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Treatment planning considerations for permanent breast seed implant

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ABSTRACT

PURPOSE: To determine an optimal planning strategy for permanent breast seed implant that minimizes dose heterogeneity without degrading coverage and conformity.

METHODS AND MATERIALS: A simple model was developed to investigate planning strategies incorporating a range of ^{103}Pd seed activities, needle and seed spacings, and implants in which seed positions are either restricted to or permitted outside of spherical planning target volumes (PTVs). To address more realistic target geometries, model parameters were used to retrospectively replan a 10-patient cohort in MIM Symphony.

RESULTS: We confirm that the current clinical modified uniform implantation pattern provides the most favorable dose distributions, given the resolution of the template grid and spacer length. We show that needle and seed counts for replans with seed placement permitted 0.3 cm outside of the PTV are most comparable to clinical preplans, but offer a 13 ± 11% average reduction in the $V_{PTV}150\%$. Replans produced with seed placement 0.5 cm outside of the PTV provide the largest improvement in dose homogeneity, at the cost of a slight increase in irradiated volume and an increase in the number of needles and seeds.

CONCLUSIONS: Implanting seeds beyond the PTV within a 0.3−0.5 cm margin, and optimizing seed activity on a per patient basis, allows for improvement in dose homogeneity. However, these plans require higher needle and seed counts and result in a small increase in irradiated volume. Before planning recommendations can be made, the implications of these changes must be investigated in the context of clinical outcome for permanent breast seed implant.

Keywords: Permanent breast seed implant; Breast brachytherapy; Dosimetry; Pd-103; Forward planning; Treatment planning

Introduction

Over the past decade, permanent breast seed implant (PBSI) has emerged as a viable partial breast irradiation treatment for early-stage breast cancer patients (1−3). PBSI is a one-day outpatient procedure in which stranded ^{103}Pd seeds are permanently implanted in and around the post-lumpectomy seroma (2). Published results from pilot and registry trials have been promising, achieving local regional control comparable to nomogram-based estimates for whole breast irradiation (WBI), minimal skin toxicity, and excellent patient satisfaction (2−4). Overall, PBSI is appealing because it offers an effective and condensed alternative to standard fractionated WBI.

Although the concept of PBSI was inspired by permanent prostate implant (PPI), PBSI possesses unique challenges that cause the planning and dosimetric criteria to differ between the two brachytherapy techniques. In particular, the lack of critical structures within the target volume and concern of an increased risk of seed motion in breast tissue motivate the use of a ''modified uniform'' implantation pattern and a relatively high seed activity of 2.5 U ($1\ U\ =\ 1\ cGy \cdot cm^2 \cdot h^{-1}$) for PBSI (5, 6). This implantation pattern involves placing needles every 1 cm, in a triangular or square pattern, to cover the whole projection of the planning target volume (PTV; 1.0−1.5 cm isotropic expansion of the seroma and adjacent fibrosis, cropped to the skin

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and chest wall muscle) (2). Seeds are evenly spaced 1 cm apart (center-to-center) along strands in the periphery of the PTV, and 1.5 cm apart in the PTV interior. The implant is forward planned to achieve a minimum peripheral dose of 90 Gy to the PTV. In 2012, Keller *et al.* (6) published the preplan dosimetry for 95 consecutive patients accrued to one of three phase I/II pilot or registry trials for PBSI. The seed activity was increased, and varied, following the first 10 patients from 1.59 U per seed to a mean (±standard deviation) of 2.56 ± 0.13 U. The average preimplant volumes of the PTV receiving at least 90% ($V_{PTV}90\%$), 100% ($V_{PTV}100\%$), 150% ($V_{PTV}150\%$), and 200% ($V_{PTV}200\%$) of the prescription dose were the following: 98.8 ± 1.2%, 97.3 ± 2.1%, 68.8 ± 14.3%, and 27.8 ± 8.6% (6). These results suggest that acceptable target coverage is achievable with this planning strategy; however, significant proportions of the PTV receive greater than 150% of the prescribed dose (6). This is expected to some extent, as it is well known that dose distributions produced by interstitial implants include steep dose gradients and regions of high dose around each seed. Although Keller *et al.* (6) showed the skin toxicity profile to be acceptable, despite the relatively large $V_{PTV}200\%$ metrics for some patients, there is a lack of evidence-based planning recommendations for the $V_{PTV}150\%$ in PBSI. Parallel work has investigated the relationship between high dose volumes and clinical outcome for alternative treatment modalities. In 2006, Wazer *et al.*(7, 8) reported the relationship between clinical or treatment-related variables and normal tissue toxicity for high-dose-rate multicatheter interstitial breast brachytherapy. High dose volumes, characterized by the 150% and 200% isodose lines, were found to be significantly associated with a suboptimal cosmetic score, late skin toxicity, and clinically evident fat necrosis (7, 8). In addition, global dose heterogeneity was found to be correlated with a suboptimal cosmetic score, late skin toxicity, and late subcutaneous toxicity (7, 8). Investigating such relationships for PBSI is of interest, as it has been noted that the incidence of asymptomatic skin induration is higher for PBSI compared with WBI (39% vs. 7%) (3, 9). Consequently, the dosimetric impact of planning parameters in PBSI should be well characterized so that the seed arrangement and activity are optimally selected.

The purpose of this study is to determine an optimal planning strategy for PBSI that minimizes dose heterogeneity without degrading coverage and conformity. A simple model is used to simulate spherical PTVs with clinically relevant sizes and perform a systematic investigation of the dose distributions produced by variations of the modified uniform implantation pattern for a range of ^{103}Pd seed activities. Spherical PTVs were selected for investigation in the model to develop an understanding of the general trends for the simplest target geometry before exploring more realistic PTVs. Clinically relevant target geometries are addressed by using the model parameters to replan a cohort of 10 previously treated patients. These results are used to validate the model and provide future direction for the development of PBSI planning recommendations.

Methods and materials

Simplified PBSI planning model

An in-house program (a ''simplified PBSI planning model'') was developed in MATLAB (version R2015a; MathWorks, Natick, MA) to simulate spherical PTVs, automatically generate seed arrangements, and perform dose calculations using the two-dimensional dosimetry formalism recommended by the American Association of Physicists in Medicine Task Group No. 43 (TG-43) (10, 11). Spherical target volumes were the initial focus of this investigation so that an understanding of the general implications of each planning parameter could be developed for the simplest geometry before exploring more realistic, complex target geometries. To encompass the full range of target volumes eligible for PBSI (eligibility criteria: PTV $\leq$ 120 cm^3, which corresponds to a spherical PTV radius of $\lesssim$ 3 cm) (6), PTVs were simulated with radii ranging from 1.0 to 3.2 cm. The corresponding range in target volumes is approximately 4–137 cm^3. The planning parameters employed by the model are described in detail below, and their assigned values are summarized in Table 1.

In practical planning scenarios, seeds are frequently implanted outside of the PTV to ensure appropriate target coverage. However, this is not done in a consistent manner. Consequently, it was necessary to investigate the dosimetric impact of a parameter termed the ''implant margin'' (IM). Figure 1 provides a two-dimensional representation of this parameter. The IM is defined as an isotropic expansion of the PTV. Three values were examined: 0.0, 0.3, and 0.5 cm.

Clinically, needle-to-needle and seed-to-seed spacing are restricted by the template grid resolution (0.5 × 0.5 cm) and spacer length (0.5 cm), respectively. A preliminary investigation of cubic seed grids with resolutions of 0.5, 1.0, and 1.5 cm revealed that the 1.0 cm grid provides the most favorable dose distributions for all target volumes. Our preliminary results (not shown) also

Table 1
List of parameters varied in the simplified permanent breast seed implant planning model

Parameter	Assigned value(s)
Seed activity (U)	Range: 0.6–5.2, Increment: 0.2
Spherical PTV radius (cm)	Range: 1.0–3.2, Increment: 0.1
Implant margin (cm)	0.0, 0.3, 0.5
Volume of peripheral rind (% of implant volume)	0, 25, 50, 75, 100
Needle-to-needle spacing (cm)	1.0
Peripheral seed-to-seed spacing (cm)	1.0
Internal seed-to-seed spacing (cm)	1.5

PTV = planning target volume.