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Dosimetric Comparison Between Photon and Proton Treatment for Breast Cancer

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Abstract

The study aims to compare dose distribution between modern photon and proton therapy techniques for early stage left breast cancer. Optimum treatment planning were performed with 6MV photon energy for partial VMAT technique, then the plans were performed with proton beam for PBS technique using Monaco® TPS. We compared heart(mean), heart(max), dose(max), lung V5, V10 and V20 doses for both techniques. We determined an average 3.8 Gy heart(mean) doses, 8.6 Gy LAD(mean) doses and 40.6 Gy heart(max) doses by using 2 symmetrical partial VMAT technique. The advantage of proton beam was bragg peak properties, therefore we could highly spare critical organs, we determined an average 0.98 Gy heart(mean) doses, 20.9 Gy heart(max) doses, 3.1 Gy LAD(mean) doses, %9.8 lung V5, 4.6% V10 and %1.6 V20 doses. The results show that plans for both techniques satisfied all OARs dose constraints. Modern photon VMAT therapy yields limited risk of cardiac toxicity in most patients, but proton IMPT therapy can reduce the predicted risk of cardiac toxicity. Especially, heart(mean) dose is critical for cardiac disease, therefore proton beam treatment has advantages for decreasing cardiac disease probability.

Keywords: Proton therapy, VMAT, IMPT, Breast cancer

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1. Introduction

Cancer is a group of diseases characterized by the uncontrolled growth and spread of abnormal cells. If the spread is not controlled, it can result in death. One of the most common cancer is breast cancer in women. About 260,000 new breast cancer cases are expected to be diagnosed in United States for this year.[1]

Adjuvant radiotherapy (RT) is recommended for all patients with breast cancer after breast-conserving surgery or node-positive (N+) mastectomy.[2] Breast-conserving surgery (BCS) combined with postoperative radiotherapy to the residual whole breast has become the standard treatment for the majority of early stage breast cancer patients. Whole-breast irradiation (WBI) followed by tumor bed boost improves local control and overall survival.[3,4] There have been significant advances in the delivery of radiotherapy over the past few decades. Newer radiation techniques, such as, intensity modulated radiotherapy (IMRT), have been developed. There has been some interest in arc-based or rotational therapies to overcome some of the limitations associated with fixed field IMRT, e.g., volumetric modulated arc therapy (VMAT). Especially tangential partial VMAT is a radiation technique that can achieve highly conformal dose distributions with improved target volume coverage and sparing of normal tissues compared with three dimensional conformal radiotherapy (3DCRT) technique and field-and-field forward IMRT technique. Several clinics utilize VMAT either for all patients or for selected patients for whom the organ at risk (OAR) tolerances are exceeded in traditional planning.[5-9]

Proton therapy (PT) is an increasingly utilized radiation treatment alternative to photon (x-ray) therapy for malignancies of the breast. The main motivation for the use of protons lies in the potential reduction of radiation-induced side effects such as cardiac toxicity (especially for left-side BC patients) and pulmonary toxicity.

Intensity-modulated proton therapy *(*IMPT*) is a highly precise* type of radiation therapy using proton therapy. IMPT also provides the most conformal dose delivery technique for radiation therapy, at the same time it is so attractive for sparing OARs. But not all proton therapy can deliver IMPT, only pencil beam scanning (PBS) can. With its highly accurate targeting of tumors.

The potential survival benefit from radiation in breast cancer patients has been lessened by an increase in cardiac mortality related to incidental radiation exposure of the heart.[10-12] Several studies have suggested that the use of proton may reduce the risk of late cardiac mortality in breast cancer survivors receiving radiation therapy, thus positively impacting ultimate breast cancer survival rates.[13-15]

This study included all patients referred to our standard protocol for left-sided postlumpectomy radiation therapy with comprehensive nodal irradiation. The study aims to compare dose distribution between modern photon and proton therapy techniques for early stage left breast cancer.

2. Materials and Methods

Ten patients were imaged with 3-mm slice thickness using Biograph mCT/S20 PET/CT (Siemens, USA) in the supine position with arms above the head, using breast board (IT-V, Austria). Optimum treatment planning were performed with 6 MV photon energy for 2 symmetrical partial arcs 50° to 70° VMAT technique by using Monaco 5.11.02® treatment planning system (TPS) for the Agility® multileaf collimator (MLC). Plans were calculated with 0.3 cm grid size using Monte Carlo Algorithm (MC). The prescribed dose was 48 Gy to the 95% coverage of PTV(breast), 60 Gy in 28 fractions to the 95% coverage of PTV(tumor bed). All patients undergoing definitive partial VMAT for early stage left breast cancer were included in this study.

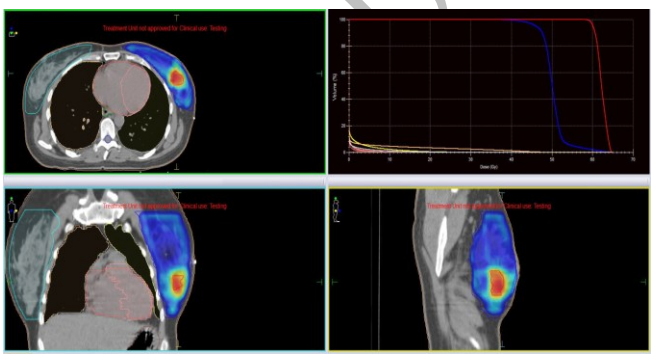

Figure 1. Review of one early stage left breast cancer patient's proton IMPT plan

Proton IMPT plans were optimized with PBS technique using Monaco® 5.30.00 TPS with MC algorithm, as shown in Figure 1. The proton plans were planned on a nonclinical system. We analysized retrospectively heart(mean), heart(max), LAD(mean), lung V5, V10 and V20 doses for photon and proton techniques.

Small uncertainities in density may result in larger dose uncertainities as compared to MV photons, therefore we should have high level Image guided radiotherapy (IGRT) and/or Surface guided radiotherapy (SGRT) systems for elimination misallignment of patient positioning. Organ motion with beam scanning leads to interplay effects. We should consider this effect and intra-fraction motion detection might be mandatory for eliminating dose uncertainities.

3. Results

When we compared photon and proton therapy for ten early stage left breast cancer patients. We determined an average 3.8 Gy heart(mean) doses, 8.6 Gy LAD(mean) doses and 40.6 Gy heart(max) doses by using 2 symmetrical partial VMAT technique, these are shown in Table 1**.** IMPT reduced the dose in all OARs for similar target coverage (%95) and heterogenity index (HI). The benefit of IMPT was higher in the lower dose region than higher dose region, the main reason was bragg peak (Figure 2.) properties of proton beam, therefore we could highly spare critical organs, such as we determined an average 0.98 Gy heart(mean) doses, 3.1 Gy LAD(mean) doses, 20.9 Gy heart(max.) doses, %9.8 lung V5, 4.6% V10 and %1.6 V20 doses. These are shown in Table 2.

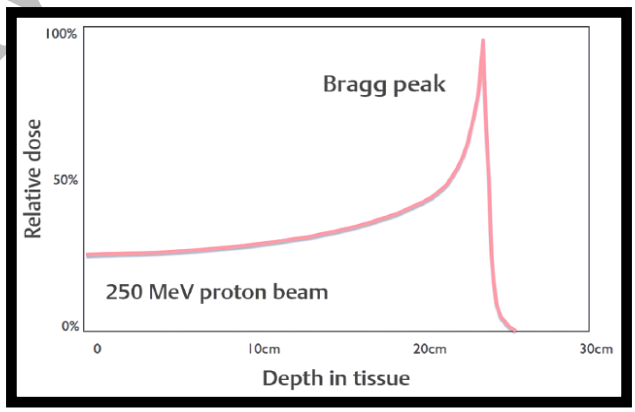

Figure 2. Review of depth dose curves 250 MeV proton beam

4. Discussions

The use of a VMAT technique is shown to improve the dose homogeneity and conformity of the PTV compared with traditional tangential fields in breast cancer RT planning. VMAT spares the high doses to nearby OARs, especially in the ipsilateral lung, and in the heart for left-sided cases. Studies showed that patients who received radiotherapy for breast cancer had an increased risk of developing nonbreast complications in the long term.[16-18] Darby et al.[10] have

Table 1. Dosimetric results of partial VMAT plans for early stage left breast cancer patients

Patient	Left Lung V5Gy (%)	Left Lung V10Gy (%)	Left Lung V10Gy (%)	Heart (max) (cGy)	Heart (mean) (cGy)	LAD (mean) (cGy)	PTV %95 (cGy)	Dose (max) (cGy)	HI PTV
1	47.1	25.9	17.1	3835.1	334.6	778.4	4618.3	6511.6	1.08
2	48.5	28.5	14.8	3937.3	322.2	557.2	4593.1	6503.2	1.13
3	51.5	27.2	13.3	4598.4	471.2	653.9	4565.2	6522.5	1.12
4	36.7	18.1	11.5	4373.3	425.5	1309.4	4699.4	6618.9	1.09
5	56.7	33.2	16.5	3810.5	312.1	933.9	4821.8	6450.6	1.06
6	41.7	24.0	13.5	3002.1	201.1	765.3	4742.8	6705.9	1.08
7	64.0	38.7	25.2	4523.1	490.1	683.8	4686.5	6436.3	1.06
8	52.5	28.8	19.2	4696.1	472.5	1136.1	4551.7	6444.7	1.09
9	45.0	29.3	20.0	4111.2	438.7	1077.6	4679.1	6616.8	1.11
10	53.6	29.0	12.1	3668.1	325.8	718.7	4708.3	6371.6	1.05
Mean ±SD	49.7 ±7.8	28.3 ±5.4	16.3 ±4.2	4055.5 ±517.5	379.4 ±94.0	861.4 ±243.1	4666.6 ±84.6	6518.2 ±101.9	1.09 ±0.03

Table 2. Dosimetric results of IMPT plans for early stage left breast cancer patients

Patient	Left Lung V5Gy (%)	Left Lung V10Gy (%)	Left Lung V10Gy (%)	Heart (max) (cGy)	Heart (mean) (cGy)	LAD (mean) (cGy)	PTV %95 (cGy)	Dose (max) (cGy)	HI PTV
1	7.8	3.9	1.1	2051.6	121.7	334.2	4725.6	6574.1	1.11
2	13.2	5.4	2.2	2200.8	90.4	249.9	4688.1	6522.6	1.10
3	10.7	5.9	2.0	1982.8	50.8	275.2	4618.6	6467.9	1.10
4	4.4	2.2	0.5	2268.7	125.0	389.3	4686.7	6483.6	1.07
5	9.1	5.6	1.1	2003.1	103.5	322.7	4704.6	6504.8	1.08
6	10.6	5.8	1.4	2202.2	112.7	296.2	4632.4	6356.4	1.06
7	12.6	5.0	1.9	2028.4	75.4	293.4	4601.7	6562.9	1.08
8	11.2	5.2	2.2	1925.8	87.6	306.6	4688.6	6579.0	1.07
9	8.6	3.0	1.1	2021.7	116.4	296.2	4604.5	6485.2	1.08
10	10.0	4.2	2.2	2185.4	95.2	288.1	4598.8	6420.1	1.06
Mean ±SD	9.8 ±2.5	4.6 ±1.2	1.6 ±0.6	2087.1 ±106.3	97.9 ±23.1	305.2 ±37.7	4655.0 ±48.4	6495.7 ±70.4	1.08 ±0.02

shown that the relative risk of ishemic heart disease increases with %7.4 per Gy increased mean heart dose, with no apparent threshold. Modern photon therapy yields limited risk of cardiac toxicity in most patients. VMAT and DIBH have been independently used to improve target coverage and conformity while minimizing heart dose in left-sided breast cancer patients. However, these advantages come with the expense of low dose spread to the contralateral side.[19] The VMAT technique may therefore increase the risk of secondary cancer in comparison with conventional tangential fields.[20-22]

IMPT can reduce more the predicted risk of cardiac toxicity and low dose spread to the contralateral side at the same time. Especially, heart(mean) dose is critical for cardiac disease, therefore proton beam therapy has advantages for decreasing cardiac disease probability.

Proton therapy is an extremely precise method, but the biggest challenge is organ motion. Interplay effects in proton therapy can create large distortion and severely degrade the plan quality. For eliminating this effect we could use compression, gating and rescanning or we could create 4D robust plans against interplay effect.

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