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Dosimetric comparison of ^{192}Ir high-dose-rate brachytherapy vs. 50 kV x-rays as techniques for breast intraoperative radiation therapy: Conceptual development of image-guided intraoperative brachytherapy using a multilumen balloon applicator and in-room CT imaging

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ABSTRACT

PURPOSE: At our institution, the availability of a shielded procedure room with in-room CT-on-rails imaging allows for the exploration of a high-dose-rate (HDR) brachytherapy approach for breast intraoperative radiation therapy (IORT). We hypothesize that HDR brachytherapy will permit a higher prescription dose without increasing toxicity. In this study, we compare the dosimetry of intraoperative HDR brachytherapy, using multilumen balloon applicator, to IORT with a 50 kV source and then select a prescription dose for a subsequent clinical trial.

METHODS AND MATERIALS: The CT scans of 14 patients who had previously received multilumen balloon-based breast brachytherapy were replanned to a standard prescription to the target volume. The same 14 cases were planned to the specifications of a 50 kV x-ray system. Uniform volume optimization and prescription doses were used to permit direct comparisons. All plans were evaluated for the dose homogeneity index, tumor coverage, and dose to normal tissues, including skin, ribs, and heart (for left breast plans).

RESULTS: The HDR brachytherapy plans were superior to 50 kV superficial photon plans for IORT in all dosimetric parameters except for the heart and rib dosimetric parameters. Prescription dose of 12.5 Gy to the planning target volume for evaluation yielded a dose to 95 percent of the balloon surface of 19.7 Gy.

CONCLUSIONS: Image-guided HDR intraoperative brachytherapy with a multilumen balloon applicator provides superior target volume coverage compared with 50 kV photons, while maintaining doses within tolerance limits for normal tissues. An ongoing prospective clinical trial will evaluate the safety and feasibility of this technique.

Keywords: Intraoperative radiation; Accelerated partial breast irradiation; Brachytherapy; High dose rate; Image-guided

Introduction

Accelerated partial breast irradiation (APBI) is an increasingly popular postoperative alternative to whole breast irradiation (WBI) for breast cancer because of the shorter overall treatment time and theoretically decreased radiation dose to uninvolved tissue (1, 2). Intraoperative radiation therapy (IORT) is a form of APBI that involves the delivery of a single fraction of radiation therapy at the time of breast-conserving surgery. IORT offers several conceptual benefits for many patients and physicians, namely, that

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local therapy may be completed at the time of surgery and that patients may experience fewer skin side effects with APBI compared with WBI (3, 4).

Despite these potential benefits, the lack of pathologic information at the time of therapy and technical limitations pose critical challenges to the use of IORT (5). Furthermore, long-term followup data on the use of IORT are limited at this time. Two prospective randomized trials with 5-year followup data, comparing IORT techniques and WBI, provide evidence that IORT may be a reasonable option for select patients: the Milan Cancer Institute studies of intraoperative radiation therapy with electrons (ELIOT) (4, 6) and the trial of targeted IORT (TARGIT-A) with a kilovoltage (kV) x-ray source (Intrabeam system) (3, 7). The primary end point in both of these trials was ipsilateral breast tumor recurrence (IBTR) rates, and prespecified equivalence margins were met at 5 years of followup. However, neither trial was without concern regarding the IBTR rate. Although remaining within prespecified equivalence margins, the 5-year IBTR rates in both trials for the respective IORT technique statistically significantly exceeded that of WBI (3, 4).

Technical challenges of IORT techniques vary by method. When compared with APBI with brachytherapy in the postoperative setting, the ELIOT and TARGIT-A IORT methods suffer from technical drawbacks such as the lack of image-based planning for either approach, the requirement of full quadrantectomy of the breast for ELIOT, and the low dose delivered (5−7 Gy) at 1 cm from the applicator surface for TARGIT-A. The large dose (21 Gy) and dose homogeneity delivered in ELIOT provide high dose to the tumor bed but with increased risk of late toxicity because of large single fraction size (8). A previous dosimetric comparison by Nairz *et al.* (9) of electron beam, orthovoltage x-ray, and single-channel balloon-based and interstitial high-dose-rate (HDR) brachytherapy demonstrated that electron beam IORT delivers the most homogeneous dose distributions. However, that study did not evaluate the potential impact of three-dimensional planning with multichannel balloon devices and implications for dose prescriptions. The superior dose distribution of multichannel compared with single-channel balloon devices has been well documented (10), and three-dimensional planning should theoretically bolster this superiority.

The higher energy photons provided by HDR ^{192}Ir should allow for an increase in the dose at 1 cm with a concomitant decrease in the balloon surface dose compared with 50 kV x-rays, thus potentially allowing for enhanced target coverage whereas minimizing risk of fat necrosis. However, this requires a shielded procedure room, which is not available at most institutions. At our institution, the availability of an integrated brachytherapy suite with in-room CT-on-rails imaging, shielding for HDR delivery, and an operating room table with full anesthesia capability presents the potential to develop a novel method of breast IORT using image-guided HDR ^{192}Ir via a multichannel/multidwell balloon catheter. In the present study, we compare the dosimetric characteristics of IORT with HDR brachytherapy using three-dimensional CT-based planning and a multichannel/multidwell balloon catheter to IORT with a single central lumen with a stepping 50 kV source. We further develop the treatment-planning platform for IORT by considering potential prescription doses using this technique to inform the technical details of a prospective clinical trial planned at our institution.

Methods and materials

Cohort and treatment planning details

The CT scans of 14 patients who had previously received Contura (Hologic, Inc., Bedford, MA) multilumen balloon breast brachytherapy were used for this study (six right breast and eight left breast). All planning was performed on the Varian BrachyVision v11 treatment planning system (Varian Medical Systems, Inc., Palo Alto, CA). For ease of comparison, the HDR treatments were standardized for a 10 Gy prescription dose to encompass the evaluation planning target volume (PTV_EVAL) defined for each patient according to the approach described in the National Surgical Adjuvant Breast and Bowel Project B-39 clinical trial protocol for APBI with brachytherapy (11). Plan objectives included: (*1*) dose to 95% of the PTV_EVAL (D_{95}) of 95% of the prescription dose and (*2*) target percent volume receiving 150% of the prescription dose (V_{150}) of 28%. Thus, the objectives were similar to those of a recent multi-institutional Phase IV study on Contura multilumen balloon breast brachytherapy for APBI by Arthur *et al.* (12). Volume optimization included parameters to constrain the volume of high dose outside the PTV_EVAL. A structure named PTV_1 mm was created by expanding the balloon to 1 mm and subtracting the balloon volume from the contour. The D_{95} to PTV_1 mm was used for surrogate of surface dose, because the dose at the surface of a structure cannot be determined directly in the treatment planning system. A range of possible HDR prescription doses were evaluated to approximate the threshold prescription dose that allows maximal dose to PTV_EVAL without exceeding balloon surface dose of 20 Gy—the surface dose reported in the TARGIT-A trial that has shown acceptable toxicity at 5 years of followup (3).

The Task Group 43 data for the Xoft 50 kV treatment device (Xoft, Inc., San Jose, CA) were loaded into the treatment planning system, so that comparisons could be made between ^{192}Ir based brachytherapy and 50 kV electronic brachytherapy. The same volume optimization parameters were used for the 50 kV plans as for the ^{192}Ir plans. The 50 kV treatment plans were scaled to a 10 Gy prescription dose to permit direct comparison to the HDR brachytherapy plans. A representative comparison in a single patient is