Improvement of dose distribution with irregular surface compensator in whole breast radiotherapy

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ABSTRACT

Aim of this study was to compare the dosimetric aspects of whole breast radiotherapy (WBRT) between an irregular surface compensator (ISC) and a conventional tangential field technique using physical wedges. Treatment plans were produced for 20 patients. The Eclipse treatment planning system (Varian Medical Systems) was used for the dose calculation: For the physical wedge technique, the wedge angle was selected to provide the best dose homogeneity; for the ISC technique, the fluence editor application was used to extend the optimal fluence. These two treatment plans were compared in terms of doses in the planning target volume, the dose homogeneity index, the maximum dose, ipsilateral lung and heart doses for left breast irradiation, and the monitor unit counts required for treatment. Compared with the physical wedge technique, the ISC technique significantly reduced the dose homogeneity index, the maximum dose, the volumes received at 105% of the prescription dose, as well as reducing both the ipsilateral lung and heart doses ($P < 0.01$ for all comparisons). However, the monitor unit counts were not significantly different between the techniques ($P > 0.05$). Thus, the ISC technique for WBRT enables significantly better dose distribution in the planning target volume.

Key words: Dose distribution, irregular surface compensator technique, physical wedge technique, whole breast radiotherapy

Introduction

Whole breast radiotherapy (WBRT) is the standard therapy for preventing local recurrence of early breast cancer following breast conservation surgery. WBRT uses the tangential field technique; however, dose distribution is complicated because of irregularities in the chest-wall contour and the varying thickness of the underlying lung tissue. Therefore, wedge filters are used to improve dose distribution. With regard to a physical wedge (PW), homogeneous dose distribution is obtained in the central axis of the target volume, and high dose changes are observed owing to the decrease in separation at the superior and inferior aspects. Although the International Commission on Radiation Units and Measurements (ICRU) recommends that the planning target volume (PTV) should be within the 95% and 107% isodose surfaces, radiation dose homogeneity is seldom achieved in WBRT using PW.

The early and late complications of WBRT are related to both target volume and treatment technique. To date, several breast irradiation techniques have been reported to improve the dosimetry distribution. These include the field-in-field (FIF) technique, the use of electronic compensation and inverse planning intensity modulated radiation therapy (IP-IMRT).

In the present study, an irregular surface compensator (ISC) technique with a fluence editor tool was used to increase the dose homogeneity of the target volume, whereas decreasing the dose absorbed by tissue surrounding the targeted tissue. Electronic compensation involves radiation beam modulation using dynamic multi-leaf collimators (dMLCs) instead of PW. There are two types of electronic compensators available in the Eclipse treatment planning system (TPS). The electronic compensator is a planar compensator that compensates to a flat plane perpendicular to the central axis of the beam. To generate the electronic compensator, a physical planar compensator must first be generated. The software will then allow for the planar compensator to be converted to an electronic compensator. The ISC will compensate to a curved surface. Using a curved compensation surface provides better distributions in cases

Access this article online

Website: www.jmp.org.in
DOI: 10.4103/0971-6203.116361
where the shape of the target volume is rounded, such as breast treatment. This type of electronic compensation is called the ISC in the Eclipse.

In a previous study of the ISC technique, the fluence editor was not used much. Although user experience and time to master the fluence editor is required, its use shows greater improvement of dose distribution than the skin flash tool. Shun et al. performed a study that used the ISC technique with the fluence editor. However, the dose distribution was insufficiently improved. The present study aimed to compare and evaluate the dosimetry of whole breast radiotherapy between the ISC and PW techniques.

Materials and Methods

Treatment plans were implemented in 20 patients with breast cancer (10 left and 10 right breasts) following breast conservation surgery. Patient localization and positioning followed our standard departmental protocols for breast treatment. Before the computed tomography (CT), breast tissue was palpated by the radiation oncologist, and radiopaque wires were fixed around the breast tissue in the medial and lateral central axes. Breath coaching was delivered to maintain a regular breathing rhythm. Patients underwent CT with 1.0-mm thickness with free breathing. Thereafter, CT data were transferred to the Eclipse (version 8.9, Varian Medical Systems, Palo Alto, CA, USA) TPS.

The contours of both the body and the ipsilateral lung were generated automatically using a contouring feature of TPS. The radiopaque wires, heart and the clinical target volume (CTV) were contoured by a medical physicist. The PTV was generated by expanding CTV by 5 mm in all directions except in the direction of the skin surface. PTV for evaluation of the dose distribution (PTVeva) was defined as the volume of PTV enclosed by contours drawn 5 mm below the skin surface to eliminate the region of dose build-up.\(^{[15]}\)

For each patient, treatment planning was designed using two tangential fields for breast irradiation with two different techniques: PW and ISC. The treatment fields were created with reference to the anatomic and the radiopaque wires. In addition, the anisotropic analytical algorithm (ver. 8.9.17)\(^{[16]}\) was used for dose calculation. The tissue heterogeneity correction was used in all the treatment plans. The prescription dose was 50 Gy in 25 fractions at the isocenter. All the plans were treated with 6 MV photon energy from the Clinac iX with 120 MLCs (Varian Medical Systems, Palo Alto, CA, USA).

Initially, the three-dimensional conformal radiotherapy (3D-CRT) planning was undertaken conventionally using two parallel opposing tangential fields without PW. Subsequently, wedges were added, and the wedge angle and beam weightings were optimized by forward planning for achieving better homogeneous dose distribution.

ISC, a type of electronic compensation, is a feature of the Eclipse device which enables improved dose homogeneity for irregular surface shapes. If the dose is not sufficiently homogenous, the fluence editor (painting the fluence map) can modify the fluence distribution to achieve better dose homogeneity. The fluence editor, which visualizes the fluence of the selected field in the beams eye view (BEV), allows the user to graphically extend the fluence outside the body surface with a paint brush. The ISC technique is a manual forward-planning IMRT (FP-IMRT) and is designed to reduce the hot and cold regions. The plan was modified on the basis of the original 3D-CRT planning without wedges for ISC technique.

First, by viewing the dose distribution along the BEV, the fluence editor was manipulated to shield the breast areas receiving >105% of the prescribed dose. On the BEV windows, the value of the transmission factor of the hot spot regions was measured. The transmission factor was replaced by the paintbrush. The transmission factor of the cold spot regions was similarly replaced. The hot and cold spot regions could be modified by replacing the transmission factor. Fluence maps were converted to leaf sequences for dMLC delivery. After recalculation of dose distribution, if the dose remained >105%, the processes described were repeated to achieve an optimal dose distribution. A typical initial fluence pattern is presented in Figure 1a, and a fluence pattern after modification using the fluence editor is presented in Figure 1b.

The two different treatment plans (PW or ISC) were compared objectively using the dose volume histograms (DVHs) for doses in PTVeva, the organ at risk (OAR) and the monitor unit (MU) counts required for treatment. With regard to PTVeva, the following values were compared: Mean dose (Dmean), maximum dose (Dmax) and dose homogeneity index (DHI) and the percent volumes receiving at least 95% and 105% of the prescribed dose (V95% and V105%).

DHI is defined as follows:

\[
DHI = \frac{D2% - D98%}{D_{\text{prescription}}} \times 100\%
\]

where D2% for PTVeva is the dose corresponding to 2% volume on the cumulative DVH, D95% for PTVeva is the dose corresponding to 98% volume on DVH, and Dprescription is the prescription dose at the isocenter.

The following parameters were compared: For ipsilateral lung, the values of Dmean and the volumes receiving more
than 5, 10, 20, and 30 Gy ($V_{5\, Gy}$, $V_{10\, Gy}$, $V_{20\, Gy}$, and $V_{30\, Gy}$) and $V_{5\, Gy}$, $V_{10\, Gy}$, $V_{20\, Gy}$, $V_{30\, Gy}$, and $D_{mean}$ values for the heart in left breast irradiation.

The Wilcoxon signed rank test was used for comparing each dosimetric parameter. The significance level was set at $P < 0.05$. The statistical analyses were performed using IBM SPSS Statistics 21 for Windows (IBM Japan, Chuo-ku, Tokyo, Japan).

Results

The dose distributions obtained in a typical plan for the PW and ISC techniques are presented in Figure 2. The comparisons of DVHs for both the techniques are presented in Figure 3. The result of dose variation analysis of the 20 patients with breast cancer compared with the DVH values are listed in Table 1.

Compared with the PW technique, the ISC technique was superior: It significantly reduced DHI for the volumes receiving 105% of the prescription dose, the maximum dose and the ipsilateral lung and heart doses for dose evaluation ($P < 0.05$ for all comparisons). With regard to the PW technique, 16 of the 20 patients used 15° wedges, and four patients used 30° wedges. The average values of the treatment MUs of the PW and ISC techniques were 308.9 and 324.1 counts, respectively. Furthermore, the MU counts revealed no significant difference between the two techniques ($P = 0.085$).

Discussion

The present study aimed to compare two techniques of WBRT in terms of the homogeneity of dose distribution and the number of hot spot regions. Various techniques have been developed to provide homogeneous dose distribution in PTV, for example, FIF, FP-IMRT, and IP-IMRT. The FIF technique is a practical method and less operator-dependent. However, the procedures used to
optimize the plans for WBRT have not been well established at our institution. Moreover, IP-IMRT requires more planning time and advanced planning skills. Therefore, to further improve the dosimetry of the irradiated breast, we utilized the ISC technique, a technique in which we have sufficient experience.

In several studies of IP-IMRT, $D_{\text{max}}$ was more than 110% of the prescribed dose,$^{[12,13]}$ and the dose distribution of IP-IMRT-only fields showed insufficient improvement. In addition, several studies have compared dosimetry in the FIF and PW techniques for WBRT, and several investigations have focused on the use of the FIF technique to improve dose distribution. However, reducing high-dose (>107%) volumes resulted in a small increase in the tissue volume receiving <95% prescribed dose,$^{[10]}$ this trade-off is a disadvantage of the FIF technique. In the present study, the ISC and PW techniques not only resulted in a significantly smaller hot spot within the breast volume ($V_{(105\%)}$) but also resulted in an increase in the mean of $V_{\text{eva}}$. The ISC technique reduced the three-dimensional (3D) maximum dose by 4%. As a result of the DHI evaluation, the ISC technique was determined to significantly improve the dose homogeneity of $\text{PTV}_{\text{eva}}$ when compared with that of the PW technique. Figure 2 presents the difference of the dose distributions between the PW and ISC techniques. The ISC technique for whole breast radiotherapy enables significantly better dose distribution in $\text{PTV}_{\text{eva}}$.

Furthermore, our results indicated that with the ISC technique, ipsilateral lung volumes receiving 5, 10, 20, and 30 Gy and mean doses decreased significantly. Similarly, $V_{5\text{ Gy}}$, $V_{10\text{ Gy}}$, $V_{20\text{ Gy}}$, and $V_{\text{mean}}$ values were significantly lower for the heart in the ISC technique when compared with those of the PW technique. Although WBRT for early breast cancer can reduce the risk of death, it usually involves some irradiation of the heart and lung.$^{[17]}$ It is expected that with this technique, the risk of late radiotherapy-associated complications will be reduced.

The mean $\text{PTV}_{\text{eva}}$ volume for 20 patients was 501 cc (range: 157-1185 cc). Most patients were classified with a small breast size. The initial dose distribution was significantly impacted by the size of the intact breast and the separation distance between the two fields. However, this impact decreased for the dose distributions when the breast size was small. In addition, the initial dose distribution would be futile if the fluence pattern was modified using the fluence editor. Thus, we did not address the breast size in this study.

In a similar study by Shun et al.$^{[14]}$ ISC was demonstrated to provide improved dose homogeneity compared with the PW technique. However, the dose distribution was only slightly improved, and the maximum dose was greater than 105% of the prescribed dose. The results of the study showed that the ISC technique could provide slight improvements in breast coverage for patients with smaller breast sizes. In the present study, the ISC technique was shown to successfully improve dose homogeneity despite small size breast. It is considered that improvements in dose homogeneity using the ISC technique would be dependent on the efficacy of the fluence editor.

### Table 1: Dosimetric parameters of 20 patients with breast cancer for the physical wedge and irregular surface compensator techniques

| Parameters | Wedge technique | ISC technique | $P$ value |
|------------|----------------|---------------|-----------|
| $\text{PTV}_{\text{eva}}$ Volume (cc) | Mean $\left(\pm SD\right)$, Range: 157-1185, SD±274.8 | Mean $\left(\pm SD\right)$, Range: 157.2-1184.5, SD±271.8 | <0.01 |
| $\text{DHI}$ | 13.3 (3.7) | 9.9 (2.6) | <0.01 |
| Maximum dose (%) | 108.3 (4.2) | 104.3 (0.5) | <0.01 |
| $V_{95\%}$ | 92.3 (6.6) | 95.4 (3.5) | 0.03 |
| $V_{105\%}$ | 6.6 (7.4) | 0.0 (0.0) | <0.01 |
| Ipsilateral lung (%) | | | |
| $V_{5\text{ Gy}}$ | 32.5 (7.0) | 24.6 (5.3) | <0.01 |
| $V_{10\text{ Gy}}$ | 17.9 (4.3) | 15.1 (4.2) | <0.01 |
| $V_{20\text{ Gy}}$ | 11.6 (3.4) | 10.5 (3.6) | <0.01 |
| $V_{30\text{ Gy}}$ | 9.4 (3.2) | 7.9 (3.8) | 0.02 |
| Mean dose | 9.5 (4.6) | 7.5 (3.7) | <0.01 |
| Heart (%) | | | |
| $V_{5\text{ Gy}}$ | 14.7 (9.3) | 6.6 (4.5) | <0.01 |
| $V_{10\text{ Gy}}$ | 4.7 (3.6) | 3.9 (3.4) | <0.01 |
| $V_{20\text{ Gy}}$ | 2.8 (2.3) | 2.4 (2.2) | 0.02 |
| $V_{30\text{ Gy}}$ | 2.2 (1.9) | 1.9 (1.9) | 0.02 |
| Mean dose | 5.7 (3.8) | 3.9 (3.8) | <0.01 |
| Total MU (count) | 308.9 (42.2) | 324.1 (31.8) | 0.085 |

$\text{PTV}_{\text{eva}}$: Planning target volume for evaluation, $\text{DHI}$: Dose homogeneity index, $V_{\text{eva}}$: Percent volumes receiving at least 95% and 105% of the prescribed dose, respectively, $V_{5\text{ Gy}}$, $V_{10\text{ Gy}}$, $V_{20\text{ Gy}}$, and $V_{\text{mean}}$: Volumes receiving more than 5, 10, 20, and 30 Gy, respectively, MU: Monitor unit.
The typical planning time was 10-15 min longer for the ISC technique than the PW technique. Although the MU counts were not significantly different between the two techniques, the treatment delivery time of PW technique was longer compared with that of the ISC technique by approximately 1 min. Because wedges are not used in this technique, radiotherapy technicians do not need to reenter the treatment room.

The selected patients in this study were treated with the ISC techniques generated by an expert physicist. A limitation of the ISC technique is that a high level of planning skill is required; however, our institution has two expert planners. Hence, this technique could be performed with little additional workload, and the superior levels of dose homogeneity could be readily achieved compared with those with the PW technique.

Another issue is the effects of dose distribution because of breast movement during radiation delivery. The patients were engaged in breath coaching before CT and radiation therapy to reduce breast movement and to maintain a regular breathing rhythm. Several studies have revealed that breast movements can affect the dose distribution with dynamic IMRT. However, Furuya et al. reported that the effects of dose distribution were relatively small when both the factors of respiratory motion and setup error were evaluated simultaneously. In any case, careful attention must be provided to breast movements during radiation in WBRT.

Conclusion

The ISC technique for WBRT enables a significant reduction in radiation doses received by the heart, lung, and surrounding tissues. In addition to providing a significant increase in dose homogeneity in PTV_{on}, a dose reduction in the inferior and superior regions of the breast makes this technique advantageous. Because of these advantages, this modern technique has been applied for most patients with breast cancer at our institution.

References

1. Warlick WB, O’Rear JH, Earley L, Moeller JH, Gaffney DK, Leavitt DD. Dose to the contralateral breast: A comparison of two techniques using the enhanced dynamic wedge versus a standard wedge. Med Dosim 1997;22:185-91.
2. McParland BJ. The effect of a dynamic wedge in a medial tangential field up on the contralateral breast dose. Int J Radiat Oncol Biol Phys 1990;15:151-20.
3. ICRU Report No. 50. Prescribing, recording and reporting photon beam therapy. ICRU Bethesda, Maryland, 1993.
4. Cross MA, Elson HR, Aron BS. Breast conservation radiation therapy technique for women with large breasts. Int J Radiat Oncol Biol Phys 1989;17:199-203.
5. Mazonakis M, Varveris H, Damilakis J, Theoharopoulos N, Gourtsoyiannis N. Radiation dose to conceptus resulting from tangential breast irradiation. Int J Radiat Oncol Biol Phys 2003;55:386-91.
6. Caudell J, De Los Santos J, Keene K, Fivelash J, Wang W, Carlisle JD, et al. A dosimetric comparison of electronic compensation, conventional intensity modulated radiotherapy, and Tomotherapy in patients with early-stage carcinoma of the left breast. Int J Radiat Oncol Biol Phys 2007;68:1505-11.
7. Murthy KK, Sivakumar SS, Davis CA, Ravichandran R, El Ghamrawy K. Optimization of dose distribution with multi-leaf collimator using field-in-field technique for parallel opposing tangential beams of breast cancers. J Med Phys 2008;33:60-3.
8. Su M, Ayzenberg V, Li W. Dosimetric parameter comparison of the electronic tissue compensator technique with the conventional physical wedge technique for the whole breast treatment. Med Phys 2008;35:2587.
9. Emmens DJ, James HV. Irregular surface compensation for radiotherapy of the breast: Correlating depth of the compensation surface with breast size and resultant dose distribution. Br J Radiol 2010;83:159-65.
10. Sasoaka M, Futami T. Dosimetric evaluation of whole breast radiotherapy using field-in-field technique in early-stage breast cancer. Int J Clin Oncol 2011;16:250-6.
11. Erkan T, İğdem S, Akoç G, Zengin F, Atilla S, Dinger M, et al. Dosimetric comparison of field in field intensity-modulated radiotherapy technique with conformal radiotherapy techniques in breast cancer. Jpn J Radiol 2010;28:285-9.
12. Descovich M, Fowble B, Bevan A, Schechter N, Park C, Xia P. Comparison between hybrid direct aperture optimized intensity-modulated radiotherapy and forward planning intensity-modulated radiotherapy for whole breast irradiation. Int J Radiat Oncol Biol Phys 2010;76:91-9.
13. Al-Rahbi ZS, Al Mandhari Z, Ravichandran R, Al-Kindi F, Davis CA, Bhash S, et al. Dosimetric comparison of intensity modulated radiotherapy isocentric field plans and field in field (FIF) forward plans in the treatment of breast cancer. J Med Phys 2013;38:22-9.
14. Tsai SH. A dosimetric comparison of electronic tissue compensation and conventional wedge field technique in treating breast cancer. College of Science and Health, Medical Dosimetry Program, University of Wisconsin-La Crosse, MS Thesis; 2012.
15. Frazier RC, Vicini FA, Sharpe MB, Yan D, Fayad J, Baglan KL, et al. Impact of breathing motion on whole breast radiotherapy: A dosimetric analysis using active breathing control. Int J Radiat Oncol Biol Phys 2004;58:1041-7.
16. Tallikainen L, Helminen H, Torsti T, Siljamäki S, Alakuijala J, Pyyry J, et al. A 3D pencil-beam based superposition algorithm for photon dose calculation in heterogeneous media. Phys Med Biol 2008;53:3821-39.
17. Cuzick J, Stewart H, Rutqvist L, Houghton J, Edwards R, Redmond C, et al. Cause-specific mortality in long-term survivors of breast cancer who participated in trials of radiotherapy. J Clin Oncol 1994;12:447-53.
18. Xing L, Crooks S, Li JG, Ozhasoglu G, Chen Y, Metha V, et al. Incorporating respiratory motion into the design of intensity maps in IMRT treatment of breast cancer. Int J Radiat Oncol Biol Phys 2000;48:199.
19. Cao J, Roeske JC, Chmura SJ, Salama JK, Shoushtari AN, Boyer AL, et al. Calculation and prediction of the effect of respiratory motion on whole breast irradiation dose distributions. Med Dosim 2009;34:126-32.
20. Furuya T, Sugimoto S, Kurokawa C, Ozawa S, Karasawa K, Sasai K. The dosimetric impact of respiratory breast movement and daily setup error on tangential whole breast irradiation using conventional wedge, field-in-field and irregular surface compensator techniques. J Radiat Res 2013;54:157-65.

How to cite this article: Hideki F, Nao K, Hiroyuki H, Hiroshi K, Hanuyuki F. Improvement of dose distribution with irregular surface compensator in whole breast radiotherapy. J Med Phys, 2013;36:115-9.

Source of Support: Nil, Conflict of Interest: None declared.