ELSEVIER

Brachytherapy ■ (2016) ■

BRACHYTHERAPY

Technical Note

Automated construction of an intraoperative high-dose-rate treatment plan library for the Varian brachytherapy treatment planning system

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ABSTRACT

PURPOSE: The ability to create treatment plans for intraoperative high-dose-rate (IOHDR) brachytherapy is limited by lack of imaging and time constraints. An automated method for creation of a library of high-dose-rate brachytherapy plans that can be used with standard planar applicators in the intraoperative setting is highly desirable.

METHODS AND MATERIALS: Nonnegative least squares algebraic methods were used to identify dwell time values for flat, rectangular planar applicators. The planar applicators ranged in length and width from 2 cm to 25 cm. Plans were optimized to deliver an absorbed dose of 10 Gy to three different depths from the patient surface: 0 cm, 0.5 cm, and 1.0 cm. Software was written to calculate the optimized dwell times and insert dwell times and positions into a .XML plan template that can be imported into the Varian brachytherapy treatment planning system. The user may import the .XML template into the treatment planning system in the intraoperative setting to match the patient applicator size and prescribed treatment depth.

RESULTS: A total of 1587 library plans were created for IOHDR brachytherapy. Median plan generation time was approximately 1 minute per plan. Plan dose was typically 100% ± 1% (mean, standard deviation) of the prescribed dose over the entire length and width of the applicator. Plan uniformity was best for prescription depths of 0 cm and 0.5 cm from the patient surface.

CONCLUSIONS: An IOHDR plan library may be created using automated methods. Thousands of plan templates may be optimized and prepared in a few hours to accommodate different applicator sizes and treatment depths and reduce treatment planning time. The automated method also enforces dwell time symmetry for symmetrical applicator geometries, which simplifies quality assurance.

Keywords: Intraoperative; IOHDR; Brachytherapy; Sarcoma; Atlas; Library; Optimization

Introduction

Intraoperative high-dose-rate brachytherapy (IOHDR) has been used to reduce the rate of local recurrence in cancer patients with head and neck, gastrointestinal, colorectal, gynecologic, and other solid tumors (1−5). IOHDR delivers a large dose of radiation in a single fraction and may be combined with either preoperative or postoperative external beam radiotherapy (6, 7).

The tumor bed is exposed at the time of surgery, and therefore, intraoperative treatments traditionally do not use three-dimensional imaging to localize the treatment site. The radiation oncologist identifies the treatment site and positions a high-dose-rate (HDR) applicator onto the tumor bed. The HDR applicators, including Freiburg Flap (Nucletron, Stockholm, Sweden) and Harrison−Anderson−Mick (Mick Radio-Nuclear, Mount Vernon, NY), are flexible and may be shaped to conform onto the tumor bed. Mobile nearby healthy tissue, such as bowel and ureters, may be retracted from the treatment site and protected with lead shields as needed.

The patient is anesthetized throughout the treatment preparation, planning, and delivery process, and it is important to make the radiation treatment process as efficient as possible. Because the radiotherapy treatment plan is based on the applicator geometry, several authors have suggested that users create a library of plans for a range of applicator sizes and treatment depths before the treatment (8). Library plan generation may require a substantial amount of time

Received 10 February 2016; received in revised form 25 March 2016; accepted 5 April 2016.

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1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2016.04.001

using traditional methods of digitizing applicators and performing plan optimization inside a commercial treatment planning system. For example, a library containing standard plans prescribed to treatment depths of 0 cm, 0.5 cm, and 1.0 cm and for rectangular applicator shapes that range in size from 2 cm to 25 cm in 1 cm increments requires 1587 different plans. At a rate of 30 minutes per plan, completing the library would require nearly 20 weeks of full-time equivalent effort.

A method is presented for rapidly creating a large library of standard IOHDR treatment plans. The advantages of the proposed method are (*1*) the method provides a uniform absorbed dose over the target surface; (*2*) thousands of plans may be generated in a few hours, whereas manual creation of such plans would require several months of full-time equivalent; and (*3*) the increased efficiency may allow the user to build a library that contains more applicator sizes and curvatures than manual methods. The disadvantages of the proposed method are (*1*) the user must write a computer program to generate plans; (*2*) the method currently only works for treatment planning systems that allow users to import plan templates (e.g., Varian brachytherapy treatment planning system [VBTPS]) (Varian Medical Systems, Brachytherapy Planning v13.6, Palo Alto, CA); and (*3*) library plans are limited to the geometries that the user decides ahead of time, and the planner may not be able to anticipate all the curvature and scatter differences that occur in the intraoperative setting (9−11).

Methods and materials

Plan optimization

Software was written to automatically generate plans for a wide range of rectangular applicator sizes and shapes. In our clinic, we generated plans for rectangular applicators ranging in size from 2 cm × 2 cm to 25 cm × 25 cm and at treatment depths of 0.0, 0.5, and 1.0 cm from the surface of the applicator.

The catheters were defined to be spaced 1.0 cm apart and at a distance of 0.5 cm above the patient surface. These dimensions are consistent with the Freiburg Flap and Harrison−Anderson−Mick surface brachytherapy applicators. The distance between neighboring dwells within a catheter, or the step size, was defined to be 1.0 cm. The target surface and patient surface (if different) were defined to equal the dimensions of the applicator and have lateral boundaries that pass through the centers of the peripheral dwell positions.

For example, consider the 2 cm × 2 cm applicator shown in Fig. 1. The applicator contains three catheters, each spaced 1 cm apart. Each catheter contains three source positions with 1 cm spacing (Fig. 1a). The lateral boundaries of the applicator and target surfaces pass through the centers of those dwells that lie on the perimeter of the applicator (Fig. 1a). The patient surface is located 0.5 cm below the source applicators, whereas the target surface plane is located at an additional depth from the patient surface (Fig. 1b).

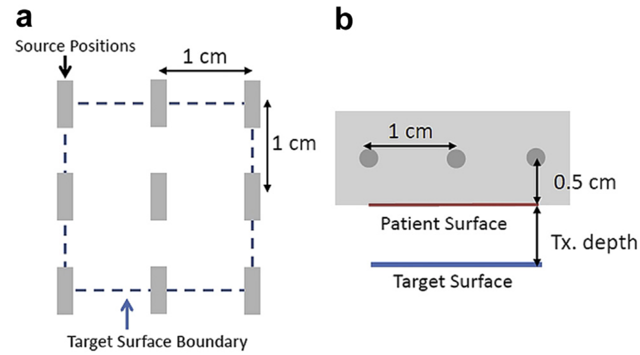

Fig. 1. Applicator geometry. (a) The superficial brachytherapy applicator catheters are spaced 1 cm apart. Source dwells are spaced 1 cm apart within catheters. The patient surface and target surface boundaries used in optimization are defined to pass through the centers of the peripheral dwell positions. (b) The patient surface is located 0.5 cm below the source applicators. The target surface plane is located at an additional depth from the patient surface.

Arrays of reference points were generated to represent both the patient and target surfaces. In this work, 5000 points were evenly spread over the patient surface beneath the applicator (Fig. 1b), and 5000 points were evenly spread over the target surface using a low discrepancy Halton series (12). A Halton series may be implemented in MATLAB version 8.0 (Mathworks, Natick, MA) using the *haltonset* function.

The library plans were optimized using the algebraic, nonnegative least squares (NNLSs) algorithm. The algorithm identified the total reference air kerma (TRAK) values, in units of Gy m^2, for all source positions in a treatment plan. A detailed description of the NNLS algorithm and its implementation was previously published, and the NNLS optimization method has been shown to yield results of equal or better quality as commercial optimization methods for planar applicator treatments, where a uniform absorbed dose is prescribed to a depth below the applicator (13). NNLS may be implemented in MATLAB using the *lsqnonneg* function.

The NNLS optimization solved the equation

$$\boldsymbol{S} = \boldsymbol{G}^{-1}\boldsymbol{D} \quad (1)$$

where $\boldsymbol{S}$ represents the source TRAK values, in units Gy m^2, for the source dwell positions; $\boldsymbol{D}$, in units of Gy, represents the desired absorbed doses to the reference points (e.g., the prescription dose); $\boldsymbol{G}$ represents an array, whose elements have units of m^{-2}, that represents the absorbed dose calculation; and $\boldsymbol{G}^{-1}$ represents the weighted inverse or pseudoinverse to $\boldsymbol{G}$: