Original article

Dose correction in lung for HDR breast brachytherapy

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Abstract

Purpose: To evaluate the dosimetric impact of lung tissue in Ir-192 APBI.

Material and methods: In a 40 × 40 × 40 cm^3 water tank, an Accelerated Partial Breast Irradiation (APBI) brachytherapy balloon inflated to 4 cm diameter was situated directly below the center of a 30 × 30 × 1 cm^3 solid water slab. Nine cm of solid water was stacked above the 1 cm base. A parallel plate ion chamber was centered above the base and ionization current measurements were taken from the central HDR source dwell position for channels 1, 2, 3 and 5 of the balloon. Additional ionization data was acquired in the 9 cm stack at 1 cm increments. A comparable data set was also measured after replacing the 9 cm solid water stack with cork slabs. The ratios of measurements in the two phantoms were calculated and compared to predicted results of a commercial treatment planning system.

Results: Lower dose was measured in the cork within 1 cm of the cork/solid water interface possibly due to backscatter effects. Higher dose was measured beyond 1 cm from the cork/solid water interface, increasing with path length up to 15% at 9 cm depth in cork. The treatment planning system did not predict either dose effect.

Conclusions: This study investigates the dosimetry of low density material when the breast is treated with Ir-192 brachytherapy. HDR dose from Ir-192 in a cork media is shown to be significantly different than in unit density media. These dose differences are not predicted in most commercial brachytherapy planning systems. Empirical models based on measurements could be used to estimate lung dose associated with HDR breast brachytherapy.

J Contemp Brachyther 2012; 4, 2: 106-110
DOI: 10.5114/jcb.2012.29367

Key words: lung, dosimetry, partial breast irradiation, HDR.

Purpose

Accelerated Partial Breast Irradiation (APBI) using Iridium-192 (Ir-192) in high dose rate (HDR) brachytherapy is becoming a common radiation oncology treatment modality for breast conserving therapy [1-5]. APBI is delivered in a hypofractionated regimen that treats a 1 cm margin around the resected tumor cavity, reducing the dose to normal tissue when compared to three dimensional (3D) conformal external beam radiotherapy (EBRT) [6-9]. APBI has been shown to have good cosmetic outcomes while providing a level of convenience that makes adjuvant radiation therapy accessible to more patients with breast cancer [10-12]. Proximity of the planning target volume (PTV) to the lung makes lung dose evaluation and PTV dose accuracy important. However, reporting an accurate lung dose is a dosimetric challenge due to the paucity of commercial brachytherapy treatment planning systems (TPS) capable of dose calculation in heterogeneous media [4,13-16]. Most TPS calculation algorithms conforming to TG-43 recommendations are based on Monte-Carlo simulations of a single source in a 15 cm water phantom [13,16-20]. As such, they do not account for differences in tissue size, shape or density [16].

One of several devices used in APBI is the Contura Multi-Lumen Balloon (CMLB) (SenoRx, Inc., Irvine, CA, USA). The CMLB is surgically inserted into the resulting cavity following tumor resection; the CMLB is then filled with saline and radiographically opaque contrast solution, for localization during treatment planning and for monitoring the diameter prior to each treatment. Within the balloon are five channels into which an Ir-192 source can be driven by a remote afterloader. It has been shown that the versatility afforded by the multiple channels may offer reduced skin and rib doses, greater compliance with treatment planning goals and no increase in toxicity when compared to single channel devices [5,21,22]. Additionally, the CMLB has a vacuum port through which fluid and air can be removed from the treatment cavity to optimize target conformity, and which otherwise might introduce further heterogeneities [23]. However, it has also been shown that dose perturbations can be introduced through the use of certain contrast solutions such as Iodine [3,4,24,25].

The lungs are recognized as organs at risk (OAR) in partial breast radiotherapy [26-28]. For 3D EBRT, the NSABP trial B-39 requires that not more than 15% of the ipsilateral lung receive 30% of the prescribed dose, and specifies that

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Received: 03.04.12
Accepted: 06.06.12
Published: 30.06.12

the dose computations should take into account tissue density. The NSABP trial B-39 is a randomized phase III study of conventional whole breast irradiation (WBI) versus partial breast irradiation (PBI) for women with Stage 0, I or II breast cancer. Lung dose has been reported to be lower from brachytherapy than from 3D EBRT [13,29]. However, lung dose comparisons for breast EBRT and brachytherapy are questionable if tissue density is not accurately accounted for in dose calculations. Inconsistencies arise since most commercial brachytherapy TPS do not take into account the effect of tissue densities while EBRT TPS are required to. Despite that, many studies report lung dose from breast brachytherapy [26,28,29]. It has been reported that the inverse square fall-off is an appropriate approximation because scatter buildup offsets attenuation; it has also been reported that there are minimal heterogeneity effects when using Ir-192 [15]. However, several Monte-Carlo studies have demonstrated measurable heterogeneity effects during brachytherapy near the lung [4,14-16]. These findings complement studies showing that the lung-soft tissue interface is the region most dependent on dose calculation algorithm and that these differences can be statistically significant [30-32]. This study attempts to address the issue of lung dose from HDR breast brachytherapy, enabling valid dose comparisons between EBRT and brachytherapy. In it, a CMLB device was used to make dosimetric comparisons of measurements in heterogeneous and homogeneous phantoms. TPS calculations of dose in the two phantoms were also compared. The results of this experiment are intended to improve lung dose estimation for partial breast brachytherapy.

Material and methods

The CMLB brachytherapy device for APBI is a spherical balloon filled with saline and contrast, containing five channels into which an HDR Ir-192 source can be driven (Fig. 1). A MicroSelectron V2 HDR (Nucletron B.V., Veenendaal, The Netherlands) was used to control the Ir-192 source. The CMLB was filled with 37 cm^3 of saline to 4 cm diameter and positioned in a 40 × 40 × 40 cm^3 water tank beneath a 30 × 30 × 1 cm^3 solid water slab. Solid water (Model Solid Water, RMI Inc, Madison, WI, USA) is a convenient water substitute material for phantom dosimetry, composed of epoxy resins and powder with density 1.04 gm/cm^2. A Scanditronix parallel plate ion chamber (Type NACP-02, IBA Dosimetry America, Inc., Bartlett, TN, USA) was centered within a 30 × 30 × 1 cm^3 solid water slab, which was placed on the initial slab. The ion chamber was aligned to channel 1 of the CMLB with the incident chamber surface facing the CMLB (Fig. 2). Additional 30 × 30 cm solid water slabs of varying thickness were added to the stack for a total height of 10 cm. A CNMC K602 electrometer (CNMC Company Inc., Nashville, TN, USA) was used to measure the ionization current. The 'sweet spot' dwell positions for channels 1, 2, 3 and 5 of the CMLB were established through an iterative process at the source position that gave the highest ionization reading. Channel 4 was not included in the study, because it is represented by channel 2. Ionization measurements were taken at 1 cm increments within the solid water stack, up to 6 cm from the CMLB surface, using the established 'sweet spot' dwell position for each channel (Fig. 3A). The measurements were repeated after replacing the top 9 cm of solid water with 30 × 30 × 1.27 cm compact cork slabs (ρ = 0.25 g/cm^3) (Fig. 3B). Cork is a common substitute material for lung in dosimetry studies [33-39]. The measured ionization currents were normalized for source activity, temperature and atmospheric pressure.

The cork data were acquired at different depth increments than solid water due to differing slab thicknesses. Therefore, the data were fitted based on depth interpolation before being compared to the solid water data. The data were fitted using power functions of the form:

$$f(x) = \alpha \cdot x^{-\beta} \quad \text{(eq. 1)}$$

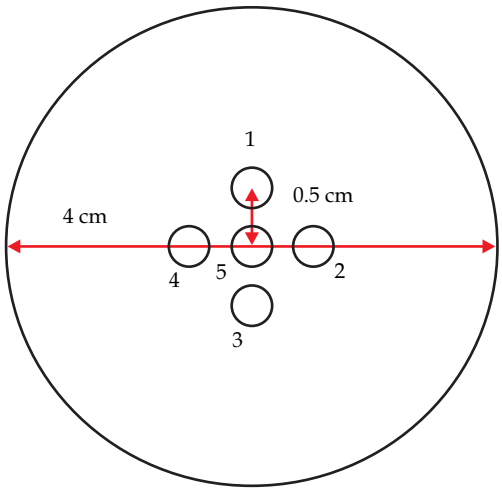

Fig. 1. Cross-sectional diagram of the Contura through channel centers

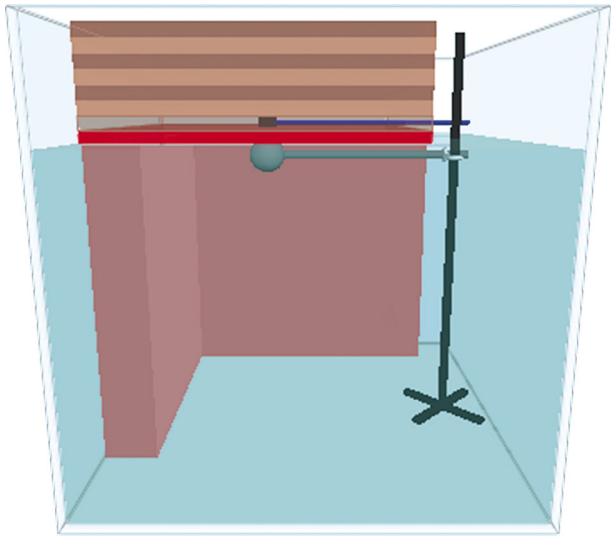

Fig. 2. Experimental setup in water tank showing the ion chamber above Contura

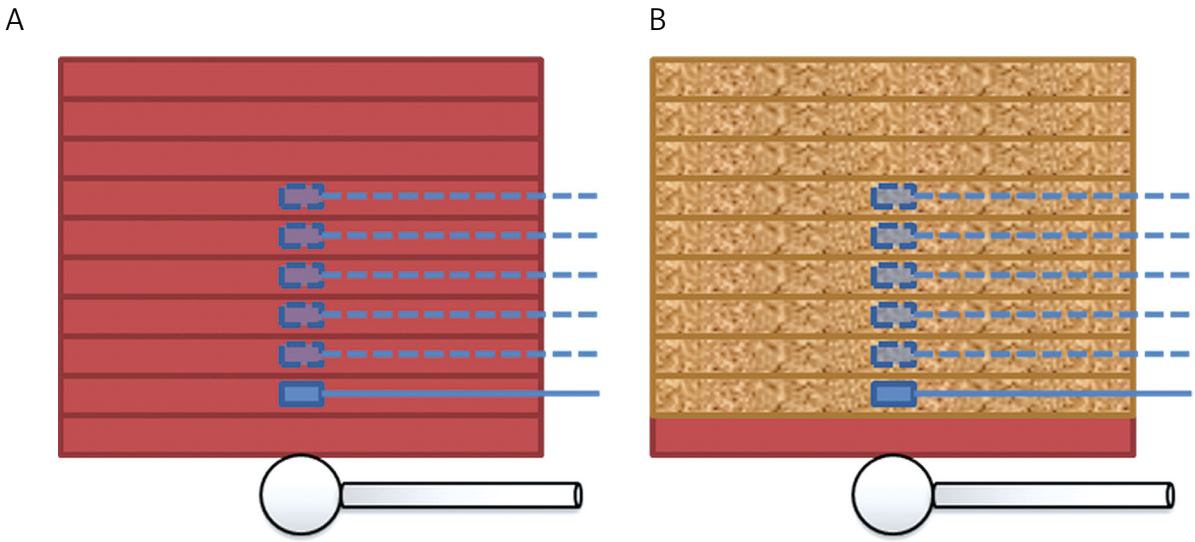

Fig. 3. Setup for measurements in (A) solid water phantom and (B) cork phantom

where α and β are fitting parameters. Data analysis utilized the application Microsoft Excel, Version 10 (Microsoft, Inc, Redmond, WA, USA). Resultant data were normalized to the 1 cm depth in solid water that was common to both setups. Ratios of the fitted cork to solid water measurements were calculated. The data were plotted as relative dose vs. source-to-chamber distance. Measurement data were repeatedly acquired in two experimental sessions and average values analyzed. The two experimental phantom setups were also CT scanned to compute doses using the Oncentra MasterPlan treatment planning system (Nucletron B.V.). Dose computations were evaluated at points corresponding to the measured dose point range from channel one.

Results

The acquired data were fitted to eq. 1 with R^2 values > 0.99. Dose ratios were calculated by considering the analytic ratios of the trend line equations for each channel and are shown in Fig. 4. This analytic result agreed with interpolated ratios at the measured distances.

The first data point of each channel was measured with identical attenuation, 1 cm of solid water, but with different backscatter conditions. At this first point, averaged over all channels, there was 3.6% (σ = 2.7%) less dose in the cork phantom than in the solid water phantom. Over the measurement range (6 cm in cork), the dose in cork exceeds the dose in solid water by as much as 10%. The magnitude of this dose effect increases with path length. Table 1 lists the computed dose comparisons for both phantoms. Despite the difference in phantom composition, the dose computation results agree to 0.5 ± 0.005%. The dose calculations using the Oncentra MasterPlan brachytherapy planning system do not predict either the backscatter effect or the increase in dose with path length through cork (Table 1).

Discussion

Lung is an organ at risk (OAR) in breast radiotherapy [26-28]. For 3D EBRT, the NSABP trial B-39 requires that < 15% of the ipsilateral lung can receive 30% of the prescribed dose and specifies that the dose computations take into account tissue density. Lung dose has been reported to be lower from brachytherapy than from external beam [13,29]. However, lung dose comparisons for breast teletherapy and brachytherapy are questionable if tissue density is not determined consistently. That is clearly the case since most brachytherapy planning systems do not take into account the effect of tissue densities while the external beam planning systems are required to. Despite that, many studies report lung dose from breast brachytherapy [26,28,29]. One can argue that the effects from inverse square falloff predominate, but reporting on lung dose needs some correction for valid comparison to EBRT doses. This study has attempted to address the issue of lung dose from HDR breast brachytherapy. Understanding the effect of low density tissue on breast brachytherapy dose will validate dose comparisons between teletherapy and brachytherapy. In this study, measurements indicate low doses adjacent to the interface of unit density and low density structures due to reduced backscattering in the low density material. This dose perturbation effect has also been reported based on Monte Carlo calculations [40].

The measurement results in this study also demonstrate that the dose in low density media relative to unit density increases with path length. However, the degree to which this dose increase occurs may be overstated in this study since the solid water material has been shown to attenuate by approximately 4% more than liquid water [41]. Considering that tissue densities are variable for different patients, as well as across a given structure, the results of this study should be regarded qualitatively.

Conclusions

In an experiment evaluating the dose differences between Contura based HDR brachytherapy in water and lung equivalents, measurements demonstrated significant dose differences at the inhomogeneous interface. Measurements further demonstrated that the differences increase with path

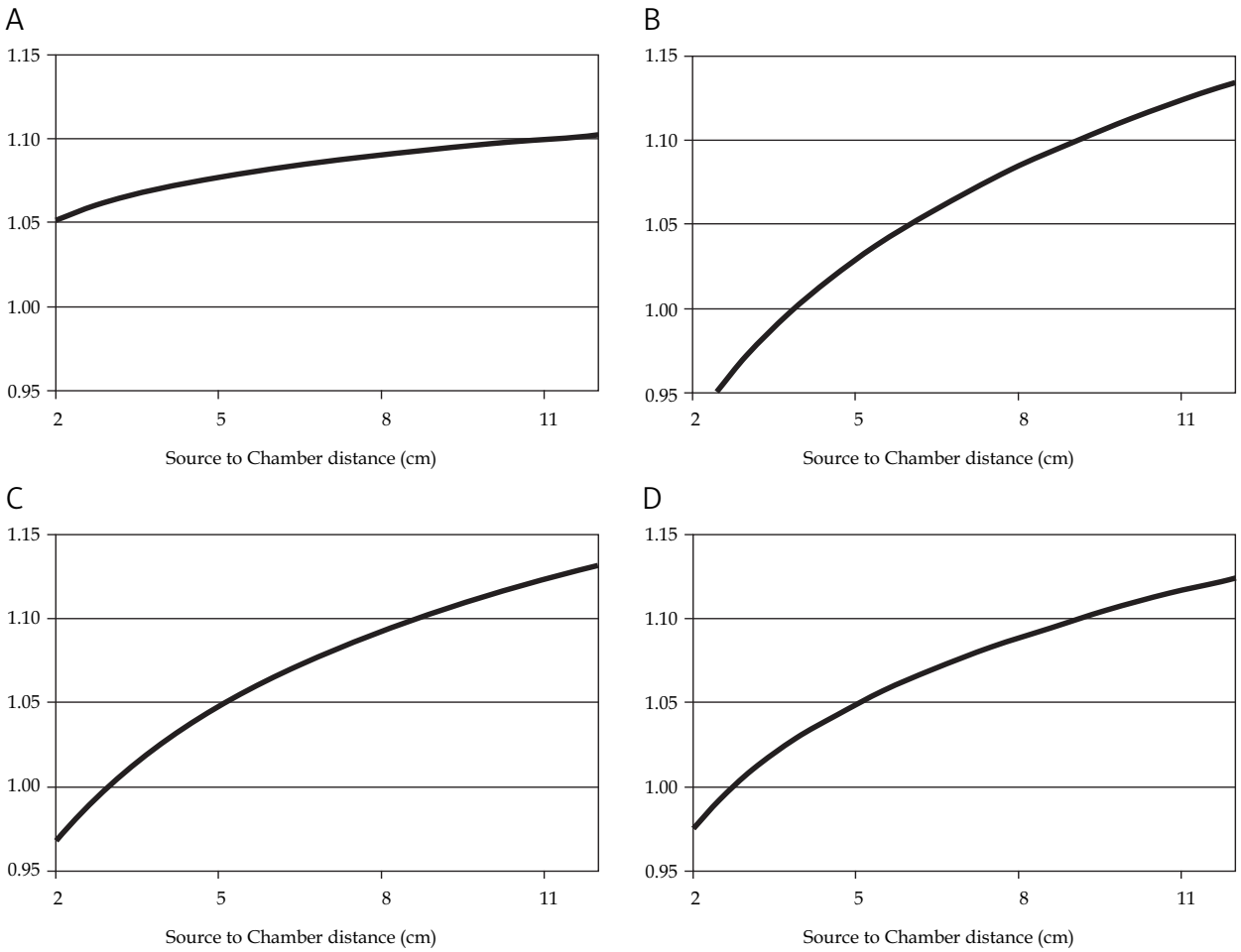

Fig. 4. Plots of the trend line-based analytical ratios of relative dose in cork to solid water vs. source-to-chamber distance for **(A)** Channel 1 with the cork-solid water interface at 2.5 cm, **(B)** Channel 2 with the cork-solid water interface at 3.04 cm, **(C)** Channel 3 with the cork-solid water interface at 3.5 cm, and **(D)** Channel 5 with the cork-solid water interface at 3 cm

Table 1. Comparison of Oncentra dose calculations from channel one for the two phantom configurations

Solid Water	Cork		Ratio	
Depth [mm]	Relative Dose	Depth [mm]	Relative Dose	Cork/Solid Water
30	58.78	30	57.99	0.99
40	32.09	40	31.79	0.99
50	20.07	50	19.94	0.99
60	13.67	60	13.62	1.00
80	7.47	80	7.47	1.00
100	4.67	100	4.68	1.00

length through the low density medium. These findings are not predicted by most commercial brachytherapy planning systems and may serve as a model to better understand lung dose during breast brachytherapy with Ir-192, enabling proper dose reporting for OAR.

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