A Method for Automatic Optimization of Breast Electronic Tissue Compensation Treatment Plans Based On the Breast Radius and Separation

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Introduction

In this work, we develop and assess a semi-supervised algorithm for optimization of breast electronic tissue compensation treatment plans based on the breast radius and separation.

Background

Electronic compensation is a forward-planned intensity modulated radiation therapy technique which can account for variation in the breast size and shape in both the anterior-posterior and cranio-caudal direction, improving the homogeneity of the dose delivery. Within treatment planning software, the irregular compensation surface is defined by a transmission penetration depth (TPD).

Current clinical standard is empirical TPD selection by the medical dosimetrist, dose profile computation by the planning software, and dose homogeneity improvement by manual editing of the x-ray fluence maps. This can be time consuming (> 30 minutes) and can have large variability between users depending on the experience or skill of the planner.

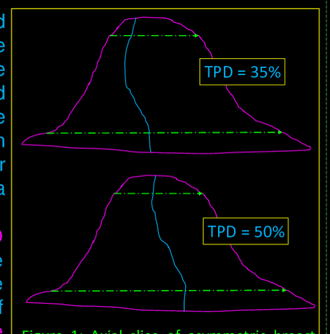

Figure 1: Axial slice of asymmetric breast (pink) with irregular compensation surface (blue) for diverging field (green). Higher TPD pushes compensation surface deeper

Work has been published (Alghufaili 2019, James 2002, Friend 2014) correlating the breast radius and separation to the TPD which yielded the most homogenous dose distribution, however it requires hand-measurement of the breast radius and separation and does not account for variation of radius and separation in the cranio-caudal direction. We look to correlate the full breast shape in the cranio-caudal direction to the x-ray fluence map needed for the most homogenous dose delivery, extending previous work in the literature.

Methods - Breast radius and separation measurement

CT-simulation data were anonymized and used to develop our semi-supervised breast radius and separation framework. A combination of morphological operations and the elliptical Hough transform results in the treated breast being fitted with an ellipse. The major axis length of the fitted ellipse is the estimated breast separation, half of the fitted ellipse minor axis length is the estimated breast radius. Three sets of CT data were used to assess the accuracy of our measurement framework. Hand-measurements of the breast radius and separation were performed over all slices within the treatment volume in the cranio-caudal direction, and compared with the algorithm's measurement. Average percent error and error measurement in centimeters between the breast radius and separation hand-measurements and our proposed framework's estimation were computed.

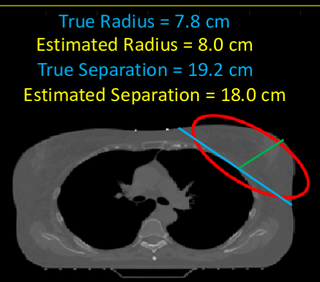

Figure 2: Axial CT slice with fitted ellipse (red) and left breast radius and separation estimation (yellow) and hand-measurement (blue).

Methods – Model correlating breast shape with x-ray fluence

Semi-circle uniform breast phantoms with radii varying from 5-12 cm and separations varying from 12-24 cm were generated and used to correlate the breast radius and separation to x-ray fluence needed for the most homogenous dose delivery. These phantoms were input to Eclipse treatment planning software, and the TPD was selected based on the breast phantom radius and separation in-accordance with previously published work (Alghufaili 2019). The treatment field was set to 20 cm by 20 cm, and beam energies of 6 and 23 MV were assessed. Eclipse was used to measure the x-ray fluence needed to deliver the dose profile based on the optimal TPD. A mathematical model relating the optimal beam fluence as a function of breast separation and radius was determined using a least-squares minimization bilateral fitting to the fluence measurements from Eclipse. These models are used to compute a mapping of the x-ray fluence at the breast surface needed to deliver a homogenous dose across all axial slices of the treatment volume.

$$f(radius, separation, 6\ MV) = 0.753 + 0.006 * radius - 0.005 * separation$$

$$f(radius, separation, 23\ MV) = 0.888 + 0.006 * radius - 0.007 * separation$$

where f is the optimal fluence for the axial slice with a breast radius and separation estimation from the semi-supervised framework.

Assuming exponential beam dropoff through the breast volume due to attenuation, a 2D x-ray fluence map needed to deliver the most homogenous dose profile can be created. Coupled with the breast radius and separation estimation framework, pre-treatment CT image data are used to generate x-ray fluence maps which, when put to Eclipse, lead to breast electronic compensation treatment plans with much less user supervision compared with the current clinical standard.

To validate these models, 10 electronic compensation breast cancer treatment courses planned and delivered at our institution were retrospectively collected. Our measurement framework estimated the breast radius and separation in each axial slice of the treatment volume, and the models were used to generate 2D x-ray fluence maps, which when put to Eclipse, generated a new treatment plan. The dose distributions from these generated fluence maps were compared with those from the original plans generated by the iterative, manual editing of the fluence maps by the dosimetrist. Additionally, plans generated by assuming a single TPD throughout the treatment volume (current starting point for iterative process of the dosimetrist) were generated from each course. These plans would be compared using dose homogeneity index (HI) averaged over all 10 of the collected treatment courses.

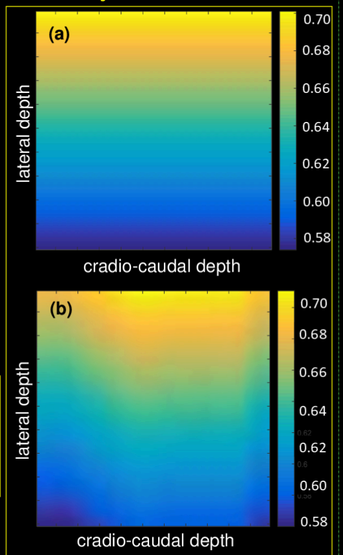

Figure 3: Optimal fluence maps from (a) assuming a single optimal penetration depth through the breast volume (current standard) and (b) our proposed model which assumes a new penetration depth for each slice in the cranio-caudal direction. Colorbar is the beam fluence. Note the variation in beam fluence in the cranio-caudal direction in (b) compared with (a) lacking this feature. Considering the variation in breast radius and separation in the cranio-caudal direction leads to the generation of treatment courses

$$HI = \frac{D_2 - D_{98}}{D_p} \times 100\%$$

where D_2 and D_{98} represent doses to 2% and 98% of the PTV respectively, and D_p represents the prescription dose

Results

Average percent difference and error measured in centimeters between the breast radius and separation estimation and hand-measurement over all axial slices in the 3 test breast volumes shown in Table 1. Dose HI between different treatment course generation strategies shown in Table 2. Selected treatment course comparing proposed method and use of single TPD show in Figure 4. Note the anterior hotspot present in the single TPD course and lacking in the course from proposed method. This would require fluence editing by the dosimetrist to bring the treatment within institutional constraints. This is not needed with our method's course.

Table 1: Agreement between breast radius and separation hand-measurements and semi-supervised algorithm estimations in average percent difference and cm difference. 95% confidence interval included.

Radius		
Number	% Difference	Difference (cm)
1	9.6 [9.3-9.9]	0.70 [0.68-0.72]
2	6.2 [5.7-6.7]	0.40 [0.39-0.41]
3	22.0 21.5-22.5]	1.00 [0.98-1.02]
Average	12.6 [10.4-14.8]	0.69 [0.59-0.79]

Separation		
Number	% Difference	Difference (cm)
1	6.1 [5.0-7.2]	1.13 [1.11-1.15]
2	4.2 [4.1-4.3]	0.71 [0.68-0.74]
3	5.3 [5.1-5.5]	0.91 [0.71-1.11]
Average	5.2 [5.1-5.3]	0.92 [0.79-1.05]

Table 2: Homogeneity indices (HI) over 10 treatment courses. Included are courses generated with our method, original dosimetrist optimized courses, and courses generated using a single TPD and no dosimetrist optimization.

Number	Proposed Method HI	Dosimetrist Optimized HI	Single TPD HI
1	26.7	16.5	23.0
2	17.8	14.1	19.1
3	10.6	11.2	17.2
4	11.8	9.51	13.3
5	8.49	3.32	8.04
6	8.79	6.64	12.6
7	4.59	3.82	8.19
8	7.57	8.84	23.5
9	11.3	8.29	18.7
10	10.6	10.5	17.8
Average	12.6	9.87	17.0

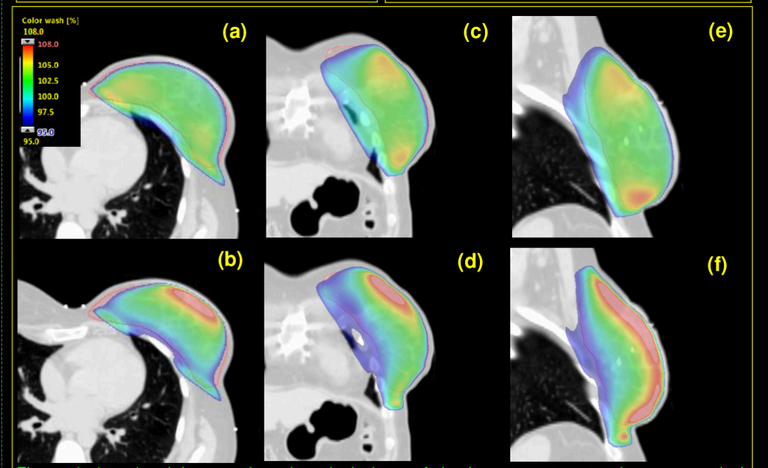

Figure 4: (a,c,e) axial, coronal, and sagittal views of the breast treatment volume respectively showing isodose color washes (percent prescription dose) from the treatment course generated with the proposed method. (b,d,f) axial, coronal, and sagittal views of the breast treatment volume showing the isodose color washes from the treatment course generated by assuming a constant TPD of 30%. This case has an HI of 10.6 using our method, and 17.2 using a TPD of 30%. The course shown in (a,c,e) is a more homogenous starting point for the dosimetrist optimization compared with (b,d,f).

Conclusions

This work detailed a method for semi-supervised determination of breast radius and separation, resulting in the output of the x-ray fluence needed for optimal dose delivery in terms of homogeneity. This work also indicates the need to consider the variation of breast shape in the cranio-caudal direction. Plans generated with a single TPD are inferior to those with dynamic TPD.