Physical Comparative Analysis of Dose-Volume Histogram between Multistatic Field Technique and Three Dimensional Radiation Therapy Planning for Postoperative Radiation Therapy of Breast Cancer

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The purpose of this study was to determine the clinical feasibility of multistatic fields technique (MSF) and to compare dosimetric factors with 3-dimensional conformal radiation therapy (3DCRT). Thirty breast cancer patients were randomly selected for comparison of MSF radiation treatment plan with 3DCRT. Both MSF planning and 3DCRT planning were performed employing the Plato planning system (Plato Sunrise V 26.4). The dosimetric data showed that improved dose homogeneity in the whole breast volume and reduction in the dose to ipsilateral lung and heart for MSF treatments, which may be of clinical value in potentially contributing to improved cosmetic results and reduced late treatment-related toxicity.

Keywords: Breast cancer; Multistatic field technique; Three-dimensional conformal radiation therapy

INTRODUCTION

Breast conserving radiotherapy is a commonly used treatment for early-stage breast cancer. In breast-conserving treatment, radiation therapy irradiates the whole breast at a dose of 45 to 50 Gy. Tangential parallel-opposed pair is almost always the technique of choice for this endeavor. In spite of the complex geometry of the breast, the treatment planning of tangential breast irradiation is conventionally performed using a 2-dimensional planning system and the data of body contour and the location of the lung only on the transverse plane [1,2]. The dose distribution in a transverse plane, usually taken at the middle of the radiation field, is assumed to model the dosimetry in other parts of the irradiated target. The efficacy of this empirically derived treatment approach has been established in multiple clinical trials, with local control rates ranging from 90 to 95% and complication rates less than 3 to 5% [3-5]. Despite the positive results in terms of local control rate, however, several studies have demonstrated dose inhomogeneities as large as 20% due to rapid changes in the patient contour [6,7]. The unavoidable presence of lung tissue, coupled with changing patient separation near the deep border of the tangents creates additional regions of high dose in the medial and lateral aspects of the breast. These regions of increased dose may contribute to an inferior cosmetic outcome, particularly in large breasted patients [8,9], as well as variability in the total dose delivered to the primary tumor bed [6,10].

During the last few decades, many researches have been performed and many techniques which improve the dose homogeneity have been proposed. All the proposed techniques can be understood as a method being able to modulate the intensities of the beam in a desired pattern within the treatment volume while keeping the tangential arrangement of the beams [11-13]. The modulated beams are generally delivered by a physical compensator or by a dynamic multi-leaf collimator. The use of physical compensator is, however, time consuming and the use of dynamic multi-leaf collimator requires extensive quality assurance. Therefore, in this study, we investigate the possibility that multistatic fields technique (MSF), applied from the concept of forward planning by Kestin et al. [14], can make up for the shortcomings of the wedged tangential fields technique ideally by analyzing differences in dose uniformity, plan-
ning target volume (PTV) coverage, exposure of organs at risk (OAR), etc.

MATERIALS AND METHODS

1. Computed Tomography Scanning

In computer tomography (CT) scanning (SOMATOM Sensation 16, Siemens AG, Medical Solutions, Forchheim, Germany), the patients were set up using a tilt breast board (AXION 01 carbon fiber breast board, AKTINA Medical, Congers, NY, USA) on the scanner table. A head sponge was placed on the breast board, and the patient’s head was put on the head sponge. The patient was then positioned with both arms up and holding the handles above her head. The patient’s axis was aligned with sagittal laser below the anatomical midline. The scanner couch was driven through the aperture to make sure that the patient would clear the scanner. If the patient did not clear, then the arm position was adjusted. All the patients were educated on breathing control in order to minimize the radiation exposure of the normal lung by respiratory movement. The radiation oncologist marked the superior, inferior, medial and lateral borders of the radiation treatment field on the patient’s skin using wire. With a CT scanner (SOMATOM Sensation 16), the whole volume of the thorax including the left and right breasts, both lungs and heart was scanned at 5 mm’s intervals, and axial CT images of the thorax were obtained. Obtained CT images were transmitted to the treatment planning system (Plato Sunrise V 26.4, Nucletron, Veenendaal, The Netherland) through the Digital Imaging and Communications in Medicine network.

2. Contouring

PTV and OAR were contoured on the axial CT images. PTV was defined as breast tissue inside the radiation beam except the ipsilateral lung (Fig. 1). Then the size of PTV was reduced additionally by 5 mm for all directions. The 5 mm margin reduced corresponds to the area in which the increase of radiation dose may be hindered by build-up, penumbra, lack of electron equilibrium, etc. If the size of PTV is not reduced, the segment weight optimization of MSF can be magnified in the reduced margin. For this reason, the size of PTV was reduced additionally by 5 mm in all directions. Auto-contouring for skin and both lungs was performed using the tools in the Radiation Treatment Planning System.

3. Multistatic Fields Technique

The MSF treatment planning process was similar to the method presented by Kestin et al. [14]. The plans were normalized to a point at the lung-chest wall interface along the perpendicular bisector of the posterior border of the medial and lateral fields. All treatment plans were normalized such that 95% of the prescribed dose covered the entire PTV. A dose of 50 Gy in 25 fractions was prescribed to the whole breast using 6-MV photon beams. An initial calcula-

Fig. 1. Markers and contours on the representative axial computed tomography slice for radiation treatment planning. PTV, planning target volume.

Fig. 2. Example of an open-beam sagittal plane dose distribution. The plane is perpendicular to the beam axis at midseparation. In reality, the overdose irradiation part of prescribed dose (PD) varies according to the shape and size of the patient’s breast. Therefore, by understanding an open-beam sagittal plane dose distribution, we can define the multileaf collimator segment edges, with the leaf end set on each 105% of PD, 110% of PD, and 115% of PD.
tion was performed with the two equally weighted open tangential fields with no blocks or wedges. The hot dose areas were confirmed while examining dose distribution on the open-beam sagittal plane perpendicular to the beam axis in the midseparation (Fig. 2). The hot dose areas were defined as the areas of 105%, 110%, and 115% of the prescribed dose. And then, the additional subfields were designed to block overdose regions with a multileaf collimator in the beam’s eye view. Weighting of the beams was tuned until an ideal dose distribution was obtained, and another pair of subfields were added when the dose homogeneity was not satisfactory. All dose distributions were calculated using the Plato planning system (Nucletron) with a 0.5 cm³ dose grid.

4. Dosimetric Comparison of MSF with 3-Dimensional Conformal Radiation Therapy

Dosimetric parameters were calculated to compare the MSF plan to 3-dimensional conformal radiation therapy (3DCRT) in terms of dose uniformity and reduction in dose to critical organs. The CT data of 15 randomly selected left-sided breast cancer and 15 right-sided breast cancers were used for this retrospective treatment planning study. All of these patients were treated with MSF. The same beam arrangements and contours were kept for 3DCRT. Optimized distributions were obtained using wedge and different beam weights on Plato planning system. A dose distribution was prepared across the target volume using a wedge as compensator to ensure dose inhomogeneity of no more than ± 5% (Fig. 3). Lung correction employing a correction factor within the range 0.2 to 0.3 was used when calculating the dose distribution. Exposure dose for PTV and OAR was recorded based on cumulative dose-volume histograms (DVH) data of all the patients. The compared dosimetric parameters of PTV coverage were: V95 (the volume percentage of PTV receiving over 95% of prescription dose [PD]), dose homogeneity index (DHI): V95-110 (the volume percentage of PTV receiving 95 to 110% of PD), V105 (the volume percentage of PTV receiving over 105% of PD), V110 (the volume percentage of PTV receiving over 110% of PD). Analyzed dosimetric parameters of OAR were: heart V10 (the volume percentage of the heart receiving over 10 Gy), V20, V30; lung V10 (the volume percentage of the ipsilateral lung receiving over 10 Gy), V20, V30; percent of volume of contralateral lung receiving >5% of PD; the maximum dose and mean dose to the contralateral breast (unit: Gy). The total monitor unit (MU) was also compared.

5. Statistical Analysis

A 2-tailed t-test was performed for the mean values of the two treatment methods. The statistical significance level was P < 0.05. All these analyses used SPSS statistical software (SPSS Inc., Chicago, IL, USA).

RESULTS

The mean V95, DHI (V95-110), V105, and V110 for PTV of MSF was 90.5 (standard deviation [SD], 4.6), 90.1 (SD: 4.0), 22.1 (SD: 15.8), 2.2 (SD: 5.8), respectively; and for 3DCRT, 90.04 (SD: 3.1), 86.23 (SD: 7.1), 51.21 (SD: 13.1), and 9.35 (SD: 8.4), respectively. The dose comparisons showed that V95 for the PTV of MSF was about the same as those of 3DCRT. The homogeneity index V95-100 was increased by 4.49% with MSF compared to 3DCRT. The improvement in dose homogeneity was statistically significant (P < 0.05). The reductions of V105 and V110 for the MSF compared to 3DCRT were 56.8% and 76.4%, respectively. The reductions were statistically significant (P ≤ 0.002) (Table 1). The V10, V20, and V30 for

| Table 1. Dosimetric comparison of mean planning target volume coverage for MSF and 3DCRT |
| Parameter | MSF (% [SD]) | 3DCRT (% [SD]) | % Difference (MSF/3DCRT) × 100 - 100 | P-value |
| V95 | 90.5 (4.6) | 90.04 (3.1) | +0.51 | 0.681 |
| DHI (V95-110) | 90.1 (4.0) | 86.23 (7.1) | +4.49 | 0.030 |
| V105 | 22.1 (15.8) | 51.21 (13.1) | -56.80 | 0.001 |
| V110 | 2.2 (5.8) | 9.35 (8.4) | -76.40 | 0.002 |

MSF, multistatic fields technique; 3DCRT, 3-dimensional conformal radiation therapy; SD, standard deviation; DHI, dose homogeneity index.
heart with MSF were 15.7 (SD: 5.4), 10.3 (SD: 7.5), and 11.1 (SD: 6.2), respectively. The percent reduction in dose with MSF compared to 3DCRT were 10.2%, 11.9%, and 13.2%, respectively. However, there was no statistical significance between MSF and 3DCRT for the dosimetric factors of heart.

The V10, V20, and V30 for ipsilateral lung with MSF were 17.0 (SD: 5.7), 14.3 (SD: 2.25), and 12.4 (SD: 4.83), respectively. The percent reduction in dose with MSF compared to 3DCRT were 6.74%, 1.65%, and 10.1%, respectively. Also, there was no statistical significance for the dosimetric factors of ipsilateral lung between MSF and 3DCRT.

The percentage of volume of contralateral lung receiving >5% of PD was reduced by about 37.5% with MSF compared to 3DCRT. The reduction was statistically significant (P < 0.05). The mean and maximal doses of contralateral breast with MSF were 180.5 (SD: 43.10), 380.5 (SD: 107.0), respectively. The percent reduction in the mean and maximal doses with MSF compared to 3DCRT were 62.9%, 38.6%, respectively, and the P-values were 0.048, 0.032, respectively. The mean of total MU was different between MSF and 3DCRT (235 vs. 389) (Table 2). The reduction in total MU with MSF was statistically significant (P = 0.03).

### DISCUSSION

Because the conventional wedged tangential fields technique produces poor cosmetic results due to the excessive hot spot in the breast and dose nonuniformity, it is desirable to minimize the excessive hot spot and achieve uniform dose distribution over the entire breast volume in treatment planning. Previous research has already reported that the wedged tangential fields technique has dose nonuniformity of around 15 to 20% in the superior and inferior regions of the breast [15-17]. What is more, the relatively low attenuation of the lung tissue in the radiation treatment field may result in the exposure of the lung to a high dose of radiation in the medial and lateral field of the breast. In this way, the wedged tangential fields technique has raised the problem of nonuniform dose distribution in the total radiation dose delivered to the lumpectomy site due to the exposure to excessive dose of the superior and inferior regions and the medial and lateral regions of the breast [8-10,18]. The breast has a complex three dimensional shape, and the site of postoperative adjuvant radiation therapy is deformed nonuniformly. Furthermore, because the breast is close to major normal organs like the lungs and the heart (especially in the case of left breast cancer), it is not easy to attain uniform dose distribution. This problem is more severe in women with large breasts. Nonuniform dose may increase side effects in normal tissue and produce a poor cosmetic result. In some cases, it may cause a serious mental disease in the patient. Therefore, many institutions have studied various radiation therapy methods in order to solve problems in the wedged tangential fields technique, and several recent studies reported that intensity modulated radiation therapy (IMRT) achieves higher dose uniformity than the wedged tangential fields technique [13,19-21].

This study chose MSF as a treatment method that can make up for the shortcomings of the wedged tangential fields technique, and examined difference in dosimetric parameters such as PTV coverage, dose uniformity, ipsilateral lung exposure dose, heart exposure dose, contralateral breast exposure dose, and total MU through comparison of the two treatment methods, including MSF and 3DCRT of wedged tangential field.

MSF is one way to provide an optimized dose distribution to the whole breast in a rapid and efficient manner. The results of our study suggest better dose homogeneity and reduced volume of hot spots.
with MSF in comparison to 3DCRT. This better dose homogeneity may translate into reduced skin toxicity and better cosmetic outcome in comparison with the conventional plan. The use of leaves instead of wedges as compensator also reduces scatter dose to the contralateral breast and to the other parts of the body. We found in the present study that dose to the contralateral breasts was reduced significantly with MSF in comparison to conventional 3DCRT. In our study, the dose to contralateral lung was also significantly reduced, reflecting reduction in scatter dose to other parts of the body. Similarly, in a study by Woo et al. [22], the use of physical wedges as a compensation technique was the most significant factor associated with increased scattered dose (P < 0.001), resulting in approximately three times more exposure compared with breast IMRT. This decrease in scatter dose has the potential to reduce second malignancies, specifically in younger women with breast cancer treated with radiation.

The reduction in dose to critical organs, including heart and lung, with this technique is very modest because with the tangential breast MSF technique, the beams go through the similar volume of critical organs as 3DCRT, as the beam size and angles are same. This reduces the ability of forward planning used in MSF to optimize and further reduce the dose to critical organs. The IMRT using multiple beam technique can achieve this goal better but with the disadvantages of increasing scatter dose and exposing larger volume to lower dose. One way to further reduce heart dose, if critical, would be to remove the region of breast overlapping the heart from the target volume, thus allowing the optimizer to reduce the heart dose. This would result in inferior coverage of breast volume; thus, this decision has to be made by the treating physician based on clinical information.

The biggest problem in breast radiation therapy is nonuniform dose distribution. In order to solve this problem, various methods may be applicable including representative examples like physical compensator [12,23], wedge, and field-in-field technique [19,21,24]. Among the methods listed above, the most conventional one is the use of physical compensator made based on CT images of the patient’s body contour. However, this method has a limitation in a wide application because the use of physical compensator is not practical in most institutions. In addition, customized compensator may increase scatter dose to the contralateral breast. Another commonly used method is the use of an external or internal wedge for correcting a part of variation in the thickness of tissue in the whole breast. This is convenient to apply because it is not necessary to make customized compensator for each patient, but the two-dimensional dosimetric profile of a wedge shows that it is impossible to correct the nonuniformity of dose distribution. The third method is field-in-field technique that uses multileaf collimators. This is a quick and efficient method that can achieve optimized dose distribution over the whole breast. Based on these efforts, IMRT came to be applicable to the breast cancer. In determining the beam weight of the irradiation segment, it uses two different optimization algorithms, which are forward planning and inverse planning. Several previous studies have already reported that breast IMRT provides benefits such as improvement in dose uniformity, decrease in exposure dose to the lungs and the heart, and decrease in scatter dose to the contralateral breast, and maintained that these improvements in the dosimetric aspect can bring about better cosmetic results, lower risk of complications in the heart and the lungs, lower risk of contralateral breast cancer, etc. [25-27]. However, IMRT requires additionally an inverse planning module and intensive investment of time, so it cannot be used widely in all institutions. Thus, this study approached IMRT as an effort to solve dose non-uniformity and tried to find an efficient solution easily applicable in all institutions and, as a result, we applied MSF from the concept of forward planning by Kestin et al. [14]. Forward planning uses transit dosimetry information from the electronic portal imaging of tangential fields in order to build patients’ breast thickness model, and corrects the nonuniformity of dose distribution using the model [19,20,28].

Through this study, we confirmed that MSF has more improved DHI compared to 3DCRT and its low-dose exposure volume of the ipsilateral lung and heart is relatively small. What is more, we found its advantages in terms of treatment head leakage. These results suggest that institutions, which want to apply IMRT but do not have IMRT equipment, may use the MSF technique to get better results than the conventional wedge technique. In the future after building up clinical data from wide application of MSF to patients, we may need to conduct clinical research related to acute and chronic side effects.

REFERENCES