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Brachytherapy 14 (2015) 380−384

BRACHYTHERAPY

Technical Note

Customized vaginal vault brachytherapy with computed tomography imaging-derived applicator prototyping

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ABSTRACT

PURPOSE: A novel customized vaginal brachytherapy mould technique has been developed for clinical use. This image-guided technique provides a brachytherapy applicator solution for irregular vaginal vault configuration and/or a wide vaginal apex relative to the vaginal introitus that would be sub-optimally treated with standard cylinders.

METHODS: The customized vaginal applicator is generated by the following process: CT images are obtained with contrast-soaked vaginal packing in situ to highlight unique anatomical detail. A 3-dimensional digital model is developed from the images and subsequently converted into a custom applicator with the use of stereolithography, which is an additive manufacturing technique whereby layers 50−100 μm thick of resin are deposited and polymerized using a laser to create intricate 3-dimensional objects. The density of the applicator and the dose delivered using the custom applicator were both measured to ensure accurate dosimetry.

RESULTS: The CT-based densities of a clinical vaginal cylinder and the cylinder generated using stereolithography were 1.29 ± 0.06 g/cm^3 vs 1.28 ± 0.01 g/cm^3, respectively. The mean measured dose from a representative stereolithographed applicator normalized to dose measured for a single plastic catheter was $99.8 \pm 4.2\%$. In patient dosimetric results indicate improved coverage of the lateral aspect of vaginal vault with the custom cylinder relative to the standard cylinder; 700 cGy vs 328 cGy, respectively, at a representative lateral vaginal dose point, while simultaneously achieving relatively narrow dose distribution in the anterior/posterior direction.

CONCLUSIONS: Stereolithographic applicator production was available within a clinically acceptable timeframe, and its clinical feasibility and utility has been demonstrated.

Keywords: Vaginal brachytherapy; Custom applicator; Image-derived prototyping; Stereolithography

Introduction

Intracavitary vaginal brachytherapy is typically delivered with a standard applicator of uniform diameter. The American Brachytherapy Society recommends an applicator that conforms to the apex, achieves mucosal contact, and offers optimal dosimetry (1). For irregular vault shapes or asymmetric tumor within the vaginal canal, interstitial brachytherapy (2) or conventional vaginal moulds have been used (3, 4). Drawbacks to the use of interstitial brachytherapy are the level of clinician skill to place the catheters, common use of multiple fraction high-dose-rate (HDR) techniques, and a requirement for patient analgesia and/or anesthesia.

Standard mould approaches require careful attention in cases with narrow vaginal openings relative to the width of the cavity at the vaginal apex. Since fast setting dental alginates are used to create a mould that conform to the patient's vaginal cavity, care must be taken to avoid filling the vaginal fornices; otherwise, the mold, once hardened, may be difficult to extract (5). Additionally, with standard mould techniques, it is difficult to incorporate curved catheter paths,

Received 31 October 2014; received in revised form 3 December 2014; accepted 16 December 2014.

Conflict of interest: The authors have no personal or financial conflict of interest associated with this work.

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1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2014.12.006

thereby limiting catheter paths to straight trajectories. Stereolithography is a method to create solid objects through successively polymerizing layers of photopolymer (resin) that is typically 50−100 μm in thickness. Using this rapid prototyping process, a model of patient and tumor anatomy can be created, which can then be evaluated, manipulated, and optimized to create a custom brachytherapy applicator that can address patient tissue irregularities in an individualized manner. The clinical use and benefits of rapid-prototyping and stereolithographic mould technique are described here. We demonstrate the production of a customized vaginal mould shape and optimization of brachytherapy dose distribution with the use of a custom applicator.

Methods and materials

Clinical case

A patient with a post-hysterectomy pathologic diagnosis of early endometrial cancer was identified for adjuvant treatment with vaginal intracavitary brachytherapy. On clinical examination, this patient had an irregular vaginal vault configuration with deep ‘‘dog-ear’’ configuration and a wide vaginal apex (4.4 cm) relative to the 2.5 cm vaginal introitus. Of the standard cylinders available, only a 2.5 cm intracavitary cylinder could be placed, which would lead to underdosing of the lateral vaginal apex. A custom brachytherapy applicator solution was pursued with 3-D rapid prototyping.

Creation of the 3-dimensional image

CT simulation images were obtained with barium contrast-soaked vaginal packing in situ to highlight unique anatomical detail (Fig. 1a). Using the 3D Slicer (http://www.slicer.org) software platform, the volume with packing was contoured and converted into a 3D digital model (Fig. 1b). The 3D digital model was then converted into a stereolithography file format and transferred to Inventor (Autodesk, Valley, CA), a 3D computer-assisted design software platform.

Applicator development

Within the Inventor platform, an optimized array of catheters for HDR brachytherapy sources was introduced into the model. The 3D tracks of the catheters were designed to achieve an even horizontal spacing of the catheters throughout the applicator. A minimum of 1 mm of material was maintained between catheters and the wall of the applicator. All catheter tracks were situated in the mid-coronal plane of the applicator. This arrangement of catheters provided sufficient dwell positions distributed evenly throughout the applicator to provide lateral dose dispersion at the wide vaginal apex, while simultaneously limiting the dose that would contribute to the bladder and rectum. In addition to customized catheter tracks, applicator features to accommodate the specific clinical and dosimetric considerations were introduced into the design. Objectives included an applicator that could be reproducibly placed in the desired anatomical orientation, with minimal patient discomfort, and with confirmatory markers. To optimally treat the vaginal apex, a 4.4 cm wide applicator was required; however, given the anatomical limitation of a 2.5 cm narrow vaginal introitus, such an applicator could not be inserted into the patient. Therefore, the applicator was designed with two pieces of smaller diameter, such that one half could be inserted first and then the second half could be slid along side of the first and attached using an alignment dowel (Fig. 2). The two pieces were designed such that as they slid along each other in the introitus at no point would the cross-sectional area exceed that of a standard 3.0 cm diameter cylinder. Additional fixation apparatus were designed to enable immobilization of the applicator during treatment.

The 3D digital prototype was then converted into a custom applicator through stereolithography, with a 50 μm layer resolution to ensure smooth applicator surface. The material used in the fabrication process was a USP class VI medical-grade photopolymer Accura Clearvue (3D Systems, Inc., Valencia, CA), which can be chemically

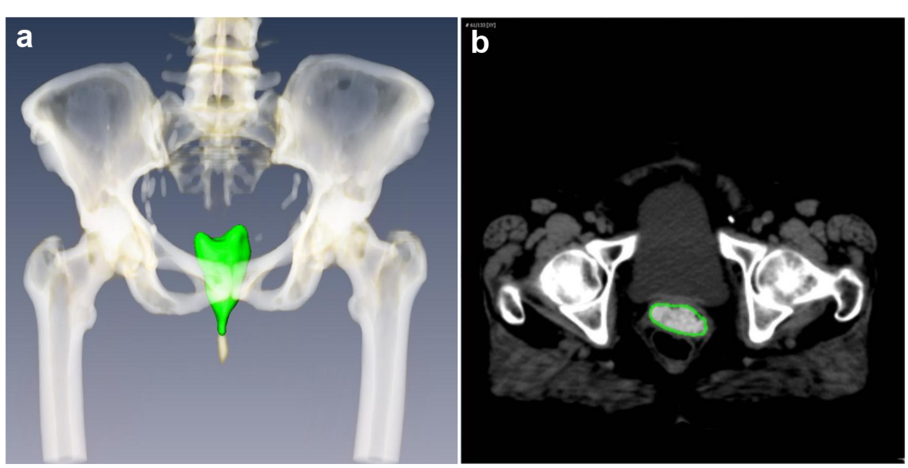

Fig. 1. (a) CT image with contrast-soaked packing in situ; (b) 3D digital image created from contours on CT simulation.