

The out-of-plane contact shield and mA-modulation – the effect on fetal absorbed dose

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Abstract

The effect of patient shielding on fetal radiation dose was evaluated in computed tomography pulmonary angiography with the out-of-plane shield visible in the localizer but absent in the scan range in chest computed tomography (CT). An anthropomorphic phantom with additional prosthetic pregnancy belly was scanned with different CT scanners using clinical imaging protocols and radiophotoluminescence dosimeters (GD-352 M). The out-of-plane shield decreased the fetal absorbed radiation dose with Siemens Somatom go.Up, Canon Aquilion Prime SP and Canon Aquilion One scanners. The decrease was 3.9%–39.4% (0.01–0.09 mGy). With GE Optima the shield increased the fetal dose by 100% (0.23 mGy), with Canon Aquilion One and GE Optima scanners the abdomen dose increase was 17.5% and 36.4%, respectively (0.61 and 1.38 mGy). Applying an out-of-plane shield outside the scanned volume may increase the fetal radiation dose during CT when using tube current modulation, depending on the make and model of the CT scanner.

Introduction

Pregnancy is a special condition when considering ionizing radiation. According to the International Commission on Radiological Protection (ICRP), there are gestational age-dependent patterns of in-utero radiosensitivity [1]. In addition, the risks of malformation after in-utero exposure to doses well <100 mGy are not expected. However, excess brain cancers are estimated to occur 1 per 10 000 pediatric head computed tomography (CT) scans [2, 3], and the risk seems to strongly follow the linear-non-threshold-model [3]. The younger the imaged person is, the greater the risk [1, 4]. The risk for the fetus in the end of pregnancy is assumed to be similar to the postpartum risk [1].

The routine use of patient in- or out-of-plane shielding during x-ray-based imaging has received a lot of attention in recent years and continues to be a source of intensive debate. Concerns related to the use of contact

shielding have led to a variety of publications. While, for example, ICRP and International Atomic Energy Agency endorses its use [5, 6], others like the European as well as the American Association of Physicist in Medicine guidelines discourage its use [7, 8]. This mismatch between guidelines can also be seen in practice. According to the survey by Johnston *et al.* [9], there are differences in the use of patient contact shielding in clinical CT practice. Patient contact shield, as defined by the British Institute of Radiology, means radiation protection applied directly to a patient undergoing diagnostic X-ray procedures. However, the definition excludes shielding built into the imaging equipment or included in the room design [10]. There are two types of contact shielding: bismuth shields placed on the patient and inside the imaged volume (in-plane shields), and lead shields wrapped around the patient, outside the imaged volume (out-of-plane shields). The use of bismuth shields requires specific knowledge of

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the scanner's dose modulation algorithms and may not be recommendable [11].

Pulmonary embolism (PE) is the leading cause of maternal mortality in the developed world [12]. Accurate and timely diagnosis of suspected PE in pregnancy is of crucial importance [13]. The two most commonly used advanced imaging techniques, CT pulmonary angiography (CTPA) and lung scintigraphy, expose patients to ionizing radiation [14]. There are multiple research articles that evaluate the fetal radiation dose during CTPA [15–17].

To our knowledge, there are no publications on research where radiation dose from scanners of different manufacturers has been measured simultaneously using out-of-plane lead shielding and tube current modulation (TCM) algorithm. Yet, this technique has been and still is widely used, and it is known to have unexpected effects on the radiation dose outside the imaged volume [18].

The objective of this research is to study how the fetal absorbed dose is influenced by clinical CTPA protocols where mA-modulation is applied, and where the lead shielding is placed outside the scanned volume, but inside the localizer images. Furthermore, our intention is to examine, whether there are differences between scanners from different manufacturers.

Materials and methods

An anthropomorphic phantom and clinical pulmonary angiography protocols were used to estimate the effect of patient contact shielding on fetal radiation dose, with an out-of-plane shield (Scanflex Medical AB, Sweden, 0.5 mm lead) placed to protect the abdomen and pelvis. The shield was visible in the localizer images, but was not included in the scanned volume. The phantom (Kyoto Kagaku, model PBU 60, Kyoto Kagaku Co Ltd, Kyoto, Japan) corresponds to the average size of a small adult, 50 kg and 165 cm, and is made of tissue equivalent plastic.

The prosthetic pregnancy belly and breasts were made of Aquaflex ultrasound gel pads (Parker Laboratories, Inc., Fairfield, USA) (Fig. 1). A radiologist selected a representative 36-week pregnancy candidate from PACS (Vue PACS, Koninklijke Philips N.V.) system, after which the phantom was modelled. The prosthetic was shaped to represent pregnancy belly according to the literature [19].

The CT scanners used were Optima 660 (GE Healthcare, Chicago, USA), Aquilion One and Aquilion Prime SP (Canon Medical Systems Co, Otawara, Japan, formerly known as Toshiba Medical Systems Co), and Siemens Somatom go.Up (Siemens Healthineers, Erlangen, Germany) (Table 1).

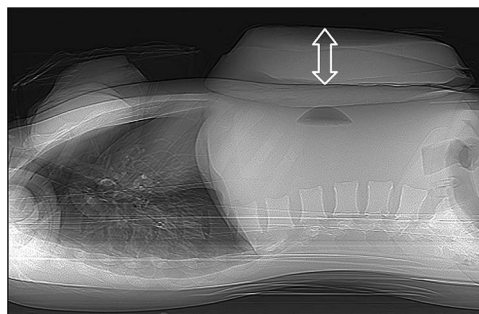


Figure 1. Kyoto phantom and the pregnancy add-on. Lateral view of the phantom. The thickness of the add-on is 6.5 cm.

The radiation dose was measured with radiophotoluminescence dosimeters (RPLD) (GD-352 M, Dose Ace, AGC Techno Glass Co, Ltd). RPLD are rod shaped dosimeters (diameter: 1.5 mm, length: 12.0 mm) with an effective atomic number of 12.04 and a density of 2.61 g per cm³. They contain different elements with atomic weight composition of 31.55% P, 51.16% O, 6.12% Al, 11.00% Na, and 0.17% Ag. GD-352 M has a Sn filter embedded in a polymethyl methacrylate (PMMA) shell (4.3 × 14.5 mm²), making the dosimeters suitable for low-energy radiation dosimetry [20]. In this study, dose calibration of dosimeters provided by manufacturer was used (against 6 mGy with a Cs-137 source performed in air). Regarding the phantom measurements, two measurement points were used. An abdominal measurement point was near the caudal edge of the imaged volume, 4.5 cm inferior to the phantom's anterior surface, and ~4 cm before the superior edge of the shield, representing the dose next to the fetus. The naval measurement point was 6.5 cm inferior to the phantom's anterior surface, representing the average fetal dose. When using the out-of-plane shield, the naval measurement point was completely covered with the contact shield. Two dosimeters were placed in each measuring point, and the scans were repeated three times with the same dosimeters to remove the effect of the x-ray tube placement in the beginning of the scanning and to improve the measurement accuracy (Fig. 2). Dosimeters were placed after the localizer images. The measured dose represents only the radiation dose received from the actual scanning protocol used. Scans were repeated with and without the out-of-plane shield.

The phantom was scanned supine with caudocranial setting, feet toward the gantry, with the clinical pulmonary angiography helical protocol of the scanner. The total length of scanned volume was 282 mm. The scan range was identical for all scans. The shield was placed 4 cm outside the caudal end of the scanned volume and wrapped around the phantom, covering

Table 1. The scanner used in the study, dose (CTDI_{vol} and DLP) and parameter (kVp, pitch, mA-range the mA-modulation algorithm used) settings, total collimation and the use of the out-of-plane shield.

Scanner	CTDI _{vol}	DLP	kVp	Pitch	The used mA-range	Total collimation [mm]	Use of shield
Siemens Somatom go.Up	2.02	70	110	0.80	33–83	22.4	no shield
Siemens Somatom go.Up	1.98	67	110	0.80	33–83	22.4	shield
Canon Aquilion Prime SP	1.8	59	100	0.81	91–200	40	no shield
Canon Aquilion Prime SP	1.9	61	100	0.81	101–360	40	shield
Canon Aquilion One	2.3	88	100	1.388	141–365	40	no shield
Canon Aquilion One	3.3	121	100	1.388	141–391	40	shield
GE Optima 660	2.26	71	100	0.98	69–120	40	no shield
GE Optima 660	2.65	85	100	0.98	69–365	40	shield

Table 2. The absorbed radiation doses in mGy in the measurement points, measured with and without the out-of-plane shield, and the dose difference in % (without shield / with shield) between the measurements.

Scanner	Abdomen [mGy]	Dose saved by shielding, %	Naval (fetus) [mGy]	Dose saved by shielding, %
Siemens Somatom go.Up / no shield	2.81		0.23	
Siemens Somatom go.Up / out-of-plane shield	2.79	0.6	0.14	39.4
Canon Aquilion Prime SP / no shield	2.12		0.13	
Canon Aquilion Prime SP / out-of-plane shield	2.04	3.9	0.12	3.9
Canon Aquilion One / no shield	3.49		0.47	
Canon Aquilion One /out-of-plane shield	4.10	–17.5	0.41	12.5
GE Optima 660 / no shield	3.77		0.23	
GE Optima 660 / out-of-plane shield	5.15	–36.4	0.46	–100

Negative dose indicates that the dose measured by the dosimeter has increased due to the shielding.

the abdomen and pelvis (Fig. 2). The clinical protocols differed between scanners (Table 1).

Results

There was notable difference between fetal absorbed doses of different scanners (Table 2). The fetal radiation doses with out-of-plane shield were from the highest to the lowest: GE Optima. 660 (0.46 mGy), Canon Aquilion One (0.41 mGy), Siemens Somatom go.Up (0.14 mGy). The lowest dose was with Canon Aquilion Prime SP (0.12 mGy).

The abdominal radiation doses with out-of-plane shield were from the highest to the lowest: GE Optima 660 (5.15 mGy), Canon Aquilion One (4.10 mGy), Siemens Somatom go.Up (2.79 mGy), and Canon Aquilion Prime SP (2.04 mGy).

The applied tube modulation range differed between scanners: the highest low-level of the mA-modulation was used in Canon Aquilion One (141 mA), whereas the smallest low-level mA-modulation was used in Siemens Somatom go.Up (33 mA).

Discussion

Using clinical CTPA protocols with TCM, the lead shield placed outside the scanned volume but inside the localizer images to cover and protect the embryo, may affect the fetal absorbed dose. With one scanner used in this study, the out-of-plane shield doubled the fetal absorbed radiation dose (GE Optima 660). With Siemens Somatom go.Up the out-of-plane shield reduced the fetal absorbed radiation dose by 39.4% compared to the dose without the out-of-plane shield. With Canon Aquilion One, the dose reduced by 12.5% and Canon Prime SP by 3.9%.

The fetal dose differences measured here may partly be due to the variations in the clinical protocols used. The mA-modulation scale used seems to have no direct effect on the fetal radiation dose. However, with GE Optima 660 scanner, lower available upper limit would possibly have reduced the fetal dose. With Canon Aquilion One, the abdomen dose rose due to the shield. Because of this increase, the percentage change in fetal dose saving is greater than with the Canon Aquilion Prime SP. However, the measured fetal average dose was higher with the Aquilion One. This is an

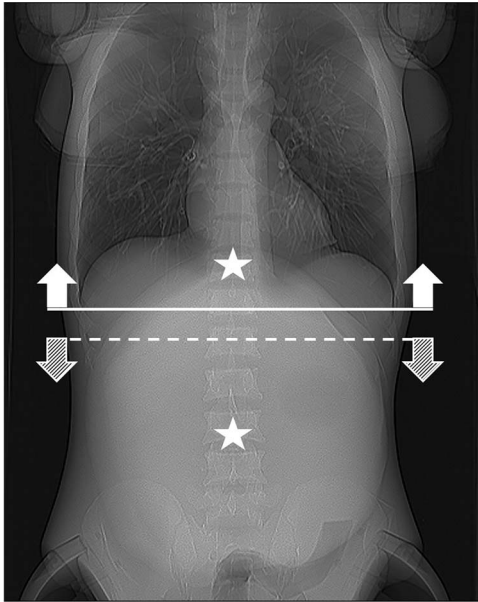


Figure 2. The placement of the out-of-plane lead shield when used (dotted line, covering abdomen and pelvis in the direction of the shaded arrows), caudal edge of the scanned volume (above the solid line, to the direction of the solid arrows), and placement of the dosemeters (stars).

excellent example of how difficult it is to provide exact information about the effect of out-of-plane shields. When using out-of-plane shielding, the fetal radiation dose seems to be positively correlated with the change of dose to the abdomen.

In the study done by Larjava *et al.* [18], the contact shield was placed 1 cm outside the scanned area, still being visible in the localizer images. It was observed that in such a setting the contact shield could increase the patient dose two-fold (evaluated from cumulative mA-values). The increase was most prominent in the last slices, when approaching the contact shield. In our study, the shield was placed further from the scanned volume: the distance between the end of the scanned volume and the edge of the contact shield was 4 cm. Despite that a fetal dose difference between -0.1 to 0.2 mGy was observed. To put these values into perspective, the working conditions of a pregnant worker, after informing the employer about the pregnancy, ought to be arranged so that additional dose to the embryo does not exceed 1 mSv during the remainder of the pregnancy [1]. Considering this recommendation and our measurements, the out-of-plane shield used on the patient may provide maximum 10% (0.1 mSv) protection compared to the acceptable maximum dose received by a worker's embryo. However, there is also a possibility that it increases the fetal

radiation dose (0.2 mSv). The effect depends on the scanner [18].

In a similar research setting as this, Begano *et al.* [11] observed that shielding increased the effective dose both to the mother and the fetus, even with a scanner that corrects the TCM values based on the localizer images with the attenuation measurement of the previous half round of the x-ray tube. In an excellent review Ryckx *et al.* [21] summarize the research done before 2017. However, even though the effect of automatic TCM is discussed in the publication, it has not been measured in their research, or in the reviewed articles.

With some scanners (Canon One, GE Optima), the fetal dose reported here is significantly higher than in the literature [10, 22] still being acceptable according to the American College of Obstetricians and Gynecologists Committee Opinion [23]. The RPLDs are meant to be used to measure a point dose. In this study, the fetal dose (naval point) is used to represent the fetal average dose. The calibration of the meters is not ideal for such small doses. This study concentrates on the effect of the out-of-plane shielding on the radiation dose, using the clinical CTPA protocols of the scanners. The protocols were not optimized for pregnant patients. Since the imaging protocols have already been optimized and the required image quality for pulmonary embolism is very high, one can speculate whether there is still room for dose reduction within the current scanner technology.

Conclusion

Applying an out-of-plane shield outside the scanned volume but visible in the localizer images may increase fetal radiation dose, especially with older scanners using only localizer-based mA-modulation. The mA-modulation scale used seems to have no direct effect on the fetal radiation dose. However, reducing the upper level of the modulation scale may prevent the most prominent dose elevation.

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Conflict of interest

None declared.

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