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Respiratory motion

When is respiratory management necessary for partial breast intensity modulated radiotherapy: A respiratory amplitude escalation treatment planning study

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ABSTRACT

Purpose: The impact of typical respiratory motion amplitudes (~2 mm) on partial breast irradiation (PBI) is minimal; however, some patients have larger respiratory amplitudes that may negatively affect dose homogeneity. Here we determine at what amplitude respiratory management may be required to maintain plan quality.

Methods and Materials: Ten patients were planned with PBI IMRT. Respiratory motion (2–20 mm amplitude) probability density functions were convolved with static plan fluence to estimate the delivered dose. Evaluation metrics included target coverage, ipsilateral breast hotspot, homogeneity, and uniformity indices.

Results: Degradation of dose homogeneity was the limiting factor in reduction of plan quality due to respiratory motion, not loss of coverage. Hotspot increases were observed even at typical motion amplitudes. At 2 and 5 mm, 2/10 plans had a hotspot greater than 107% and at 10 mm this increased to 5/10 plans. Target coverage was only compromised at larger amplitudes: 5/10 plans did not meet coverage criteria at 15 mm amplitude and no plans met minimum coverage at 20 mm.

Conclusions: We recommend that if respiratory amplitude is greater than 10 mm, respiratory management or alternative radiotherapy should be considered due to an increase in the hotspot in the ipsilateral breast and a decrease in dose homogeneity.

Several randomized multi-institutional trials are currently investigating the potential of partial breast irradiation (PBI) to minimize the dose to normal tissues, decrease toxicity, and improve cosmetic outcome in early stage, low-risk breast cancer patients [1]. In many centers, PBI is delivered using intensity modulated radiation therapy (IMRT) to further improve cosmesis through increased dose homogeneity in the target.

Previous studies have investigated the benefits of respiratory control in limiting dose to heart, lung, and normal breast tissue. Some of these PBI studies employ respiratory management techniques such as respiratory gating [2,3], deep inspiration breath hold with or without active breathing control [4], and prone delivery [5] to minimize the impact of respiratory motion. Other studies implement PBI IMRT relying on adequate margins to account for respiratory motion [6–8]. It is known that respiratory motion can degrade both the coverage and dose homogeneity of delivered treatment plans [9,10]. Given that dose homogeneity in the breast is necessary to maintain excellent cosmetic results, loss of dose homogeneity with respiratory motion is particularly important in PBI. In this study, we identify the amplitude of respiratory motion that will significantly impact dose homogeneity and target coverage.

Methods

Datasets from ten patients enrolled in the RAPID [8,11] (Randomized Trial of Accelerated Partial Breast Irradiation) trial were used to create PBI IMRT plans for this study. All relevant volumes were contoured by the primary radiation oncologist, including: seroma, ipsilateral breast and lung, contralateral breast and lung, heart, and thyroid. As part of the RAPID study, an extensive quality assurance program ensured reproducibility in contouring between centers and individual physicians [8]. The seroma was expanded by 10 mm to create the CTV (clinical target volume), then another 10 mm was added to expand to the PTV (planning target volume). The Dose Evaluation Volume (DEV), used for plan quality evaluation, was defined as the PTV cut back by 5 mm from

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the skin and lung–chestwall interface. The prescription dose was 38.5 Gy.

These PBI IMRT plans met the RAPID planning guidelines (see Supplementary Material for table of planning criteria [8,11]). The target coverage criterion for these plans is 100% of the DEV covered by 95% of the prescription dose. The RAPID study employed the CTV-to-PTV margin that is typically used in external beam PBI: 5 mm for respiratory motion and 5 mm for setup errors [12]. Based on this, we defined the volume CTVsu as the CTV plus a 5 mm margin for setup uncertainties and did not include the 5 mm for respiratory motion. By excluding the 5 mm respiratory margin in our evaluation we dosimetrically tested the robustness of the respiratory margin. There should be no degradation in coverage when respiratory motion is introduced if the 5 mm is adequate.

Three to five non-coplanar beam angles were chosen to ensure that all plans were deliverable. Beam weighting for optimal target coverage and minimal dose to organs-at-risk (OARs) was achieved using inverse planning optimization with Eclipse (Varian Medical Systems, Palo Alto, CA) treatment planning software (8.9.08) using the AAA algorithm with heterogeneity correction. Small deviations to OARs criteria (<3%) were allowed in order to achieve target coverage. After optimization, 2 cm of flash was added to plans with anterior target volumes. Target coverage criteria were strictly met and plans were reviewed under the guidance of a radiation oncologist.

The University of Calgary's Conjoint Faculties Research Ethics Board approved these studies.

Fluence convolution

The respiratory trace generator previously described was used to generate a realistic respiratory trace [13]. The peak-to-peak amplitude was scaled to 2, 5, 10, 15, and 20 mm. Traces with minimal variation were used to ensure that analysis was not confounded by the different respiratory characteristics (these respiratory traces and probability density functions (PDFs) can be found in Supplementary Materials). The trace was measured in the anterior-posterior direction and scaled by half for the superior-inferior direction as in previous work [13].

Fluence convolution methodology was used to explicitly incorporate respiratory motion in treatment planning [14,15]. The planned fluences were extracted and convolved with respiratory PDFs to simulate the delivered fluence under realistic respiratory conditions. These delivered fluences were then imported into the treatment planning system and the delivered dose was re-calculated. The resulting dose distribution modeled rigid anatomy translations due to the simulated respiratory motion.

Evaluation

We evaluated major and minor deviations at all respiratory amplitudes. For this study, minor deviations in doses to OARs were defined as $\leqslant$3% and major deviations as >3%. Failure to meet dose homogeneity or target coverage criteria was considered a major deviation. Target coverage and dose homogeneity were evaluated with ipsilateral breast hotspot (maximum dose to 1 and 2 cm^3), CTVsu cold spot (minimum dose to 1 cm^3), and CTVsu target, defined as the percentage of the CTVsu volume receiving 95% of the dose (V95%).

The evaluation limits and thresholds were chosen to match clinically acceptable dosimetric constraints. Strict adherence to the 107% hotspot in planning and designation of any deviation as a major deviation was chosen because dose inhomogeneity is correlated with poorer cosmetic outcome [16]. This is of particular importance in PBI, because one of the hypothesized advantages is improved cosmesis. The 1 cm^3 hotspot and cold spot volumes were used for evaluation in accordance with evaluation criteria used in our center. Although ideally the hotspot of the plan would be in the target volume, we found that some patient geometries did not allow for that without sacrificing coverage or the dose to OARs.

In addition to target coverage and planning criteria, two metrics were used to assessed plan quality (see Supplementary Material for a table of evaluation quality metrics): homogeneity index (HI) [17] and uniformity index (UI) [18,19]. A larger HI indicates a less homogeneous dose distribution [17]. A larger UI indicates a more uniform dose distribution [18,19]. We used a library of IMRT plans created with the same planning criteria as this study on static breast images (RAPID patient data) to calculate the mean and standard deviation of UI and HI to set a comparison baseline. We defined a major deviation for the plan quality metrics as more than two standard deviations away from their baseline values (see Supplementary Material).

Results

Table 1 demonstrates that the dose homogeneity rather than the loss of dose coverage was the limiting factor in free-breathing PBI for clinically observed breathing amplitudes when a 5 mm motion margin was used (10 mm CTV-to-PTV: 5 mm for set-up and 5 mm for motion). Fig. 1 shows how each patient plan degraded under increasing respiratory amplitude. With this margin, the 1 and 2 cm^2 cold spots and V95 coverage only showed major deviations at a respiratory amplitude of 15 mm or greater. Two of ten plans had hotspots greater than 107% at 2 and 5 mm, and this increased to five of ten plans at 10 mm motion. Coverage was generally adequate until 10 mm motion, while homogeneity gradually degraded, with no minimum amount of motion.

Both the homogeneity and uniformity indices were degraded at higher respiratory amplitudes (Figs. 2(a) and (b)). The HI was more sensitive to respiratory motion than UI, with deviations starting at 5 mm motions. Deviations in the majority of plans for both UI and HI were only found at respiratory amplitudes greater than 15 mm.

Discussion

The most relevant clinical criteria for determining an appropriate maximum allowable amplitude were target coverage, ipsilateral breast hotspot, and target cold spot. The limiting factor was hotspot to the ipsilateral breast which we found degraded gradually, even at the smallest amplitudes, while coverage metrics (cold spot and V95) were not impacted until the respiratory amplitude was 15 mm. Based on this analysis we recommend employing respiratory management or not using PBI IMRT for patients with respiratory amplitude greater or equal to 10 mm. Particular caution

Table 1
Major deviations for target coverage and plan quality metrics.

Static	2 mm	5 mm	10 mm	15 mm	20 mm
Target Coverage: CTVsu					
$V95_{CTVsu}$				4	9
HS_{IB}(1 cm^3)	2	2	5	5	5
HS_{IB} (2 cm^3)		2	2	5	5
CS_{CTVsu}(1 cm^3)				5	10
Plan quality indices: CTVsu					
HI_{CTVsu}		1	3	3	8
UI_{CTVsu}			1	2	7

V95 is the volume receiving 95% of the prescribed dose.
HS_{IB} is the hotspot to the ipsilateral breast volume.
CS_{CTVsu} is the coldspot to the CTVsu.
HI_{CTVsu} is the homogeneity index of the CTVsu.
UI_{CTVsu} is the uniformity index of the CTVsu.