Brachytherapy ■ (2016) ■

BRACHYTHERAPY

Incorporating three-dimensional ultrasound into permanent breast seed implant brachytherapy treatment planning

Daniel Morton[1,2,*], Deidre Batchelar[1], Michelle Hilts[1,2], Tanya Berrang[3], Juanita Crook[4]

[1]*Department of Medical Physics, BC Cancer Agency, Centre for the Southern Interior, Kelowna, British Columbia, Canada*
[2]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[3]*Department of Radiation Oncology, BC Cancer Agency, Vancouver Island Centre, Victoria, British Columbia, Canada*
[4]*Department of Radiation Oncology, BC Cancer Agency, Centre for the Southern Interior, Kelowna, British Columbia, Canada*

ABSTRACT

PURPOSE: Planning permanent breast seed implant (PBSI) brachytherapy using CT alone may reduce treatment accuracy because of differences in seroma visualization compared with ultrasound (US). This study evaluates dosimetric effects of seroma delineation in PBSI and the potential impact of incorporating three-dimensional (3D) US into PBSI treatment planning.

METHODS AND MATERIALS: Spatially coregistered CT and 3D US images from 10 patients were retrospectively analyzed to simulate the PBSI procedure. Seromas contoured on CT and US defined clinical target volumes, CTV_{CT} and CTV_{US}, which were expanded to create planning target volumes (PTVs). PBSI plans were generated using PTV_{CT} alone, and the resulting coverage to PTV_{US} was evaluated. To assess the potential impact of transferring to an US-guided procedure, the CT-based plans were centered on CTV_{US}. The volume encompassed by both PTVs was used to evaluate how 3D US can affect the planning procedure.

RESULTS: Median (range) PTV_{CT} V_{100} was 95.6% (93.3−97.3%), resulting in PTV_{US} coverage of 91.5% (80.5−97.9%). Centering plans on CTV_{US} decreased PTV_{CT} V_{100} by a mean of 10 ± 8%, and increased PTV_{US} V_{100} by 5 ± 4%. The combined PTVs were a mean 9±6% larger than PTV_{CT}. Acceptable dosimetry to the combined PTVs resulted in sufficient coverage to individual PTVs but with a mean 11 ± 24% increase to skin dose and 6 ± 8% increase in breast V_{200}.

CONCLUSIONS: Differences in seroma visualization have dosimetric effects in PBSI. CT-based plans can underdose US-defined volumes and may not adequately translate to an US-guided procedure. Implementing 3D US into planning can potentially compensate for differences in delineation.

Keywords: Permanent breast seed implants; Breast brachytherapy; Accelerated partial breast irradiation; 3D ultrasound; Seroma; Treatment planning

Introduction

After breast conserving surgery for early stage breast cancer, adjuvant whole breast irradiation is standard management; however, for select patients, treatment can be limited to irradiation of the postlumpectomy cavity alone (1−3). A recently developed form of partial breast irradiation is permanent breast seed implant (PBSI) brachytherapy. PBSI has been demonstrated to achieve acceptable target coverage, local recurrences rates, and normal tissue toxicity in a convenient single-day procedure (4−9). Therefore, expanded utilization can potentially benefit many women with early stage breast cancer. However, it is important to address the unique technical challenges of PBSI to enable this technique to be widely adopted with confidence.

One challenge in PBSI is the use of two different imaging modalities within the treatment process: CT for treatment planning and freehand two-dimensional (2D) ultrasound (US) for implant guidance (6, 7). The target in treatment planning is the postlumpectomy seroma defined on CT, which is the clinical standard for partial breast irradiation (7, 10−13). The seroma also aids in the implant

Received 12 July 2016; received in revised form 12 September 2016; accepted 13 September 2016.

Financial disclosure: None to report.

Conflict of interest: None to report.

* Corresponding author. Medical Physics, BC Cancer Agency, SAHC-SI, 399 Royal Avenue, Kelowna, British Columbia V1Y 5L3, Canada. Tel.: +1-250-712-3966x686877.

E-mail address: dmorton@bccancer.bc.ca (D. Morton).

1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2016.09.007

procedure, where US imaging provides intraoperative guidance to ensure that the plan is correctly positioned on the seroma. Inherent differences in the visualization of the seroma on US and CT can result in variability in the size and shape when observed on the two modalities, potentially resulting in deviation of their centroid positions within the breast (14−17). Therefore, using these different modalities for planning and delivery means the CT-based treatment plan may not translate directly to the operating room (OR) under US guidance without intraoperative adjustments (18). Any such repositioning of the implant relative to the seroma visualized under US guidance, because of apparent difference in center position from planning, could affect the dosimetry to the original target, planned on CT. Integrating three-dimensional (3D) US into the planning process alongside CT may help to address this challenge by using the same imaging modality for planning and intraoperative guidance.

3D US has been shown to be a potentially useful addition to CT-based planning in external beam partial breast radiation therapy, in part because of improved seroma visibility and high interuser consistency of contouring on US compared with CT (15). However, its application and potential impact in PBSI treatment planning is currently unknown. Through retrospective analysis of coregistered CT and 3D US images, the potential dosimetric effects resulting from planning and delivering using different imaging modalities, because of the differences in seroma visualization between CT and US, are evaluated. In addition, this study assesses the impact that the addition of 3D US into PBSI treatment planning may have on the resulting treatment plans.

Methods and materials

Registered CT and US images

Patient images and contours acquired by Berrang *et al.* (15) to assess the role of 3D US in treatment planning for partial breast external beam radiation therapy were reexamined for this study. In brief, for 20 consecutive early breast cancer patients, a 3D US was also performed at the time of CT, with identical patient positioning, using the Restitu (Resonant Medical, Montreal, QC, Canada) ultrasound system. This system uses infrared imaging to track the US probe in the CT room such that the US and CT images share a coordinate system and registration is implicit. Minimal compression was used during US image acquisition to reduce breast deformation, and registration of the image sets was validated by assessing the alignment of the skin and chest wall (15).

The CT and US seroma contours used in this study were consensus volumes defined by Berrang *et al.* (15). In the previous study, seroma contouring on the US and CT images was performed independently by three radiation oncologists, blinded to the corresponding image set, using standard clinical guidelines (10, 15). Consensus seromas were defined for each modality by overlaying the three contours and tracing the middle contour at any point to represent a typical delineated seroma. Based on the size and location within the breast of the consensus seroma defined on CT, 10 patients (six right and four left breasts) were selected for this study. Eligible seromas had volumes of <30 cc and were less than 3 cm wide orthogonal to the needle insertion direction.

PBSI plan generation

The CT and 3D US image sets complete with consensus contours were imported into MIM Symphony (MIM Software, Inc., Cleveland, OH) for PBSI planning on CT. 3D US contours were transferred to the CT images using the implicit ridged registration between the image sets (Fig. 1). The consensus seromas contoured on CT and US were used to define clinical target volumes CTV_{CT} and CTV_{US}, respectively. The CTVs were expanded by 1.25 cm (19) and cropped at the chest wall contoured on CT and 5 mm from the skin surface to create planning target volumes (PTVs). PBSI treatment plans were generated following the standard planning procedure, based on the methods developed by Pignol *et al.* (4−7, 20), in MIM Symphony. In brief, a fiducial needle that centers the treatment template on CTV_{CT} is planned to be inserted tangentially to the chest wall to a depth of the distal side of the PTV_{CT}. Treatment plans are created on CT images, resliced orthogonally to the needle insertion direction, using needles loaded with stranded palladium-103 seeds (2.5 U) and a 90 Gy prescription. Planning goals include CTV_{CT} V_{100} = 100% and PTV_{CT} V_{100} > 95%, limiting PTV coverage to V_{150} < 70% and V_{200} < 25%, and dose over a 1 cm^2 area of the skin margin to <90% of the prescription (6, 19).

After plan creation and optimization, the plan was reevaluated using the 3D US contours, which were transferred to the CT images. Dose−volume histograms were computed for the US-defined contours: CTV_{US} and PTV_{US}, and the coverage of these structures was evaluated to determine how CT-based planning, the standard PBSI procedure, provides coverage to volumes defined on US. In addition, correlations between the observed differences in the size and position of the CT and US contours and the dose differences between PTV_{CT} and PTV_{US} were evaluated.

The conformity index (CI), defined as the ratio of the volume of overlap to the total encompassing volume (21, 22), was used to quantify the agreement of the CT and US contours. A CI of one represents perfect concordance, whereas a CI of zero indicates no overlap. Disparity in the CTV and PTV positions was also examined by calculating the difference in the centroid (center of mass) positions. The mean centroid difference between imaging modalities was calculated as well as the mean directional differences to identify any systematic offsets in seroma visualization that may exist.