if necessary [41,61];
- Perform pulsed fluoroscopy at the lowest pulse rate that provides sufficient image quality [41,61,77];
- Maximize the distance between the x-ray source and the receptor and the distance between the patient and the receptor [40,61,77];
- Collimators [5,28,41,48,61,77];
- Decrease Filtration[5] with copper [77];
- Avoid taking radiographs during fluoroscopy [77];
- Increase tube voltage [77];
- Posterior-anterior projection should be preferred to anterior-posterior projection [18,28].

In a general way, protraction and fractionation of exposures of ionizing radiation to the embryo decrease the magnitude of the deleterious effects of deterministic effects [36].

**For Computed Tomography:**

- Lead shielding if it does not affect the image result, best with circumferential shielding [5,8,23-25,41,43,98,99,102];
- Reduce kilovoltage peak [3,4,23,24,35,41,42,52,96,98,100], milliampere-second setting [4,41,42,96,100], the length of the scan [35,46,96] and the number of acquisitions [23,41,42,48,61];
- Center the patient in the CT Gantry [99];
- Use a low tube current-time product for all acquisitions after the preliminary scan [3,23,24,42,43,48,52,61,73,98];
- Scan the minimum body area needed to provide sufficient guidance [3,24,32,41,42,61,99,100];

- Increase the pitch [3,23,41,42,61,97,98];
- Limit Z axis [23,35,98];
- Internal barium shielding with use of oral 30% barium sulfate solution [23,41,43,99];
- Customize protocols to patient size and clinical indication [98].

Since CT scans are associated with higher radiation exposure dosage than other medical exams, its use should be restrained [21,76]. Here the alternatives (ultrasound and MRI) have to be considered and offered to the patient if the benefit is higher than the risk [9,21,38].

Every radiology center should have its own data on fetal radiation exposure in order to determine the risks [28,61].

## CONCLUSION

With the increase of technology and availability of diagnostic exams, more and more pregnant women are irradiated unaware of their current state. The risks of fetal exposure to radiation are still very misunderstood by the general population and, to some degree, even by medical professionals. When using radiation to achieve a diagnosis, one has to balance the welfare of the mother and of her unborn child, weighing the risks and benefits. [21,64]

Deterministic effects like pregnancy loss, congenital malformations, growth retardation and neurobehavioral abnormalities have threshold doses greater 100-200 mGy [14,32,45,56,64], being that the risk is considered to be negligible at 50 mGy or less [3,5,8,13,15,16,23,28,38,43,52]. No diagnostic exam exceeds these values [3,23,24,37,45,48,52,75]. Moreover, the most crucial time to avoid radiation exposure is from the from the 8th to the 15th week of gestation [86]. The risk of carcinogenesis is slightly higher than the general population, but still very similar [45] and should be considered during the entire gestational period [45]. Intravenous contrast is discouraged during gestation, except in highly-selected patients [71].

Non ionizing procedures like ultrasound and MRI should be considered whenever possible [26,42,43,84-86]. Ideally, every radiology center should have their own data on fetal radiation exposure in order to determine the risks [28,61].

## LIMITATIONS

During the construction of this systematic review the most hindering obstacle found was the conflicting data. An attempt to present the most information was made. Additionally, there were few original articles on fetal doses of exposure to radiation and absorbed values. More studies are needed in order to warrant the safety of diagnostic exams using radiation.

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### Important Information Regarding Radiation Dosimetry

In order to adhere to the ALARA concept, authors should not submit manuscripts that describe techniques that have used inappropriately high radiation exposures for children. Furthermore, when CT has been used, the text should include the CTDI (as a single value when there is one exam or as a range in multiple exams) in manuscript submissions. This will provide significant information for appropriate dosimetry.

## Types of Papers

### Original article

This is the most important type of article because it provides new information based on original research. An original report is new because of the imaging findings in a disease or syndrome; it is new because of unique interventional processes; it is new because it expresses new manifestations or complications or follow-up of a disease or disorder. Original reports can be prospective or retrospective. They can be clinical or basic research. This type of article must not exceed 18 double–spaced typed pages excluding tables and pictures.
Format:

- Structured Abstract which should be divided into the following sections:

1) Background – reason for study
2) Objective – give hypothesis being tested
3) Materials and methods – brief but specific to number of subjects, how collected, and what was done
4) Results – the findings of the study with statistical significance
5) Conclusion

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Introduction: Briefly describe the objective of the investigation and explain why it is important.
Materials and methods: Describe the research plan, the materials (or subjects), and the methods used, in that order.
Explain in detail how disease was confirmed and how subjectivity in observations was controlled.
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Discussion:
Describe the limitations of the research plan, materials (or subjects), and methods, considering both the objective and the outcome of the study. When results differ from those of previous investigators, explain the discrepancy.
Conclusion:
In one or two sentences, present the message to be remembered when all else is forgotten. Describe the conclusion of the study, based solely on the data provided in the body of the report. Conclusions must relate directly to the objective of the paper as defined in the title and first paragraph of the report. Do not use abbreviations. Do not use reference citations.

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Brief article (6 or fewer double spaced typed pages) stating the author's personal opinion on a contentious or timely topic. Minimum illustrations. Author will review articles to align his/her viewpoint.
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A short explanation of a certain method or procedure, alteration of a method, or new equipment of interest to radiologists. Limited to 6 double-spaced typed pages. References limited to 8.
Format:

- Abstract in paragraph form of less than 125 words
- A brief, one–paragraph introduction giving the general background
- Body of report:

  Introduction with general background.

  Description of new technical innovation.

  Discussion.

**Case report**

Short discussion of a single case with unique features not previously described. A case report must be unique by imaging findings, a unique manifestation of a disease or disorder or by making unique use of imaging to reveal a disease or disorder. Images of a second case may supplement either the discussion or the illustration of findings, but a single case must remain the concentration. Limited to 6 double-spaced typed pages. References limited to 8. Authors limited to 5 who are affiliated with the institution that managed the case.
Format:

- Abstract in paragraph form (<125 words) and includes:

  1) Reason to report

  2) What was unique

  3) Ramification of this report

- Body of report:

  Introduction – is a brief paragraph giving general background and specific interest of the case.

  Case report – Stress should be on the radiologic aspects; clinical information must be limited to that which provides a background for the radiologist.

  Discussion – Concise and focuses on the specific message and significance of radiologic methods. A review of the literature is not appropriate.

Since we receive many case reports, we will attempt to publish those accepted as rapidly as possible. However, priority in getting to publication will be given to original articles and review articles.

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Scholarly examination of recent developments on a certain topic as reported in the literature. No new information is described but personal experiences may be expressed. Reviews are not encyclopedic like a chapter in a textbook; rather, they include only the highlights. Limited to 20 double–space typed pages.
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This is a teaching exercise with the message in the figures and their legends. Text is no more than 9 double–spaced typed pages, and there may be as many as 30 figure parts; however, no new information is included. The value of the paper turns on the quality of the illustrations as well as the timeliness and utility of the message.
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- Book

  South J, Blass B (2001) The future of modern genomics. Blackwell, London

- Book chapter

Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) The rise of modern genomics, 3rd edn. Wiley, New York, pp 230-257

- Online document

  Cartwright J (2007) Big stars have weather too. IOP Publishing PhysicsWeb. http://physicsweb.org/articles/news/11/6/16/1. Accessed 26 June 2007

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**Fig. 1**

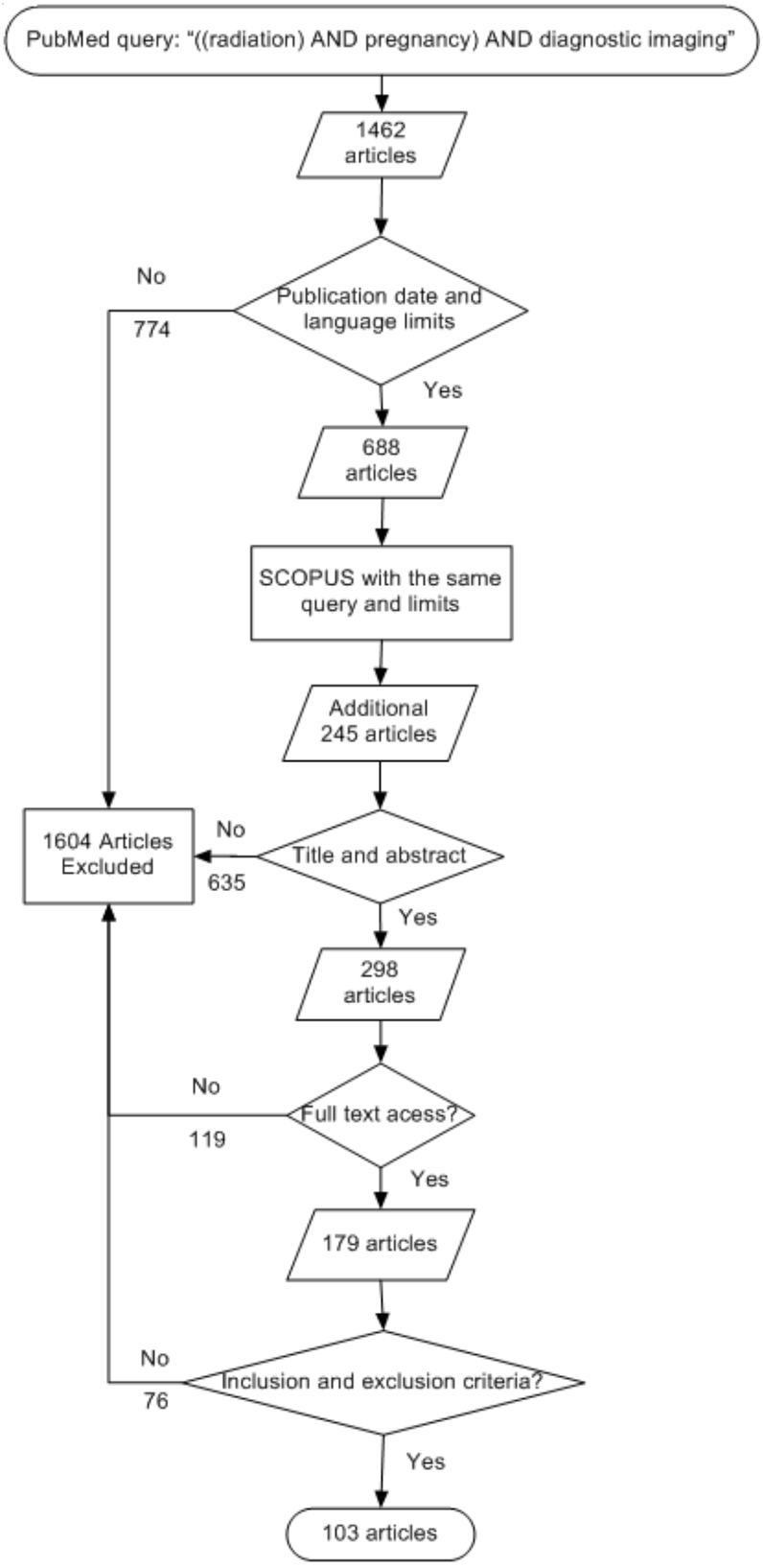
PubMed query: "((radiation) AND pregnancy) AND diagnostic imaging"
1462 articles
Publication date and language limits
No
774
Yes
688 articles
SCOPUS with the same query and limits
Additional 245 articles
Title and abstract
No
635
1604 Articles Excluded
Yes
298 articles
Full text acess?
No
119
Yes
179 articles
Inclusion and exclusion criteria?
No
76
Yes
103 articles

**Fig. 2**

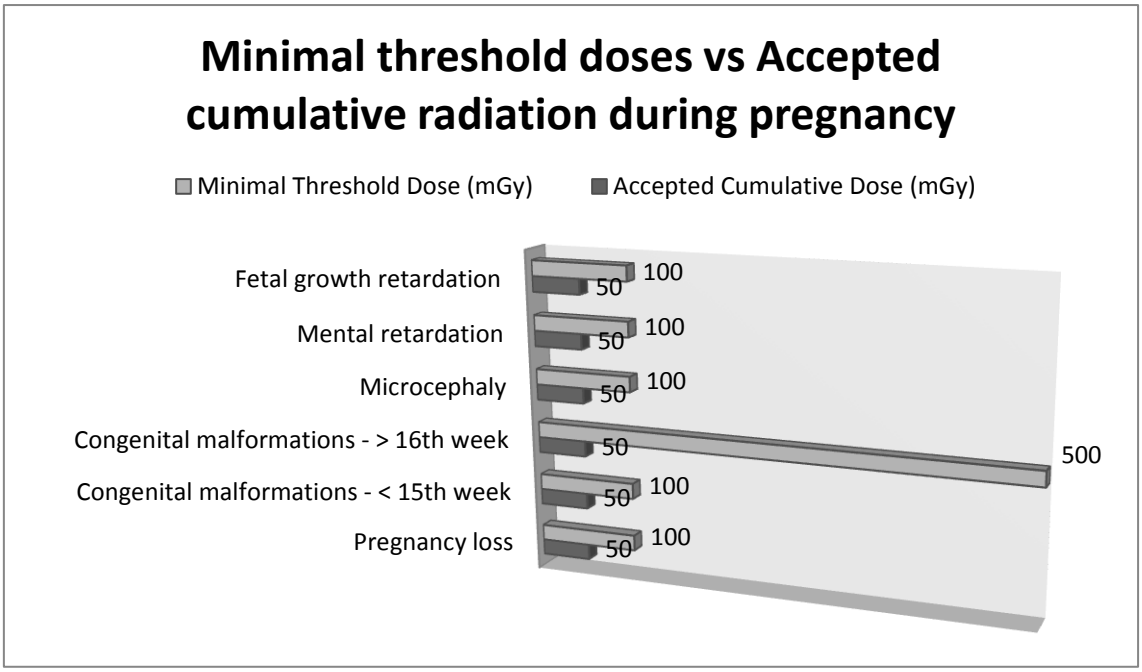
Minimal threshold doses vs Accepted cumulative radiation during pregnancy
Minimal Threshold Dose (mGy)
Accepted Cumulative Dose (mGy)
Fetal growth retardation
Mental retardation
Microcephaly
Congenital malformations - > 16th week
Congenital malformations - < 15th week
Pregnancy loss
50
100
50
100
50
100
50
500
50
100
50
100

**Table 1:** Fetal Exposure, Fetal Equivalent and Effective Doses.

| | | **Fetal Exposure (mGy)** | | | | | | **Fetal Equivalent (mSv)** | **Effective Dose (mSv)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Exam \ Article | | McCollough, Schueler et al [29] | Wieseler, Bhargava et al [43] | Toppenberg, Hill et al [9] | Hurwitz, Yoshizumi et al [103] | Helmrot, Petterson et al [104] | Damilakis, Perisinakis et al [35] | Parmaksiz, Atac et al [18] | Lockwood, Einstein et al [24] | Goodman and Amurao [4] | Parmaksiz, Atac et al [18] |
| **Radiographic and Fluoroscopic examinations** | | | | | | | | | | | |
| Cervical spine (AP, lat) | | < 0.001 | | | | | | 0 | | | 0.1 (0.007-0.2) |
| Extremities | | < 0.001 | | 0.01 | | | | | | | |
| Chest (PA, lat) | | 0.002 | | 0.0007 | | 0.001 | 0.0013-0.0138 | | 0.06 | 0.02 | |
| Chest (AP) | | | | | | <0.001 | 0.0014-0.024 | 1.4 (0.001-8.7) | | | 1.4 (0.1-4.3) |
| Thoracic spine (AP, lat) | | 0.003 | | | | | | | | | |
| Abdomen (AP): patient thickness | 21 cm | 1 | | 2.45 | | 0.31-0.63 | 0.0021-0.036 (0.0006-0.107) | 3.5 -7.6 (1.2-14) | | | 1.6-4.5 (0.4-8.5) |
| | 33 cm | 3 | | | | | | | | | |
| Lumbar spine (AP, lat) | | 1 | | 3.59 | | 0.91-1.75 | | 0.9-2.7 (0.4-5.3) | 2.1 | | 0.4-0.9 (0.2-1.3) |
| Pelvis | | | | 2.5 | | 0.66-0.72 | | 1.8 (0.7-2.9) | | 0.6 | 1 (0.4-1.5) |
| Small bowel study | | 7 | | | | | | | 15 | | |
| Double contrast barium enema study | | 7 | | 39.86 | | 7.8 | | | 8.7 | 8 | |
| Mammography | | | | | | | | | 0.6 | 0.4 | |
| Ventilation-perfusion scan | | | | 2.15 | | | | | 6.8 | | |

| Computed Tomography | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Head CT | 0 | | 0.5 | | | | | 1.8 | | |
| Chest CT routine | 0.2 | 0.02 | | | 0.21 | | 0.04 (0.03-0.06) | 7.8 | | 3.9 (2.3-5.4) |
| Chest CT pulmonary embolus | 0.2 | 0.02 | | 0.24-0.66 | | | | | | |
| Lumbar spine | | | 35 | | | | | | | |
| CT angiography of coronary arteries | 0.1 | | | | | | | 10 | | |
| Abdominal routine | 4 | 1.3 | 26 | | | | 28 (7.3-98) | 7.6 | | 24.5 (4.3-86) |
| Abdominal/Pelvis | 25 | 13 | | | | | | | 21 | |
| CT angiography of aorta (chest through pelvis) | 34 | 13 | | | | | | | | |
| Abdomen/ pelvis, stone protocol | 10 | 11 | 13.98 | Early 1st T: 4-7.2 End 1st T: 8.5-11.7 | 13.8-15.8 | | | 44.1 | | |

**Table 1:** Fetal Exposure, Fetal Equivalent and Effective Doses are presented. (AP – anterior-posterior; lat – lateral; PA – posterior-anterior; CT – Computed Tomography)

**Table 2:** Mean and Maximum of Fetal Exposure, Fetal Equivalent and Effective Doses.

| | | Fetal Exposure (mGy) | | Fetal Equivalent (mSv) | | Effective Dose (mSv) | |
|---|---|---|---|---|---|---|---|
| **Radiographic and fluoroscopic examinations** | | | | | | | |
| **Exam** | | **Mean** | **Maximum** | **Mean** | **Maximum** | **Mean** | **Maximum** |
| Cervical spine (AP, lat) | | - | 0.001 | - | 0 | 0.1 | 0.2 |
| Extremities | | 0.0055 | 0.01 | | | | |
| Chest (PA, lat) | | 0.00281 | 0.0138 | | | 0.04 | 0.6 |
| Chest (AP) | | 0.00685 | 0.024 | 1.4 | 8.7 | 1.4 | 4.3 |
| Thoracic spine (AP, lat) | | - | 0.003 | | | | |
| Abdomen (AP): patient thickness | 21 cm | 0.99345 | 2.45 | 5.55 | 14 | 3.05 | 8.5 |
| | 33 cm | - | 3 | | | | |
| Lumbar spine (AP, lat) | | 1.973 | 3.59 | 1.8 | 5.3 | 1.375 | 2.1 |
| Pelvis | | 1.595 | 2.5 | 1.8 | 2.9 | 0.8 | 1.5 |
| Small bowel study | | - | 7 | | | - | 15 |
| Double contrast barium enema study | | 18.22 | 39.86 | | | 8.35 | 8.7 |
| Mammography | | | | | | 0.5 | 0.6 |
| Ventilation-perfusion scan | | 2.15 | 2.15 | | | - | 6.8 |
| **Computed Tomography** | | | | | | | |
| **Exam** | | **Mean** | **Maximum** | **Mean** | **Maximum** | **Mean** | **Maximum** |
| Head CT | | 0.25 | 0.5 | | | - | 1.8 |
| Chest CT routine | | 0.143 | 0.21 | 0.04 | 0.06 | 5.85 | 7.8 |
| Chest CT pulmonary embolus | | 0.223 | 0.66 | | | | |
| Lumbar spine | | - | 35 | | | | |
| CT angiography of coronary arteries | | - | 0.1 | | | - | 10 |
| Abdominal routine | | 10.43 | 26 | 28 | 98 | 16.05 | 86 |
| Abdominal/Pelvis | | 19 | 25 | | | - | 21 |
| CT angiography of aorta (chest through pelvis) | | 23.5 | 34 | | | | |
| Abdomen/pelvis, stone protocol | | 11.526 | 15.8 | | | - | 44.1 |

**Table 2:** Mean and Maximum of Fetal Exposure, Fetal Equivalent and Effective Doses. AP – anterior-posterior; lat – lateral; PA – posterior-anterior; CT – Computed Tomography.

**Table 3:** Number of exams needed to reach the accepted cumulative dose of fetal exposure.

| Radiographic and fluoroscopic examinations | | | | | |
|---|---|---|---|---|---|
| Exam | | Mean exposure dose | Number of exams to reach fetal exposure of 50 mGy | Maximum exposure dose | Number of exams to reach fetal exposure of 50 mGy |
| Cervical spine (AP, lat) | | - | - | 0.001 | 50000 |
| Extremities | | 0.0055 | 9090.9 | 0.01 | 5000 |
| Chest (PA, lat) | | 0.00281 | 17793.6 | 0.0138 | 3623.2 |
| Chest (AP) | | 0.00685 | 7299.3 | 0.024 | 2083.3 |
| Thoracic spine (AP, lat) | | - | - | 0.003 | 16666.7 |
| Abdomen (AP): patient thickness | 21 cm | 0.99345 | 50.3 | 2.45 | 20.4 |
| | 33 cm | - | - | 3 | 16.7 |
| Lumbar spine (AP, lat) | | 1.973 | 25.3 | 3.59 | 13.9 |
| Pelvis | | 1.595 | 31.3 | 2.5 | 20 |
| Small bowel study | | - | - | 7 | 7.1 |
| Double contrast barium enema study | | 18.22 | 2.7 | 39.86 | 1.25 |
| Ventilation-perfusion scan | | 2.15 | 23.25 | 2.15 | 23.25 |
| Computed Tomography | | | | | |
| Exam | | Mean exposure dose | Number of exams to reach fetal exposure of 50 mGy | Maximum exposure dose | Number of exams to reach fetal exposure of 50 mGy |
| Head CT | | 0.25 | 200 | 0.5 | 100 |
| Chest CT routine | | 0.143 | 349.65 | 0.21 | 238.1 |
| Chest CT pulmonary embolus | | 0.223 | 224.2 | 0.66 | 75.75 |
| Lumbar spine | | - | - | 35 | 1.4 |
| CT angiography of coronary arteries | | - | - | 0.1 | 500 |
| Abdominal routine | | 10.43 | 4.79 | 26 | 1.9 |
| Abdominal/Pelvis | | 19 | 2.6 | 25 | 2 |
| CT angiography of aorta (chest through pelvis) | | 23.5 | 2.1 | 34 | 1.5 |
| Abdomen/pelvis, stone protocol | | 11.526 | 4.3 | 15.8 | 3.2 |

**Table 3:** Number of radiographic, fluoroscopic and computed tomography exams needed to reach 50 mGy of fetal exposure (the accepted cumulative dose). The mean and maximum exposure doses were used to calculate the number of exams needed. None of the exams presented reached the accepted level with one single exposure. AP – anterior-posterior; lat – lateral; PA – posterior-anterior; CT – Computed Tomography.

**Table 1 Protocol:** Minimum and maximum threshold doses for deterministic effects on each gestational period.

| Gestational Period | Effect | Minimum Threshold (mGy) | Maximum Threshold (mGy) |
|---|---|---|---|
| First two weeks | Pregnancy Loss | 100 | - |
| | Fetal Growth Retardation | 100 | 1000 |
| 2nd to 8th | Congenital Malformations | 100 | 250 |
| 4th to 8th week | Pregnancy Loss | 150 | 500 |
| 8th to 15th week | Congenital Malformations | 100 | 250 |
| | Mental Retardation | 100 | 250 |
| | Microcephaly | 100 | 500 |
| | Fetal Growth Retardation | 100 | 1000 |
| After 16th week | Congenital Malformations | 500 | 700 |
| | Mental Retardation | 200 | 700 |
| After 24th week | Pregnancy Loss | 100 | - |