Isodose Contours and Depth-Dose Behavior of Multi-Catheter Breast Applicators

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ABSTRACT

Purpose: HDR brachytherapy has evolved from multiple catheters individually placed to single lumen balloons and now to multi-catheter single insertion devices. Many measures of delivered dose quality exist such as V100, V200, and DHI. As single values, none can completely characterize a volumetric dose distribution. Even a DVH has inherent limitations. The present study investigates isodose contours and the depth-dose relationship in the prescription region for several multi-catheter configurations of both Ir-192 seeds and 50 kVp x-rays.

Materials and Methods: A custom software program written in LabVIEW is used to create source dose distributions, distributable in space to arbitrary locations and arbitrary relative strengths. The program provides analysis capabilities to allow investigation of the isodose contours and depth-dose behavior at various points. With this framework, many potential realistic configurations can be studied, including ones where there is a central lumen, and ones where one catheter is not used, so as to lower dose in a particular region.

Results: Multi-catheter applicators can generate more complex patterns than single catheters, and can provide reduced dose in a particular direction. However they do so with an increase in complexity of the dose distribution. Near to the off-axis catheters there is pronounced scalloping and an increase in the rate of falloff, meaning a higher surface to prescription dose ratio.

Scalloping will also appear in the longitudinal stepping direction, unless step lengths are much shorter than commonly used, e.g. 1 mm. Sources with faster dose falloff, such as 50 kVp x-rays and low energy gamma sources like I-125 behave more poorly. Scalloping and falloff can be partially ameliorated by using the central catheter to deliver the bulk of the dose, and by keeping the off-axis catheters closer to the central one.

Conclusions: Despite improvement realizable through dominant use of the central catheter, in all cases both the scalloping and increase in falloff rate persist when using the off-axis catheters. Such inhomogeneities do not necessarily show up in metrics such as the DHI, so can be missed by conventional dosimetric calculations.

BACKGROUND

- Breast cancer is the most frequently diagnosed cancer in women, with an estimated 182,460 new cases expected in the U.S. during 2008. Breast cancer is the second leading cause of cancer deaths among women, with an estimated 40,480 deaths expected in 2008. [Ref: www.cancer.org]
- External beam radiotherapy following breast conserving therapy (BCT) lasts 6 to 7 weeks. Many women elect mastectomy or omit post-operative radiotherapy because they cannot commit the required time or resources.
- Accelerated Partial Breast Irradiation (APBI) using brachytherapy can significantly shorten treatment time but is labor intensive, requires a skilled operator, and can be uncomfortable for patients. Many radiation treatment centers cannot afford to maintain active isotopes or to build the shielded treatment room for HDR brachytherapy.
- The Axxent® System, developed by Xoft, Inc., is an electronic (non-isotopic) high dose rate brachytherapy device designed to shorten treatment time compared to external beam radiation and ultimately lessen patient discomfort.
- The Axxent® System does not require a heavily shielded environment, potentially bringing treatment centers closer to the patient's home. This technology also eliminates handling and disposal of isotope sources.
- The Axxent® Electronic Brachytherapy System is being used for the treatment of breast cancer in the U.S. Xoft, Inc. has received expanded clearance from the Food & Drug Administration for the Axxent® Electronic Brachytherapy System for use in the treatment of other cancers or conditions where radiation therapy is indicated.

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PURPOSE

- APBI for post-lumpectomy care is routinely delivered using either multiple needle interstitial or single channel balloon-based techniques.
- Recently several models of multi-lumen single-insertion applicators have become available. These promise improved conformity compared to single channel devices as well as lower complexity and insertion difficulty than the interstitial approach.
- This study investigates the dosimetric advantages and disadvantages of single-insertion multiple-channel brachytherapy treatment approaches through two dimensional simulation.

METHODS

Software

- A custom software program written in LabVIEW was used to create two-dimensional source dose distributions, distributable in space to arbitrary locations and arbitrary relative strengths. The program provides analysis capabilities to allow investigation of the isodose contours and depth-dose behavior for various configurations of source positions in a plane perpendicular to the long axis of the applicators.

Configurations

- Five catheter configurations were modeled:
  - Four configurations had multiple sources, 2 with a central source at 10x the intensity and 2 with no central source.
  - One configuration had a single central source.

Sources

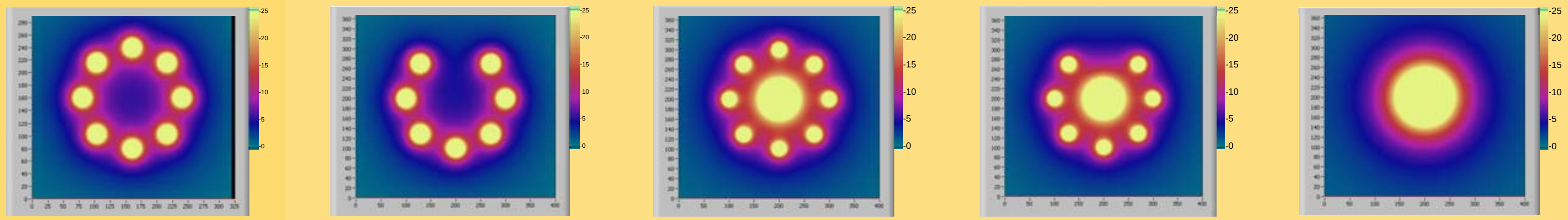
- As input data, a choice was provided between a simple $1/r^2$ source such as Ir-192 and an exponential model of a 50 kVp x-ray source.
  - Two-Dimensional Model – no pullback
  - **Prescription Depth = 3.2 cm**
- The program additively superimposed the dose patterns of the defined sources, allowing for independent arbitrary weighting factors. In this way, for example, a 2 cm diameter, 8 element array was built up, with and without a central source. The central source could easily be simulated at a much higher level by assigning an appropriate weighting function.
- Similarly the effect of not using an outer lumen could be simulated by setting the weight to 0 or another value between 0 and 1.

Endpoints

- Data is presented as false-color intensity maps, with line plots cutting across any slice either vertically or horizontally.
- Line plots, constructed from the points on a circle of arbitrary radius, were also provided at 2.2, 2.7 and 3.2 cm radii.
- Dose histograms were constructed of all points that fall within a region on interest (ROI) defined by inner and outer radii:
  - **ROI = 2.2 - 3.2 cm**
- By exporting the calculated 2D array to other analysis programs, radial dose function plots at various angles were prepared for an 8 source configuration with an $1/r^2$ source.

RESULTS

False Color Intensity Map



Configuration

8 Sources
- 8 $1/r^2$ sources at 2 cm from center
- Data shows minor modulation of dose at prescription depth of 3.2 cm, but 7 to 8x modulation near inner edge of treatment area

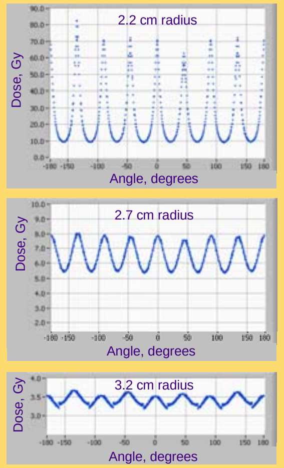
8 Sources – 1 Turned Off
- 7 $1/r^2$ sources at 2 cm from center
- Turning a lumen off (or down) allows for lowering the dose in a particular region
- At prescription depth, this can cut the dose roughly in half over ~45 degrees

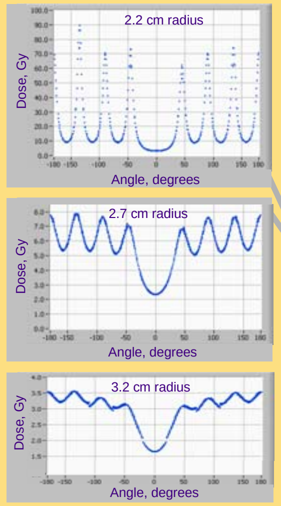
9 Sources
- 1 central $1/r^2$ source and 8 $1/r^2$ sources at 2 cm from center
- Adding a source in the center, at 10x the intensity, smoothes out the modulation

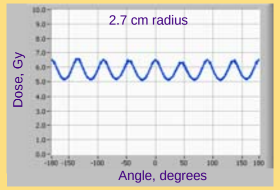
9 Sources - 1 Turned Off
- 1 central $1/r^2$ source and 7 $1/r^2$ sources at 2 cm from center
- The central source improves dose homogeneity, but lowers the degree of dose sculpting that can be accomplished

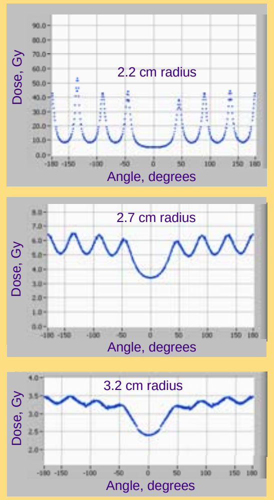
Single Source
- 1 central source for $1/r^2$ and 50kVp
- Dose along the circle plots is uniform at all distances

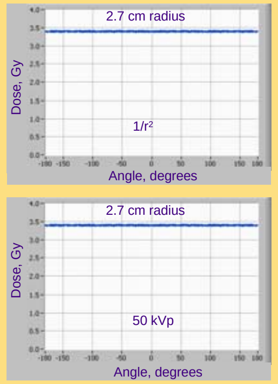
Circle Plots (Line plots along circular trajectories around the center)





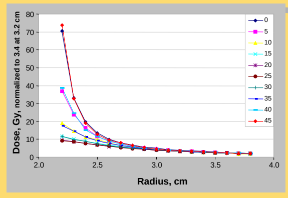


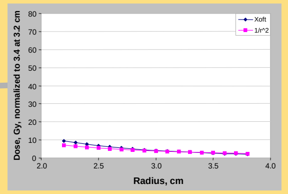




Circle Plots
- At 2.7 cm (halfway through the treated area), the effect is beset by high modulation, and the dose drops below the prescription value
- Near the inner edge, at 2.2 cm, both effects are even more extreme

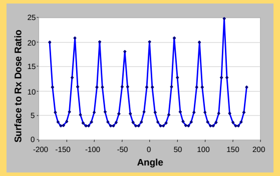
Depth-dose along radii extending outward from 2.2 cm at 5º intervals



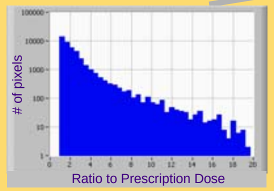


Depth Dose Effects
- High modulation from the multiple lumens creates very steep depth-dose curves at points near the lumens. In comparison the difference between $1/r^2$ and 50 kVp sources is almost negligible

Ratio of dose at 2.2 cm to Rx depth of 3.2 cm at the indicated angles

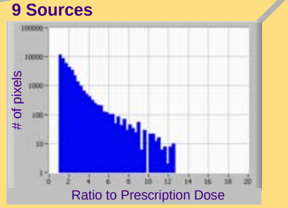


8 Sources



Here 1 = 1x or 3.4 Gray. Worst case pixels receive almost 20x the prescription dose

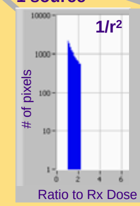
9 Sources



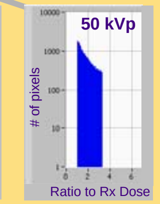
Use of the central source at 10x reduces max dose, but some pixels still receive over 10x the prescription dose.

Normalized Dose Histograms
- The dose histogram for the 9 source configuration shows an improvement in uniformity over the 8 source situation, although not as good as the uniformity with a single central source of either type

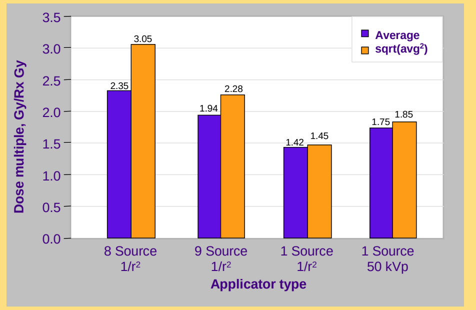
1 source



1 source



RESULTS



- The above figure shows the average dose within the ROI (from 2.2 to 3.2 cm) as a multiple of the prescription dose, for 4 symmetric configurations involving single and multiple lumens.
- With multiple lumens, the proximity of source to tissue increases the average dose. The use of multiple lumens also decreases the homogeneity, as seen in the relatively large sqrt(avg^2) dose values.
- The use of a central lumen with outboard lumens partially mitigates both average and sqrt(avg^2) values.
- The difference between sqrt(avg^2) and the simple average indicates the degree of non-uniformity, which is high for the multi-lumen applicators.

SUMMARY

- A 2-dimensional computer model was constructed to study the dose patterns emanating from an assortment of multi-lumen breast applicators. Such devices have the potential to sculpt dose in a limited way, for example to spare skin in cases where the skin bridge is narrow.
- Results show that with careful alignment, dose over a fixed angular range can indeed be lowered. However this flexibility comes with substantial costs.
  - Dose homogeneity and conformance are compromised, especially near the lumens.
  - Depth-dose, as measured by dose near the inner edge of the treatment area relative to the prescription point, is dramatically increased.
  - The increase in dose near the lumens markedly increased the average dose in the region of interest and the average-squared dose, relative to the case with a single central lumen. The difference between average and average-squared dose is a measure of the non-uniformity and is large in the multi-lumen cases.
  - Dose histograms show that small areas receive doses more than an order of magnitude higher than the prescription.
- A full 3 dimensional model, with pullback along the lumens, would have ameliorating effects, depending upon the length of the pullback, and the distance from the pullback path, which would tend to vary from case to case.
- Various means of improving the dosimetry have been explored with varying success.
  - One can, for example, tune the dwell time in a lumen rather than completely turning it off, to lower the effect.
  - Use of a central lumen with order of magnitude longer dwell times and/or the use of lumens located at a smaller radius from the tissue, inside a balloon for example, induces lower inhomogeneities and less drastic depth-dose effects.
  - However both approaches also permit substantially less significant dose sculpting.

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