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Dosimetric experience with 2 commercially available multilumen balloon-based brachytherapy to deliver accelerated partial-breast irradiation

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ABSTRACT

The purpose of this work was to report dosimetric experience with 2 kinds of multilumen balloon (MLB), 5-lumen Contura MLB (C-MLB) and 4-lumen MammoSite MLB (MS-MLB), to deliver accelerated partial-breast irradiation, and compare the ability to achieve target coverage and control skin and rib doses between 2 groups of patients treated with C-MLB and MS-MLB brachytherapy. C-MLB has 5 lumens, the 4 equal-spaced peripheral lumens are 5 mm away from the central lumen. MS-MLB has 4 lumens, the 3 equal-spaced peripheral lumens are 3 mm away from the central lumen. In total, 43 patients were treated, 23 with C-MLB, and 20 with MS-MLB. For C-MLB group, 8 patients were treated with a skin spacing < 7 mm and 12 patients with rib spacing < 7 mm. For MS-MLB group, 2 patients were treated with a skin spacing < 7 mm and 5 patients with rib spacing < 7 mm. The dosimetric goals were (1) $\geq 95\%$ of the prescription dose (PD) covering $\geq 95\%$ of the target volume ($V_{95\%} \geq 95\%$), (2) maximum skin dose $\leq 125\%$ of the PD, (3) maximum rib dose $\leq 145\%$ of the PD (if possible), and (4) the $V_{150\%} \leq 50$ cm^3 and $V_{200\%} \leq 10$ cm^3. All dosimetric criteria were met concurrently in 82.6% of C-MLB patients, in 80.0% of MS-MLB patients, and in 81.4% of all 43 patients. For each dosimetric parameter, t-test of these 2 groups showed $p > 0.05$. Although the geometric design of C-MLB is different from that of MS-MLB, both applicators have the ability to shape the dose distribution and to provide good target coverage, while limiting the dose to skin and rib. No significant difference was observed between the 2 patient groups in terms of target dose coverage and dose to organs at risk.

Introduction

Accelerated partial-breast irradiation (APBI) has been explored as an option to deliver adjuvant radiation therapy after lumpectomy in selected patients with early-stage breast cancer undergoing breast-conserving therapy.[1] Early studies using multicatheter-based interstitial brachytherapy as the APBI technique have provided the largest group of patients with the longest follow-up. However, this method of APBI has proven technically challenging. Even using the best placement methods available, the technique is complex and requires a great deal of experience and skill to position the needles or catheters to cover the required treatment volume.

Balloon-based MammoSite applicator (Hologic Inc., Bedford, MA) was developed to simplify the procedure of APBI in 2002. Since then, the balloon-based brachytherapy has been one of the most commonly used techniques to deliver APBI.[2-6] This technique provides a less complex implant with increased reproducibility of radiation delivery to the target volume compared with multicatheter-based interstitial brachytherapy. Owing to the simple design of the MammoSite single-lumen applicator, the dosimetric characteristics of using this applicator are dependent on the location of placement within the breast, the symmetry of the balloon, and the fit of the inflated balloon within the surgical cavity relative to the skin and the rib cage. The dosimetry of the applicator is also constrained by the physics of dose deposition with a brachytherapy source, *i.e.*, ^{192}Ir, together with the symmetric nature of the applicator. Because of the single central lumen geometry, the dose-shaping ability of MammoSite is limited to only along the lumen axis direction. Though multiple dwell

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positions can be used to optimize treatment delivery, significant alterations in the shape of the dose distribution are not possible. The dose to the skin is determined by the distance of the skin from the surface of the balloon. As a consequence, if the skin distance is small, the only method of reducing the skin dose is to reduce the overall target dose coverage. This can result in compromise of the target volume coverage, risk of toxicity, or both.

Two kinds of multiple lumens balloon applicator, Contura multilumen balloon (C-MLB) (Hologic Inc.) and MammoSite multilumen balloon (MS-MLB) (Hologic Inc.), were developed which sought to improve the limitations of the single-lumen MammoSite system's fixed geometry and inflexibility to sculpt dose. By introducing multiple lumen, these applicators have a greater capability to shape the dose distribution through optimization of source dwell positions and dwell times. They keep the simplicity of insertion and treatment delivery associated with balloon brachytherapy while better approximating the dose distributions achieved with multicatheter brachytherapy, providing the radiation oncologist with increased dosimetric control and the ability to maximize target coverage, reduce dose to skin and rib, and reduce the need for dosimetric compromise.[7-14]

C-MLB and MS-MLB were introduced into our clinic in 2009 and 2010, respectively. The designs of these 2 kinds of multiple lumens balloon applicator are different. The C-MLB has 5 lumens, the 4 equally spaced peripheral lumens are 5 mm away from the central lumen. The MS-MLB has 4 lumens, the 3 equally spaced peripheral lumens are 3 mm away from the central lumen. To date, there is no systematic study comparing the dosimetric results of these 2 kinds of multilumen balloons (MLBs). The purpose of this study was to report our initial dosimetric experience with MLB to deliver APBI and compare the ability to achieve target coverage and control skin and rib doses between both the groups of patients treated at a single center by the same group of physicians comprising 1 surgeon, 1 radiologist, and 2 radiation oncologists with C-MLB and MS-MLB brachytherapy.

Methods and Materials

In total, 43 patients were treated with APBI using high-dose rate ^{192}Ir brachytherapy. To balance the number of patients treated with the C-MLB and MS-MLB, C-MLB and MS-MLB were alternatively assigned for APBI patients. There were no selection criteria to choose one applicator over another. In total, 23 patients were treated with the C-MLB and 20 with the MS-MLB.

Patient selection and eligibility criteria

Patients were selected for partial-breast irradiation with a brachytherapy approach based on criteria described in the UPMC CancerCenter Breast Pathways and the Consensus Statement by American Society for Therapeutic Radiology and Oncology in 2009.[15]

Brachytherapy treatment procedure

In all cases, the balloon applicators were placed into the lumpectomy cavity and inflated in a separate procedure after 4 to 6 weeks of surgery using ultrasound guidance. A planning computed tomography (CT) scan was performed after the implant within 3 days. At the time of CT acquisition for planning, appropriateness of balloon placement was assessed. Adjustments were made (improved orientation through catheter rotation, removal of trapped air/fluid with the suction port if using C-MLB) as necessary. Patient position and balloon rotational orientation (as indicated by the shaft orientation line) were documented (via image/picture of catheter and orientation line).

CT-based 3-dimensional planning was conducted by medical physicists using Plato planning system, V14.3.5 (Elekta AB, Stockholm, Sweden). When doing the plan optimization, the inverse planning simulated annealing optimization was combined with the graph optimization to achieve a best plan. Treatment started within 4 days after the CT scan. The total prescribed dose (PD) was 34 Gy, delivered in 10 fractions over 5 consecutive working days to the planning target volume for evaluation (PTV_EVAL). The treatment fractions were delivered twice a day at least 6 hours apart. Before delivery of each fraction, the patient's position, balloon inflation, and rotational alignment status were confirmed to be identical with those at the time of initial planning CT. All treatments were completed by using Nucletron high-dose rate radiation remote afterloader and ^{192}Ir radioactive source. After completion of the final treatment, the balloon was deflated, and the applicator was removed.

Treatment planning and dosimetric goals

The following structures were contoured in the treatment planning system (TPS): (1) balloon surface, (2) PTV_EVAL, (3) trapped air and/or fluid, (4) skin surface, and (5) aspect of the rib closest to the balloon. The target volumes and normal tissue structures were outlined on all CT cuts when appropriate. As per the guidelines of the National Surgical Adjuvant Breast and Bowel Project (NSABP) B-39/Radiation Therapy Oncology Group (RTOG) 0413 protocol,[16] the PTV_EVAL = clinical target volume = PTV. The PTV_EVAL was delineated as the breast tissue volume bounded by the uniform expansion of the balloon surface in all dimensions by 10 mm and was limited to 5 mm from the skin surface and by the posterior breast tissue extent (chest wall and pectoralis muscles were not included).

The ideal dosimetric goals were (1) $\geq$ 95% of the PD covering $\geq$ 95% of the target volume ($V_{95\%} \geq 95\%$), (2) maximum skin dose $\leq$ 125% of the PD, (3) maximum rib dose $\leq$ 145% of the PD, and (4) the volume of breast tissue receiving 150% of the PD ($V_{150\%}$) $\leq$ 50 cm^3, and the volume of breast tissue receiving 200% of the PD ($V_{200\%}$) $\leq$ 10 cm^3. If the above mentioned goals could not be achieved, the guideline of the NSABP B-39/RTOG 0413 protocol was followed as minimum dosimetric goals. These criteria address the following dosimetric minimal standards that must be met concurrently: (1) $\geq$ 90% of the PD covering $\geq$ 90% of the target volume ($V_{90\%} \geq 90\%$), (2) maximum skin dose $\leq$ 145% of the PD, and (3) $V_{150\%} \leq 50$ cm^3 and $V_{200\%} \leq 10$ cm^3. Maximum rib dose is not defined.

When determining dose coverage of the PTV_EVAL, the volume of trapped air/fluid was accounted for as it displaced a percentage of the target volume beyond 10 mm from the balloon surface. The area of trapped air/fluid was contoured at each level, a total volume obtained and the percentage of the PTV_EVAL that it displaced was calculated. This volume was then subtracted from the PTV_EVAL in the final determination of dose coverage for PTV_EVAL.

Dosimetric comparison and statistical methods

A dosimetric comparison was made between these 2 groups of patients. For each of the end points (*i.e.*, maximum skin dose, maximum rib dose, $V_{90\%}$, $V_{95\%}$, $V_{150\%}$, and $V_{200\%}$), a multivariate regression model was built where minimum skin spacing, minimum rib spacing, and the group indicator (C-MLB *vs* MS-MLB) were included as exploratory variables. In these regression models, with controlling for the skin and rib spacing variables, the 2-sided t-test was used to examine whether the 2 groups were statistically significant different. The significance level is set at $p < 0.05$.

Results

The Table shows the treatment-related characteristics, implant geometry, and dosimetric findings, for both patient groups.

Skin spacing and skin dose

All 43 patients' plans met the ideal goal of the maximum skin dose $\leq$ 125% of the PD, although 10 patients were treated with a skin spacing $<$ 7 mm. Figure 1 shows a case with a minimum skin spacing of 2.5 mm and a minimum rib spacing of 6 mm. All ideal dosimetric criteria were met concurrently for this case. For the 23 patients with C-MLB, the median of minimum skin spacing was 7.6 mm, 8 (34.8%) patients were treated with a skin spacing $<$ 7 mm. The median of maximum skin dose was 100.0% of the PD. For the 20 patients with MS-MLB, the median of minimum skin spacing was 11.5 mm, 2 (10.0%) patients were treated with a skin spacing $<$ 7 mm. The median of maximum skin dose was 91.2% of the PD. Figure 2 plots the maximum dose to skin *vs* the minimum skin spacing for both group. The curves of 2-order polynomial fit data show the trend of skin dose *vs* skin spacing. With MLB, the skin dose increased much slower with the decreasing skin spacing comparing with the inverse square curve. Though the skin spacing of patients treated with C-MLB was smaller than that of patients treated with MS-MLB, there was no significant difference in terms of skin spacing ($p = 0.075$) and the maximum skin dose ($p = 0.258$) between both the groups.