Title
JOURNAL CLUB: Quantification of Fetal Dose Reduction if Abdominal CT Is Limited to the Top of the Iliac Crests in Pregnant Patients With Trauma.

Journal
American Journal of Roentgenology, 206(4)

ISSN
0361-803X

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Publication Date
2016-04-01

DOI
10.2214/ajr.15.14770

Peer reviewed

HHS Public Access
Author manuscript
AJR Am J Roentgenol. Author manuscript; available in PMC 2017 April 01.

Published in final edited form as:
AJR Am J Roentgenol. 2016 April ; 206(4): 705–712. doi:10.2214/AJR.15.14770.

Quantification of Fetal Dose Reduction if Abdominal CT Is Limited to the Top of the Iliac Crests in Pregnant Patients With Trauma

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Abstract

OBJECTIVE—The purposes of this study were to correlate fetal *z*-axis location within the maternal abdomen on CT with gestational age and estimate fetal dose reduction of a study limited to the abdomen only, with its lower aspect at the top of the iliac crests, compared with full abdominopelvic CT in pregnant trauma patients.

MATERIALS AND METHODS—We performed a study of pregnant patients who underwent CT of the abdomen and pelvis for trauma at a single institution over a 10-year period. The inferior aspect of maternal liver, spleen, gallbladder, pancreas, adrenals, and kidneys was recorded as above or below the iliac crests. The distance from the iliac crest to the top of the fetus or gestational sac was determined. The CT images of the limited and full scanning studies were independently reviewed by two blinded radiologists to identify traumatic injuries. Fetal dose profiles, including both scatter and primary radiation, were computed analytically along the central axis of the patient to estimate fetal dose reduction. Linear regression analysis was performed between gestational age and distance of the fetus to the iliac crests.

RESULTS—Thirty-five patients were included (mean age, 26.2 years). Gestational age ranged from 5 to 38 weeks, with 5, 19, and 11 gestations in the first, second, and third trimesters, respectively. All solid organs were above the iliac crests in all patients. In three of six patients, traumatic findings in the pelvis would have been missed with the limited study. There was high correlation between gestational age and distance of the fetus to the iliac crests ($R^2 = 0.84$). The mean gestational age at which the top of the fetus was at the iliac crest was 17.3 weeks. Using the limited scanning study, fetuses at 5, 20, and 40 weeks of gestation would receive an estimated 4.3%, 26.2%, and 59.9% of the dose, respectively, compared with the dose for the full scanning study.

CONCLUSION—In pregnant patients in our series with a history of trauma, CT of the abdomen only was an effective technique to reduce fetal radiation exposure compared with full abdomen and pelvis CT.

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Keywords

CT; fetal dose; pregnant; radiation dose; trauma

CT use has increased markedly in recent years for both the nonpregnant and pregnant population [1, 2]. Concerns regarding exposure to ionizing radiation are higher in pregnant patients owing to the greater radiosensitivity of fetal tissues. The use of abdominal and pelvic CT is of particular concern because it results in direct irradiation of the fetus with the primary radiation beam and results in considerably higher fetal radiation dose than CT performed outside the abdomen [3]. Therefore, imaging modalities that do not use ionizing radiation, particularly ultrasound and MRI, are generally recommended as first- and second-line tests, respectively, in pregnant patients who need imaging for acute abdominal conditions [4, 5]. However, CT may need to be performed in the pregnant patient with abdominal symptoms when other imaging modalities are not diagnostic or practical. In particular, CT remains the imaging examination of choice for evaluation of the clinically stable pregnant patient with blunt or penetrating abdominal trauma, the leading nonobstetric cause of maternal death [6]. Rapid and accurate imaging is needed in this setting, and concerns regarding fetal radiation should not deter the use of CT [7].

Despite appropriate concerns over fetal exposure, there is still an important role for abdominal CT in the pregnant patient with abdominal trauma. It is therefore crucial to optimize abdominal CT protocols to reduce fetal and maternal radiation exposure while maintaining diagnostic ability. This should be done by reducing the tube current-time product, using automated tube current modulation and iterative reconstruction techniques wherever available and limiting the number of scanning phases [8]. In addition, significant dose reduction can be achieved by limiting the *z*-axis scanning range by focusing on the anatomic ROI [9, 10]. In the case of pregnancy, a large reduction in fetal radiation dose would be expected if scanning could be limited to the maternal upper abdomen. Because the majority of the solid organs are located in the upper abdomen, scanning limited to the upper abdomen may be able to assess for the presence of solid organ injury in cases of trauma. However, the position of the gestational sac and fetus shifts in the cranial direction as pregnancy progresses, and a lower fetal dose reduction would be expected for later pregnancy using a limited abdomen-only CT protocol. Therefore, the purposes of our study were to assess the *z*-axis location of the top of the fetus within the maternal abdomen on CT as a function of gestational age and to compare estimated fetal dose between full abdominal and pelvic CT and abdominal CT limited to the top of the iliac crests.

Materials and Methods

Study Group

This HIPAA-compliant study was approved by our institutional review board, and a waiver of informed consent was obtained owing to its retrospective nature. A search of our single-institution radiology database was performed to identify all pregnant patients who underwent CT of the abdomen and pelvis for evaluation of trauma from January 1, 2003, through December 31, 2012, which yielded 39 patients. Four patients were excluded because the gestational age could not be dated, leaving 35 patients. The mean maternal age was 26.2 years (range, 18–41 years), and the gestational age ranged from 5.0 to 38.4 weeks. There were 5, 19, and 11 gestations in the first, second, and third trimesters, respectively. Gestational age was determined by obstetric ultrasound in 30 patients, with a mean time from ultrasound to CT of 7.7 days, and by last menstrual period in five patients.

CT Technique

Examinations were performed on either a 16- or 64-MDCT scanner (GE 16 detector Light Speed scanner or GE 64 detector Volume CT, GE Healthcare). The CT parameters varied due to the study period of 10 years. CT studies were performed using 120 kV in 37 patients and 140 kV in two patients. A variable tube current-time product using automated dose modulation was used in 21 patients and a fixed tube current-time product was used in 14 patients. The pitch varied from 0.98 to 1.375 and the gantry rotation time varied from 0.5 to 1.0 second. All images were reconstructed using a thickness and interval of 5.0 mm each. IV contrast material was used in 36 patients with 100–125 mL iohexol (Omnipaque 350, GE Healthcare) injected at a rate ranging from 2.0 to 2.5 mL/s. In all patients, acquisition was from the lung bases to the inguinal regions in the portal venous phase at a fixed 80-second delay after the start of the injection. Oral contrast material was administered to three patients.

Image Analysis

A single radiologist with fellowship training in abdominal imaging and 4 years of postfellowship experience reviewed all scans and marked the CT table location for the top and bottom of the acquired scan and the level of the more-superior maternal iliac crest. The level of the top and bottom of the fetus or the gestational sac if the fetus was not visualized (first trimester) was also recorded. The level of the inferior-most aspect of the most-inferior maternal solid organ (liver, spleen, kidneys, pancreas, or adrenals) and gallbladder was recorded.

The CT images for all trauma patients were separately reviewed by the same radiologist and a second fellowship trained abdominal radiologist with 10.5 years of postfellowship experience. Both radiologists were blinded to the original radiology report and any clinical information, although they were aware of the history of trauma. Scans were reviewed initially from the top of the scan to the level of the iliac crests to determine the presence or absence of abdominal abnormality. Subsequently, the full abdomen and pelvis CT images were reviewed to determine the presence of any additional abnormalities seen below the iliac crests. Any discrepancies in interpretation were resolved by consensus.

Radiation Dose Analysis

The linear fit data describing the locations of the top and bottom of the fetus relative to the maternal iliac crest were used to compute the length of the fetus. The linear fit coefficients were used to construct plots (Fig. 1) that describe fetal boundaries relative to maternal coordinates along the craniocaudal axis (defined as z).

The dose in CT, especially in the abdomen, is deposited primarily by scattered radiation. The scattered radiation propagates in both directions along the *z*-axis of the patient, making the dose profile very smooth at the edges of the primary scan [11]. A previous investigation described the shape of the absorbed dose profile for a very thin (theoretic) CT scan, and these functions were called dose-spread functions [12]. The dose-spread functions were convolved mathematically with a rectangular function describing the location of the primary beam, and the results of this convolution describe the dose profile at the edge of the CT scan. These data were used to estimate the shape of the absorbed dose profile at the edges of the standard abdominopelvic CT scan and that of the limited-extent protocol. The error function was used to generate these profiles using spreadsheet software (Excel, Microsoft). The parameters used for this assumed a 32-cm diameter "patient," an x-ray tube potential of 120 kV, and a scatter-to-primary ratio of 13:1 (determined from Monte Carlo studies under similar conditions). The full width of the dose transition from 1% to 99% was estimated to be 244 mm on the basis of these assumptions. This value was therefore estimated in the spreadsheet calculations.

In our study, a standard abdominopelvic CT scan is compared with a limited-extent CT scan that stops at the iliac crests of the mother. The *z*-axis of the patient was defined such that the iliac crest was located at $z = 0$, with a positive *z*-axis running in the superior direction and the negative *z*-axis running in the inferior direction. We determined across an average of 35 patients that the abdominal and pelvic CT scan terminated 205 mm below the iliac crest, and this value was used in this study. Hence, the full abdominopelvic CT scan starts in the upper abdomen and terminates at $z = -205$ mm, whereas the limited-extent CT scan starts in the upper abdomen and terminates at $z = 0$ mm, at the position of the iliac crest. The exact position where the CT scan starts does not affect the fetal dosimetry described here.

The two dose profiles, combined with a box describing the position of the fetus, were used to compute the relative energy imparted to the fetus (Fig. 2). The area of the box under the dose curve is a product of the vertical dimension, which is the relative absorbed dose, and the horizontal dimension, which is the length of the fetus exposed. Thus, the area is essentially the dose-length product (DLP). The DLP is proportional to the energy imparted, and in turn is a linear function of effective dose [13]. The only way to rigorously compare the dose from these two different protocols to our knowledge—because they involve irradiating different volumes of tissue—is to use the energy imparted (i.e., the effective dose). Therefore, the ratio of the two energy-imparted values corresponds to the difference in potential risk of radiation harm to the fetus.

Statistical Analysis

Linear regression analysis was performed to assess the relationship between gestational age and fetal distance from the iliac crests and between gestational age and *z*-axis length of the fetus. The relationship between relative dose-length product and gestational age was fit using a fourth-order polynomial ($R^2 = 0.9984$).

Results

For all patients, the inferiormost aspects of all the solid organs and gallbladder were located above the iliac crests. The inferior-most solid organ was the kidney in 33 patients and the liver in two patients. The CT findings are shown in Table 1. In three of six patients, pelvic findings would have been missed with the limited study as follows: the inferior aspect of a retroperitoneal hematoma; a left pelvic gunshot wound and iliac fracture; and an L5 transverse process fracture, iliac fracture, and an extraperitoneal hematoma. There was one discrepancy between the two blinded reviewers that was resolved by consensus.

There was high correlation between gestational age and distance between the top of the fetus or gestational sac to the iliac crests ($R^2 = 0.84$) (Fig. 3) and between gestational age and *z*-axis length of the fetus or gestational sac ($R^2 = 0.89$) (Fig. 4). The average gestational age at which the top of the fetus or gestational sac was at the same *z*-axis level as the iliac crest was 17.3 weeks (95% CI, 15.8–18.9 weeks; $p < 0.0001$). Figure 5 shows the relative fetal dose curves for full abdomen and pelvis CT and limited abdomen-only CT and how the energy imparted to the fetus was estimated for a variety of gestational ages.

Figure 6 shows how the relative fetal dose of limited CT-only scans compared with full abdomen and pelvis scans increases with increasing gestational age. According to the limited scans, fetuses at 5, 20, and 40 weeks of gestation would receive 4.3%, 26.2%, and 59.9%, respectively, of the dose compared with the dose received for the full scans. Figures 7 and 8 show the varying fetal locations within the maternal abdomen on CT, depending on gestational age.

Discussion

CT of the abdomen and pelvis is occasionally used in the evaluation of a pregnant patient, especially in the setting of blunt abdominal trauma [14]. However, the potential risks of fetal radiation exposure are of particular concern because the fetus receives direct radiation during this examination. Techniques including reducing the tube current-time product or peak kilovoltage, using the widest detector collimation, automated tube current modulation, and iterative reconstruction should be used to minimize the fetal dose. Another potential technique to reduce fetal dose is to image the abdomen but not the pelvis, which will avoid direct radiation of all or much of the fetus and reduce scatter radiation. The results of our study show that the maternal solid organs will be consistently evaluated with a CT performed with its lower aspect at the level of the iliac crests. Second, our study establishes the relationship between gestational age and fetal location in the *z*-axis within the abdomen such that fetal radiation dose reduction using abdomen-only CT can be estimated with knowledge of the gestational age.

The potential risks of ionizing radiation to the fetus are teratogenic and carcinogenic. The risks of spontaneous abortion in early pregnancy or fetal malformations are thought to be negligible for fetal doses less than 50 mGy, and typical CT examinations result in estimated doses well below this threshold [15]. Although the risks of carcinogenesis are less well understood, studies suggest an association between fetal radiation exposure and an increased risk of childhood cancer, and the linear no-threshold theory posits that there is no dose threshold for these effects [16, 17]. Therefore, it is important to reduce the fetal radiation exposure as much as possible during CT while maintaining diagnostic accuracy (as low as reasonably achievable). CT of maternal body parts that does not result in direct irradiation of the fetus results in significantly lower fetal doses than abdominopelvic CT because the fetus is only exposed to a lesser amount of scatter radiation. For example, estimated fetal dose for a chest CT has been reported to be 0.2 mGy compared with 25 mGy for full abdominopelvic CT [18]. Furthermore, estimated fetal doses from chest CT are lower for early-gestation fetuses compared with those of later gestational ages [19]. This is due to an exponential decease in radiation exposure due to scatter radiation with increasing distance from the source.

Therefore, abdomen-only CT has the potential to substantially reduce fetal radiation dose, particularly in early-gestation fetuses, because the embryo or fetus will be below the iliac crests. However, to our knowledge, no data currently exist that would predict, before CT, the reduction in fetal dose from a limited abdomen-only study. Fetal position within the maternal abdomen progresses cranially with increasing gestational age. Thus, older-gestation fetuses will be more likely to receive direct radiation as well as more scatter radiation. The results of our study show that fetuses below approximately 17.3 weeks of gestation will be located below the iliac crests and therefore will not be exposed to direct radiation if the CT ends at this level, although they will still receive scatter radiation. The most substantial fetal dose reductions can be expected below this gestational age with increasing dose reduction correlating with earlier gestational age because of the increasing fetal distance from the lower aspect of the scan and subsequent reduction in scatter radiation. Interestingly, Angel et al. [20] found no correlation between gestational age and normalized fetal dose during full abdominopelvic CT with similar fetal doses across all ages, likely because in full abdominopelvic CT, fetuses of all ages are exposed to primary radiation and scatter from both superior and inferior aspects of the mother. Our data provide estimates of normalized relative fetal dose with limited abdominal CT compared with full abdominopelvic CT on the basis of gestational age. For example, a 5-week-gestation fetus undergoing limited abdomen CT would only receive 4.3% of the dose that would have resulted from full abdominopelvic CT. The relative fetal dose increases with gestational age such that the fetus at full-term gestation would receive approximately 60% of the dose compared with limited abdominal CT. If abdomen-only CT is being considered in a pregnant patient, this information can be used in the risk-benefit analysis and in discussion with the patient when clinically appropriate. Informed consent of pregnant patients who undergo CT is recommended, and these data combined with knowledge of the gestational age may improve risk assessment before CT [21].

A limited abdomen-only CT is an effective technique to reduce fetal radiation exposure. However, it must also provide the necessary diagnostic information to be clinically useful. The results of our study show that the maternal solid organs will be visualized in their entirety using such a protocol. This may be useful if there is specific concern for solid organ injury in the upper abdomen but low suspicion for pelvic involvement. Ultrasound should be used as part of the initial assessment of trauma in the pregnant patient to identify free fluid in the abdomen and pelvis, but it has limited accuracy in detection of intraabdominal injury

[7]. Because the mother's status is the primary concern in the setting of trauma, CT remains a crucial part of the evaluation of the pregnant patient with blunt abdominal trauma and should not be deferred owing to fetal radiation exposure concerns [7, 22, 23]. Splenic injury is the most common cause of hemoperitoneum in both nonpregnant and pregnant patients, with possible increased risk in pregnancy because of the mild enlargement normally found with pregnancy [15]. The kidneys also mildly enlarge, and the liver and spleen are displaced superiorly and compressed against the ribs, making these organs more susceptible to injury [14, 22]. CT remains the modality of choice for the detection of solid organ injury both in pregnant and nonpregnant patients. Limited abdomen-only CT would adequately image abdominal organs while decreasing fetal radiation exposure. In our study, all four patients with solid organ injury would have been detected with limited abdomen-only CT.

The pelvic organs, bowel that is located in the pelvis, and pelvic bones would not be imaged with this protocol, and if there is clinical concern for pelvic injury, full abdominopelvic CT would be required. Thus, the limited protocol must be used judiciously and would likely be inappropriate for mothers with significant trauma to the torso and a high likelihood of injury to pelvic structures. However, there may be scenarios in which the clinical presentation clearly suggests an isolated upper abdominal injury. For example, isolated left costal margin tenderness on examination is associated with a small but important percentage of splenic injuries [24]. Furthermore, there are alternative methods that can be used to image the pelvis, particularly ultrasound for the pelvic organs and pelvic fluid and radiography for pelvic fractures. It has also been reported that the bowel is less frequently injured in pregnancy [5]. In our study, a retroperitoneal hemorrhage would have been only partially visualized in one patient and pelvic fractures with associated hematomas and a gunshot wound to the pelvis in two other patients would have been missed. However, the clinical presentation in these cases would have clearly directed imaging of the pelvis.

Limitations of our study include its retrospective nature and small sample size. The relatively long study period resulted in CT protocols with varying dose parameters, and thus calculations of actual fetal doses were not performed. However, such estimates are dependent on the CT parameters and patient characteristics and therefore will vary across institutions, whereas the relative doses can be applied similarly to studies with varying parameters. The obvious limitation of an abdomen-only CT is nonimaging of the pelvic structures. Thus, this protocol should only be used in selected clinical circumstances. Our study did not evaluate the clinical parameters that would predict the appropriateness of performing a limited CT and future studies are warranted to better define such parameters. For example, clinical prediction rules have been developed that are useful in determining the need for abdominal CT in nonpregnant patients with blunt trauma [25]. Similar rules could be developed to determine the need for full versus limited CT in pregnant patients. Lastly, although decreased compared with abdominopelvic CT, there is still fetal radiation exposure with this protocol, and CT parameters should be optimized to minimize radiation exposure.

In conclusion, CT of the abdomen limited to the iliac crests is a potentially effective technique to reduce fetal radiation exposure compared with full abdominopelvic CT. The estimated amount of fetal dose reduction decreases with increasing gestational age. This protocol enables assessment of the maternal solid organs and is potentially effective in selected cases of maternal blunt abdominal trauma.

Acknowledgments

Supported by the National Center for Advancing Translational Sciences (NCATS), National Institutes of Health (NIH), through grant UL1 TR000002.

We thank Machelle Wilson for assistance with the statistical analysis.

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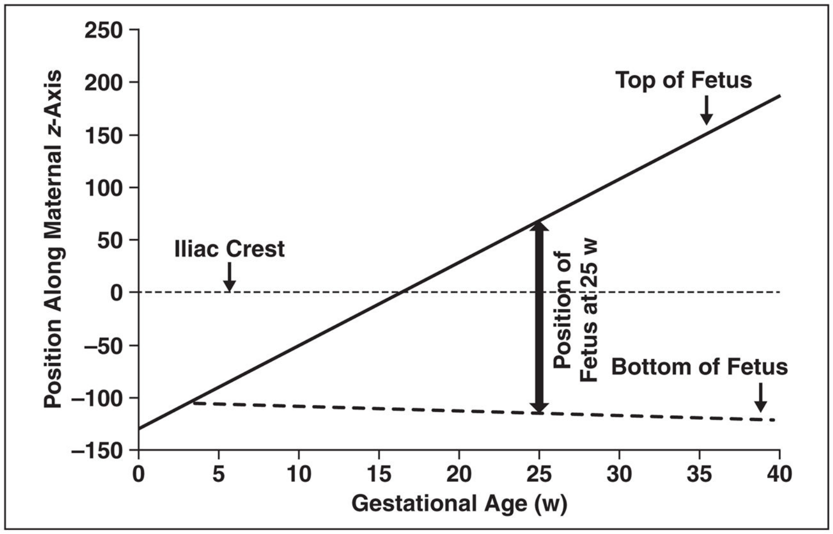

Fig. 1.
Graph of linear-fit model shows position of fetus with respect to maternal iliac crest as function of gestational age.

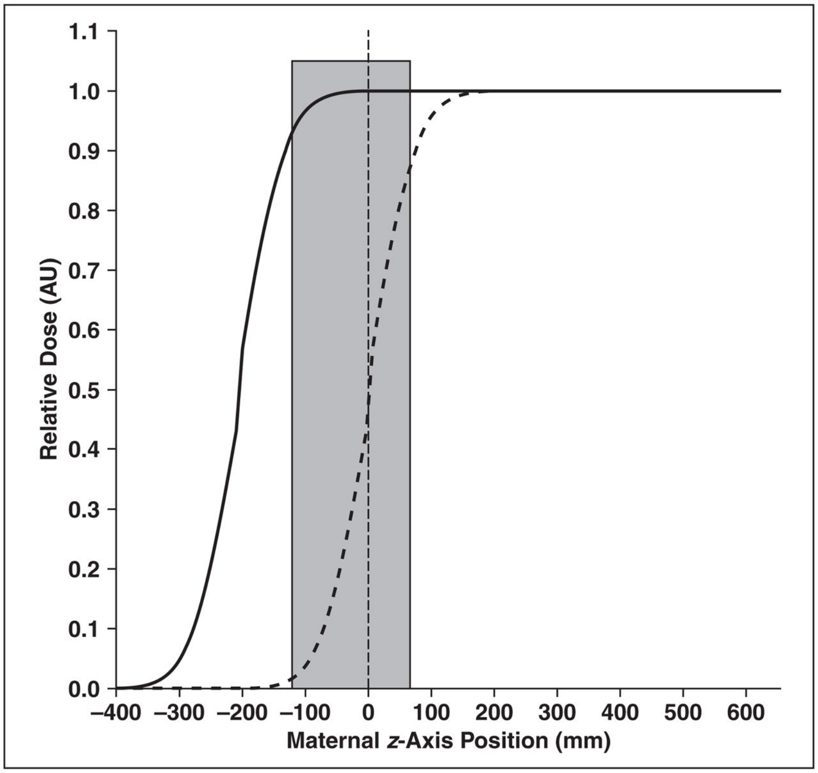

Fig. 2.

Graph shows relative absorbed dose as function of position along maternal *z*-axis for conventional abdominopelvic CT (*solid line*) and limited abdomen-only CT protocol (*dashed line*). Location of fetus at 25 weeks is shown as gray box. Area in shaded box, which is also under relative dose curve, corresponds to energy imparted to fetus; for example, dark gray region under dashed line corresponds to energy imparted to fetus from limited-extent CT protocol. Maternal *z*-axis of 0 corresponds to iliac crests.

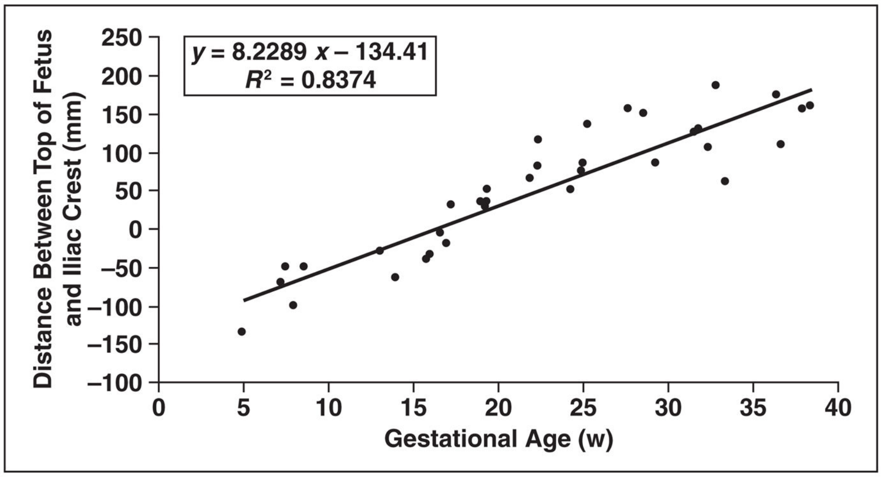

Fig. 3.

Graph shows linear regression analysis of distance from top of gestational sac or fetus to iliac crests as function of gestational age.

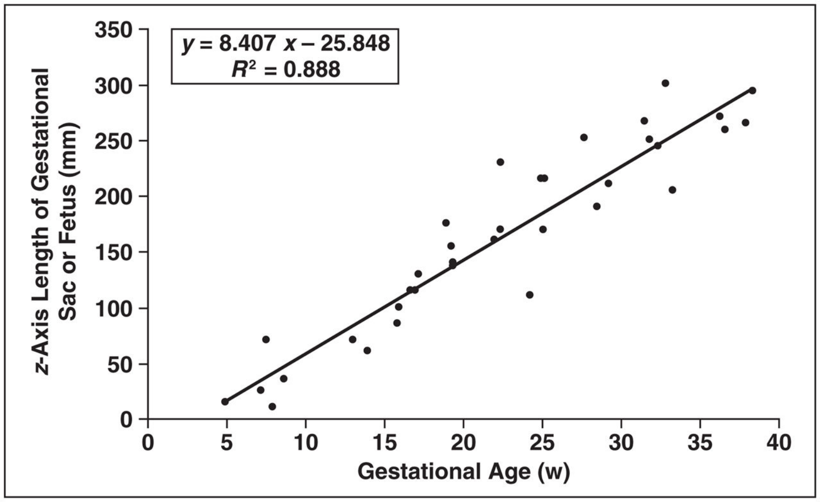

Fig. 4.

Graph shows linear regression analysis of *z*-axis length of fetus or gestational sac as function of gestational age.

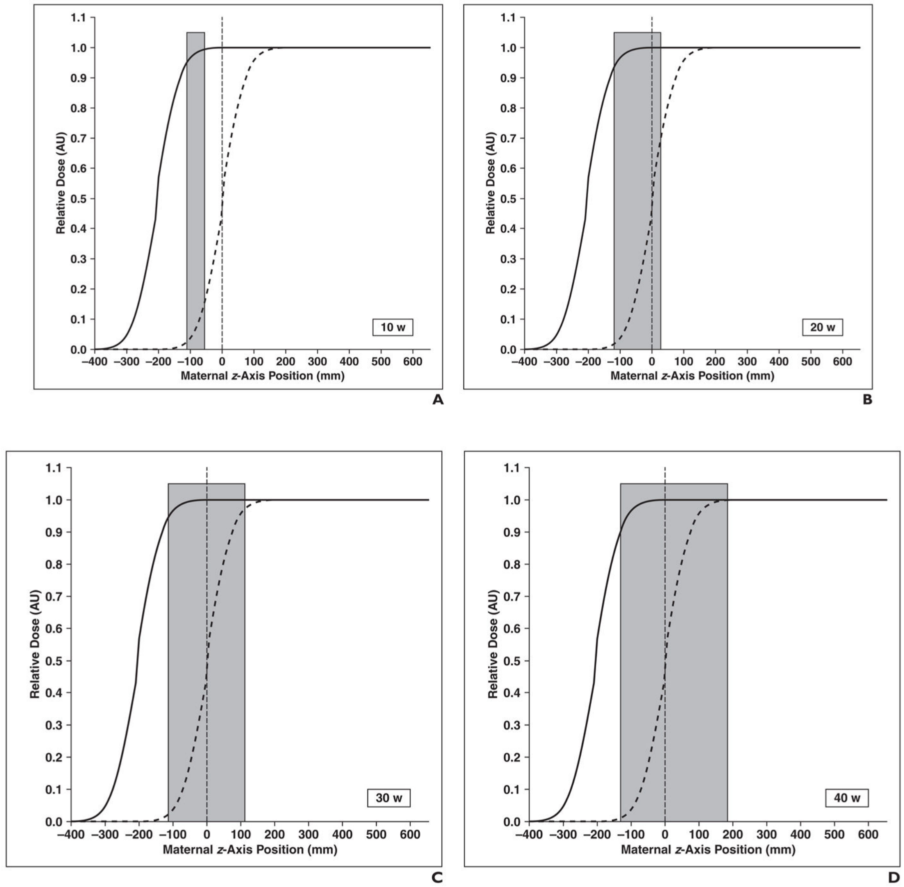

Fig. 5. Position of fetus

A–D, Graphs show position of fetus (*shaded boxes*) as function of gestational age for 10 (**A**), 20 (**B**), 30 (**C**), and 40 (**D**) weeks. Solid lines correspond to relative dose versus maternal position for standard abdominopelvic protocol and dashed lines to limited abdomen-only protocol. Area in shaded box under each dose curve shows area that is proportional to energy imparted.

Fig. 6.

Graph shows relative dose-length product (DLP) as function of gestational age. DLP is proportional to both imparted energy and effective dose, and these parameters are essentially linear with radiation risk. Thus, DLP reduction achieved by using limited-extent CT protocol shows relative reduction in risk to fetus.

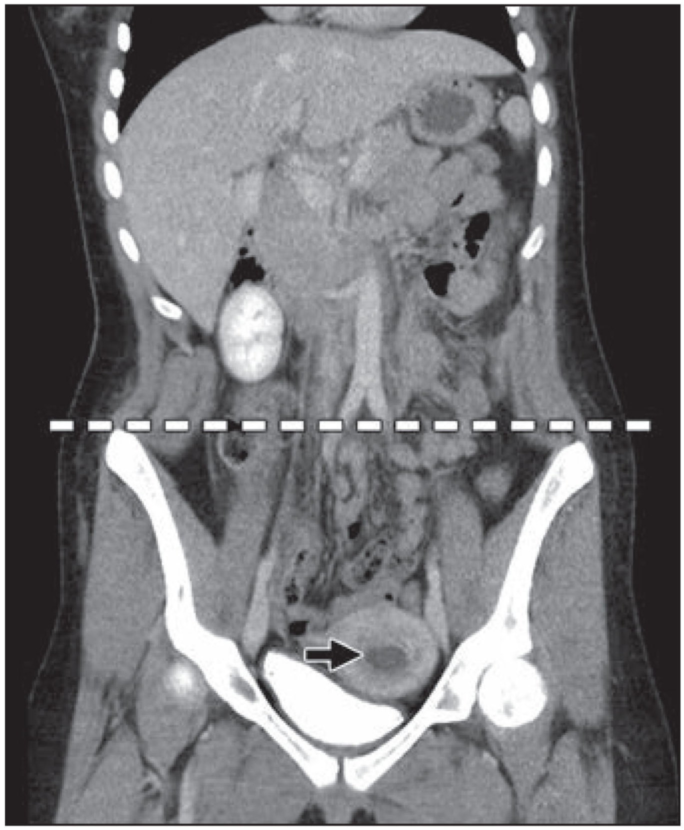

Fig. 7.

28-year-old pregnant woman at 5 weeks of gestation after motor vehicle collision. Coronal CT image shows full *z*-axis length of scan. Dotted line represents inferior aspect of limited scanning to iliac crests. Note that gestational sac (*arrow*) is well inferior to iliac crests and would receive minimal scatter radiation with limited protocol.

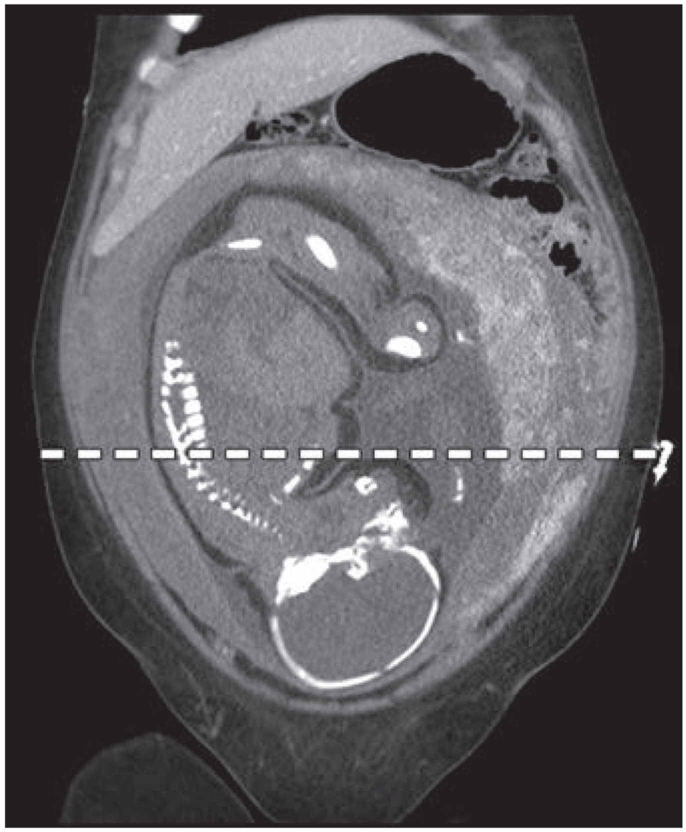

Fig. 8.

24-year-old woman at 38 weeks of gestation after motor vehicle collision. Coronal CT image shows full *z*-axis length of scan. Dotted line represents *z*-axis level of iliac crests. Note that more than half of fetus would still receive primary and high proportion of scatter radiation using limited scanning range.

TABLE 1

CT Findings in 35 Patients With History of Blunt Trauma and Diagnoses That Would Have Been Missed With Limited Abdomen-Only CT

CT Findings	No. of Patients	Diagnoses Potentially Missed With Abdomen-Only CT
Negative for intraabdominal injury	28	None
Liver laceration	2	None
Renal laceration	1	None
Liver and renal laceration	1	None
Retroperitoneal hematoma	1	Inferior aspect of retroperitoneal hematoma
Left pelvic gunshot wound and iliac fracture	1	Left pelvic gunshot wound and iliac fracture
L1–L5 transverse process fractures, iliac fracture, extraperitoneal hematoma	1	L5 transverse process fracture, iliac fracture, extraperitoneal hematoma