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Fetal Dose Estimation for Pregnant Breast Cancer Patients during Radiotherapy Using an In-house Phantom

Mostafa Shirkhani*, Sahel Heydarheydari*, Negin Farshchian,***, Mohammad Taghi Eivazi*, Abbas Haghparast*,***♦**

*Department of Medical Physics, Faculty of Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran
**Department of Radiation Oncology, Faculty of Medicine, Kermanshah University of Medical Sciences, Kermanshah, Iran
***Clinical Research Development Center, Imam Reza Hospital, Kermanshah, Iran

Abstract

Background: Up to 3% of breast cancers may be diagnosed in pregnancy, during which period radiation therapy is not preferred, yet sometimes inevitable. Due to fetal radiation sensitivity, the fetal radiation safety is of particular concern. The present study was performed to estimate fetal dose for pregnant breast cancer patients during radiotherapy using an in-house phantom.

Method: The fetal dose was estimated through phantom measurement using an ion chamber dosimeter. The phantom measurement was performed by simulating treatment planning on an in-house anthropomorphic phantom which consisted of natural human bone, cork, and paraffin. The right breast and the right supraclavicular area of the phantom were irradiated under the four-field technique with 6 and 10 MV photon beams for un-wedged and wedged fields.

Results: During the first trimester of pregnancy, the radiation dose delivered to the fetus was in the range of 0.11-0.14 Gy for a 50 Gy total tumor dose in 25 fractions. The fetal dose in the second and third trimester of pregnancy ranged from 0.14-0.19 Gy to 0.22-0.32 Gy, respectively.

Conclusion: According to the results, the fetal dose is strongly dependent upon the energy beam, treatment procedure, and gestational stage.

Keywords: Breast cancer, Radiation therapy, Fetal dose

♦**Corresponding Author:**
Abbas Haghparast, PhD
Parastar Blvd, Sorkhe Ligeh, Kermanshah, Iran
Postal code/ P.O. Box: 6714415333
Tel: +98 8334276301
Email: a.haghparast@kums.ac.ir

Introduction

Cancer diagnosis sometimes occurs after pregnancy or unrecognized pregnancy. Recently, with the increased fertility age, the cancer risk during pregnancy period has grown.[1] The most frequent type of malignancy in gestation period is breast cancer.[2] Breast carcinoma affects one in eight women in their lifetime and up to 3% of breast cancers may be diagnosed during the

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Table 1. Fetal dose in the first trimester of gestation

Beam energy	6 MV	6 MV	6 MV	6 MV	10 MV	10 MV	10 MV	10 MV
Wedge angle	0°	15°	30°	45°	0°	15°	30°	45°
Point dose (Gy)	0.1125	0.1125	0.1225	0.1275	0.1194	0.1269	0.1319	0.1407

gestation period.[3-5] Regarding breast cancer diagnosis, the median gestational age is 17-25 weeks and the median maternal age is 32-38 years.[6] Although radiation therapy is one of the most important approaches to treat breast cancer, it is not preferred (yet sometimes inevitable) during the pregnancy period.[1] Appropriate treatment plan and fetal dose decrease are essential to reduce potential risks and biological effects such as fetal mortality, mental retardation, malformations, and also cancer induction.[7]

Because of the fetal radiation sensitivity, the fetal radiation safety is of particular concern. It is worth mentioning that the effects of radiation exposure depend on the stage of fetal development. In such conditions, there is no complete instruction for fetal dose estimation in the standards and literature.[8] Therefore, it has been recommended that fetal dose estimation be done via phantom measurement and pretreatment planning in order to reduce the potential risks during treatment. So far, fetal dose has not been assessed at different points and depths by considering the phantom dimensions based on the fetal size in all three trimesters of pregnancy. Therefore, the aim of the present study was to estimate the fetal dose of a pregnant breast cancer patient during radiotherapy using an in-house phantom.

Materials and Methods

This study was funded by the Research Council of Kermanshah University of Medical Sciences (grant number 93156). This article does not contain any studies with human participants or animals performed by any of the authors.

In this phantom experimental study, the fetal absorbed dose was estimated by phantom measurement using a cylindrical ion chamber dosimeter of 0.6 cm^3 positioned in the fetal region of the phantom.Phantom measurements were performed by simulating the treatment procedures on an in-house anthropomorphic phantom comprising a natural human skeleton (real human bones borrowed from the anatomy department) encased in a tissue-equivalent material.

Anthropomorphic phantom made of tissue equivalent materials included three regions: the chest, abdomen, and pelvis, (Figure 1). The phantom had approximately 20 cm width (shoulder-to-shoulder) and 60 cm height. Soft tissues (internal organs) and lung were constructed using paraffin and cork owing to their similarities in atomic numbers and electron densities. The internal and external materials of the phantom had atomic numbers and electron densities close to the soft tissues; for instance, the electron densities of paraffin and cork are 1.01 and 0.3 g/cm^3, respectively. In the abdomen and womb regions, some holes were made, inside of which a cylindrical ion chamber (Farmer) was located

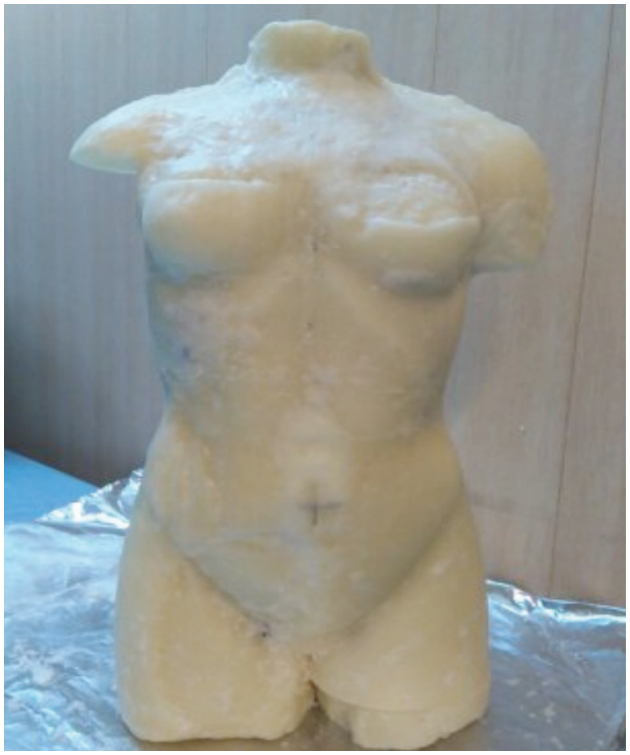

Figure 1. Anthropomorphic phantom.

Table 2. Average fetal dose for different points in the second trimester of gestation

Beam energy	6 MV	6 MV	6 MV	6 MV	10 MV	10 MV	10 MV	10 MV
Wedge angle	0°	15°	30°	45°	0°	15°	30°	45°
First point dose (Gy)	0.24	0.22	0.21	0.19	0.24	0.22	0.19	0.18
Second point dose (Gy)	0.13	0.12	0.11	0.10	0.13	0.11	0.11	0.10
Average of 2 point's dose (Gy)	0.19±0.07	0.17±0.06	0.16±0.06	0.14±0.05	0.18±0.07	0.16±0.07	0.15±0.05	0.14±0.05

as shown in figure 2. For the first trimester of gestation, the fetal dose was measured by placing cylindrical ion chamber into the phantom at 11 cm depth. Dose measurements at the second trimester of gestation were carried out at 9 and 12 cm depths. For the third trimester of gestation, the corresponding levels of dosimetric points were at 6, 7, and 10 cm depths, respectively. The dimensions of the phantom and the fetal size changed based upon the trimester of gestation. Ion chamber positions (dosimetric points) corresponded to the fetal area. For the first trimester, the point was located at 28 cm inferior to the point selected for the placement of the treatment fields common isocenter; for the second and third trimester, the points were respectively located at 21 and 29 cm, and 15, 24 and 31 cm inferior to the isocenter.

CT simulation of the developed phantom was performed using a multi-slice CT scanner (Aquilion 16 Slice; Toshiba, Japan). CT images were performed for each trimester of gestation (week 12, 24, and 36) with the same scanning technique (120 kVp, 250-300 mAs, 512×512-pixel image size) and images were reconstructed via 4 mm intersection gaps in cases. Following the examinations, the images were transferred to the ISOgray Treatment Planning System (TPS) (DosiSoft, France) through a DICOM system adjusted to the linear accelerator (Elekta, UK) with 6 and 10 MV photon beams. In this program, a reconstruction was made in three dimensions (3D), the images were then transferred to the ISOgray TPS, and the fields normally used in a breast treatment were inserted.

The phantom was irradiated in the right supraclavicular area and the right breast under the four-field technique with 6 and 10 MV photon beams for un-wedged and wedged fields. Radiation therapy fields were delivered with either 6 or 10 MV for all fields. Open field with different weights combined with internal 60° wedge was used to produce the isodose distribution of wedges with 15°, 30°, and 45° angulations. Four-field technique consists of two right supraclavicular area fields (18×10 cm^2) and two opposing tangential portals (14×8.3 cm^2). A total dose of 50 Gy was prescribed in 25 fractions (2 Gy / fraction).

Results

The fetal dose during conformal radiotherapy with four-field technique consists of two right supraclavicular area fields and two opposing tangential portals, each with a total dose of 50 Gy in different trimesters of gestation:

- The first trimester of gestation (week 12): 0.11-0.14 Gy
- The second trimester of gestation (week 24): 0.14-0.19 Gy
- The third trimester of gestation (week 36): 0.22-0.32 Gy

The results showed that due to the use of wedge in 6 and 10 MV energy beams, more dose was delivered to the fetus and the more the wedge angle, the more the dose will be, which is true

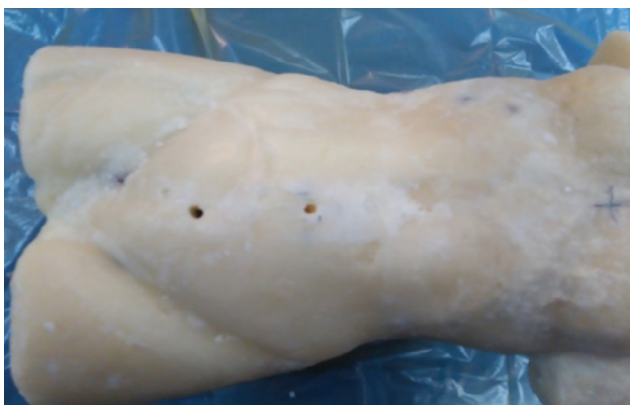

Figure 2. Location of the cylindrical ion chamber (Farmer)

Table 3. Average fetal dose for different points in the third trimester of gestation

Beam energy	6 MV	6 MV	6 MV	6 MV	10 MV	10 MV	10 MV	10 MV
Wedge angle	0°	15°	30°	45°	0°	15°	30°	45°
First point dose (Gy)	0.37	0.42	0.48	0.55	0.37	0.41	0.47	0.54
Second point dose (Gy)	0.17	0.19	0.21	0.22	0.18	0.21	0.21	0.24
Third point dose (Gy)	0.11	0.13	0.14	0.15	0.12	0.12	0.14	0.17
Average of 3 point's dose (Gy)	0.22±0.13	0.25±0.15	0.27±0.17	0.31±0.21	0.22±0.12	0.25±0.14	0.27±0.16	0.32±0.19

for the three trimesters of gestation. Since wedge is utilized to deliver a specific dose to the patient, the number of required monitor units (MUs) for radiation exposure should be increased because the wedge acts like a filter for radiation exposure, reducing the dose. Therefore, the number of MUs should be increased to compensate for the filtered dose and to deliver a definite dose to the patient, which is accompanied by the increased exposure time. On the other hand, when the wedge angle is higher, the number of MUs and exposure time are elevated due to the heightened filtering power of the wedge; accordingly, the scattered beam in tissue is also increased and a higher scattered dose is delivered to the fetus, whose effect can be observed in the tables as an increased dose (Tables 1-3).

Discussion

For the first time, the present phantom trial assessed the fetal doses in various sections and depths with regards to the phantom dimensions based on the fetal size in three trimesters of pregnancy using a developed phantom. The in-house phantom consisted of a natural human skeleton encased in tissue equivalent materials such as paraffin and cork.

Based on the literature[9] and the present findings, the presence of a wedge in the beam path and the increase in angle can augment the fetal dose. According to the results, in three trimesters of pregnancy, with or without the wedge filters, the fetal dose using a 10 MV photon beam was more than that of 6 MV (Tables 1- 3) because the increase in photon beam energy elevates the average energy of scattered beams and their penetration depth, which means that the scattered beams produced of primary 10 MV beam had more average energy, energy transfer share, and penetration depth compared with 6 MV. In the same study,[9] the estimated fetal doses in breast radiotherapy were in the range of 0.03-0.27 Gy using Alderson–Rando anthropomorphic phantom, which is in agreement with the findings of the current study. It should be noted that not all the conditions were equal in the two studies which might have caused certain differences. In the study of B. Bradley et al.,[9] only two tangential fields were used, while in the present study, two supra clave fields were additionally used. Another difference was the energy of the employed photon beam: 6 and 15 MV beams were used in the study of B. Bradley et al., whereas 6 and 10 MV photon beams were utilized in the present research.

Rincon et al.[2] reported a fetal dose of 0.04 Gy at week 15 at 15-cm depth using a 6 MV photon tangential beam (SMLC Plan) with a prescriptive dose of 0.5 Gy at isocenter, which is in line with the current research with the difference possibly due to the gestational age, fetal depth, treatment technique, field size, number of fields, and radiation geometry.

D. Filipov et al.[10] showed that the fetal dose after breast radiotherapy was 1.36 Gy which is inconsistent with our data. The high level of fetal dose in the study of D. Filipov et al. might be due to the commercial phantom which was empty and filled with water and the fact that the phantom had a density close to water. Therefore, the photons had less absorption and dispersion in water along their path compared with the phantom used in the present study which employed natural human bone, cork, and paraffin and more doses were delivered to the fetus. In another study carried out by D. Filipov et al.,[11] the fetal dose was estimated in a humanoid phantom during breast

radiotherapy with 6MV photon beam and two different types of wedge, namely physical and dynamic (30°). The fetal dose was 0.03-0.48 Gy by physical wedge and 0.01-0.13 Gy by dynamic wedge which is in agreement with the results of the present study. The differences between the two studies; however, are probably due to the differences in phantom and fetal dimensions, treatment technique, dosimetric depth, and radiation field dimensions.

The peripheral dose is the dose absorbed outside of the direct fields of radiotherapy treatment plan,[12,13] which is due to three factors: linear accelerator leakage, collimator, and in-phantom scatter. However, machine leakage and collimator scatter can be eliminated with proper shielding which has been proposed for fetal protection during conformal radiotherapy.[14,15] The peripheral dose changes with the energy beam, field size, distance to the closest edge of the radiation field, and depth.[12] By increasing the distance between the dosimetry point and radiation exposure point, the estimated dose was reduced, probably because the more the distance from the field edge to the dosimetry point, the more the photons weakened and scattered along the path and will be unable to reach the given point of dosimetry. This can be a significant parameter for reducing the fetal dose during the radiotherapy procedure where the more the distance from the field edge to the fetal, the lower the dose expected to be delivered to the fetus.

The effects of radiation exposure on the fetus depend on the dose, exposure time, and gestational age.[16] Radiation doses lower than 0.1 Gy do not seem to produce an observable effect on fetal development. A low risk of deformities may exist for fetal doses of 0.1-0.2 Gy in the stage of organogenesis.[17,18] A major potential complication for the fetus during the third trimester of gestation is the induction of malignancy with a risk of cancer 14% per Gy; this risk will be reduced if the delivered dose is fractionated.[16,19] Moreover, fetal dose increased with the progression of gestation due to the increased fetal size and the proximity of the fetus to the radiation field. Based on the dosimetric results, the average total dose exceeded the above threshold; therefore, breast cancer radiotherapy during gestation may not be safely administered since it leads to fetal radiation doses above 0.1 Gy.

Conclusions

Radiotherapy during pregnancy must be conducted in a safe and effective manner. Nevertheless, efforts must be dedicated to both estimating and diminishing the peripheral fetal radiation dose to reduce complications in healthy tissues outside the treatment field. The results showed that in case of using the wedge and its increased angle, the fetal dose in breast radiotherapy was increased in three trimesters of pregnancy using 6 and 10MV photon beams. However, the fetal dose in 10MV beam was more than that of the 6MV beam. Furthermore, in all trimesters of pregnancy, the more the distance from the treatment field edge to the fetal, the lower the dose expected to be delivered to the fetus. In addition, with the increase in the pregnancy period (gestation week), the fetal dose is increased. The results showed that the average total dose exceeded the above threshold; therefore, breast cancer radiotherapy during gestation may not be safely administered since it leads to fetal radiation doses above 0.1 Gy.

Based on the ALARA (as low as reasonably achievable) principle, the use of shielding which can reduce the fetal dose below the threshold of 0.1 Gy and postpone the radiation therapy as an adjuvant therapy is suggested; even in low doses, the pregnant patient should be informed about the radiation potential effects on the fetus due to stochastic factors.

In the current study, the results of dose estimation were obtained according to the type and dimensions of the phantom, as well as the four-field treatment technique, radiation field dimensions, and specific wedges utilized in the ELEKTA linear accelerator. In any case, it is indispensable to obtain more comprehensive data in this regard for all the treatment plans and in every radiotherapy unit.

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Conflict of Interest

None declared.

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