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Accounting for respiratory motion in partial breast intensity modulated radiotherapy during treatment planning: A new patient selection metric

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Abstract ***Purpose:*** External beam partial breast irradiation intensity modulated radiotherapy (PBI IMRT) plans experience degradation in coverage and dose homogeneity when delivered during respiration. We examine which characteristics of the breast and seroma result in unacceptable plan degradation due to respiration.
Methods: Thirty-six patient datasets were planned with inverse-optimised PBI IMRT. Population respiratory data were used to create a probability density function. This probability density function (PDF) was convolved with the static plan fluences to calculate the delivered dose with respiration. To quantify the difference between static and respiratory plan quality, we analysed the mean dose shift of the target dose volume histogram (DVH), the dose shift at 95% of the volume and the dose shift at the hotspot to 2 cm^3 of the volume. We explore which patient characteristics indicate a clinically significant degradation in delivered plan quality due to respiration.
Results: Dose homogeneity constraints, rather than dosimetric coverage, were the limiting factors for all patient plans. We propose the dose evaluation volume-to-planning target volume (DEV-to-PTV) ratio as a delineating metric for identifying patient plans that will be more degraded by respiratory motion. The DEV-to-PTV ratio may be a more robust metric than ipsilateral breast volume because the seroma volume is contoured more consistently between physicians and clinics.
Conclusions: For patients with a DEV-to-PTV ratio less than 55% we recommend either not using PBI IMRT or employing motion management. Small DEV-to-PTV ratios occur when the seroma is close to inhomogeneities (i.e. air/lung), which exacerbates the dosimetric effect

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of respiratory motion. For small breast sizes it is unlikely that the DEV-to-PTV ratio will meet these criteria.

1. Introduction

External beam partial breast irradiation (PBI) is an increasingly common method of delivering radiation therapy to early stage breast cancer patients following breast conserving surgery. In general, for whole breast irradiation, large breasted patients have more hotspots (poorer dose homogeneity), which are correlated with poorer cosmetic outcomes. PBI is motivated by the need to reduce the amount of normal tissue irradiated, potentially improving cosmetic outcomes. Depending on seroma location, PBI may also allow increase sparing of the heart and lungs.

Typically, the PBI treatment plan is developed on a static image, usually of a free-breathing patient computed tomography (CT); however, the treatment is delivered to a continuously breathing patient. The delivered treatment plan may experience reduction in both target coverage and dose homogeneity due to this respiratory motion. Loss of coverage means that part of the target could be missed leading to a higher probability of recurrence. Decreased dose homogeneity can result in poorer cosmetic outcomes due to hotspots or increased probability of recurrence due to cold spots in the target volume. One might reasonably expect that the extent of degradation depends on patient anatomy such as seroma location and breast size and shape and that, therefore, some patients will be more affected by respiratory motion than others. It is crucial to identify those patients for whom PBI is an appropriate treatment option.

Both ipsilateral breast volume (IBV) and the ratio of planning target volume (PTV) to breast volume have been proposed as metrics by which to select those patients most appropriate to receive PBI treatment [1–4]. One selection characteristic that is often used is PTV-to-IBV ratio less than 25–35%. However, large variability in breast volume contouring between physicians and clinics makes these metrics hard to compare across the literature. For PBI IMRT and 3d conformal radiation therapy (3DCRT) studies, the range of breast volume is 190–3500 cm^3 and the PTV-to-IBV ratio ranges from 6% to 99% [1–13]. The dose evaluation volume (DEV) is defined as the PTV trimmed back at the lung-chestwall and skin-air interfaces (by 3–7 mm depending on the study). Seromas that are located close to one or both of these interfaces, or in smaller breasts, will be most severely trimmed back. The DEV-to-PTV ratio, therefore, gives information about both the breast volume and the location of the seroma. We suggest that the DEV-to-PTV ratio is a better patient selection metric to predict which patient plans will experience more extensive dose degradation due to respiratory motion.

2. Methods

2.1. IMRT PBI plans

Thirty-six early stage breast cancer patients treated with the Radiation therapy for Accelerated Partial breast Irradiation (RAPID) protocol (Ontario Clinical Oncology Group) at our institution were examined. All patients had ipsilateral and contralateral breast, ipsilateral and contralateral lungs, heart, thyroid, and target volumes contoured by treating physicians during the trial and met rigorous review standards [14]. We created partial breast intensity modulated radiotherapy (IMRT) plans that met the planning guidelines used in the RAPID trial (Table 1) [14,15]. Three to five beam angles were chosen based on the existing 3DCRT PBI plans for each patient to ensure the plans were deliverable. For the RAPID study, patients were selected to ensure that the DEV was always less than 35% of the total ipsilateral breast volume and that the seroma was visible on CT and available to be contoured. Minor deviations (<3%) on organ-at-risk constraints were allowed to achieve total DEV coverage. In the RAPID protocol patients were treated with 38.5 Gy in 10 fractions BID. The University of Calgary's Conjoint Faculties Research Ethics Board approved these studies.

Fig. 1a details the distribution of patient breast volume, binned by cup size as defined by Offerman et al. [16]. From the skew of this histogram it is clear that the majority of the patients had a cup size of D or larger.

Table 1
Radiation therapy for Accelerated Partial breast Irradiation (RAPID) study dose constraint/criteria [14,15].

Contour	Volume	Dose (%)
DEV	1	95
DEV	Max dose to 2 cm^3	107
Ipsilateral lung	10%	<30
	20%	<10
Ipsilateral breast	25% (up to 35%)	<95
	50% (up to 60%)	<50
Contralateral breast	Max dose	<3
Thyroid	Max dose	<3
Heart		
Right breast	5%	5
Left breast	5%	10