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Dosimetric influence of seed spacers and end-weld thickness for permanent prostate brachytherapy

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ABSTRACT

PURPOSE: The aim of this study was to analyze the dosimetric influence of conventional spacers and a cobalt chloride complex contrast (C4) agent, a novel marker for MRI that can also serve as a seed spacer, adjacent to ^{103}Pd, ^{125}I, and ^{131}Cs sources for permanent prostate brachytherapy.

METHODS AND MATERIALS: Monte Carlo methods for radiation transport were used to estimate the dosimetric influence of brachytherapy end-weld thicknesses and spacers near the three sources. Single-source assessments and volumetric conditions simulating prior patient treatments were computed. Volume−dose distributions were imported to a treatment planning system for dose−volume histogram analyses.

RESULTS: Single-source assessment revealed that brachytherapy spacers primarily attenuated the dose distribution along the source long axis. The magnitude of the attenuation at 1 cm on the long axis ranged from −10% to −5% for conventional spacers and approximately −2% for C4 spacers, with the largest attenuation for ^{103}Pd. Spacer perturbation of dose distributions was less than manufacturing tolerances for brachytherapy sources as gleaned by an analysis of end-weld thicknesses. Volumetric Monte Carlo assessment demonstrated that TG-43 techniques overestimated calculated doses by approximately 2%. Specific dose−volume histogram metrics for prostate implants were not perturbed by inclusion of conventional or C4 spacers in clinical models.

CONCLUSIONS: Dosimetric perturbations of single-seed dose distributions by brachytherapy spacers exceeded 10% along the source long axes adjacent to the spacers. However, no dosimetric impact on volumetric parameters was noted for brachytherapy spacers adjacent to ^{103}Pd, ^{125}I, or ^{131}Cs sources in the context of permanent prostate brachytherapy implants.

Keywords: Seed spacer; Prostate brachytherapy; Dose perturbation; Monte Carlo

Introduction

Low-dose-rate permanent implant brachytherapy is a standard of care approach for the treatment of localized prostate cancer and is delivered to an estimated 40,000 men in the United States each year. Implants typically involve insertion of up to 120 radioactive seeds into the prostate; dosimetric analysis after the implant is critical for evaluating the quality of treatment delivery and is predictive of biochemical disease outcomes after prostate brachytherapy (1). CT is superior to MRI for seed localization, whereas MRI is superior to CT for the anatomic delineation of the prostate and the surrounding soft tissues (2−5). During MRI of the prostate after the implantation, the titanium seeds appear as negative contrast signal voids with susceptibility artifacts. Current MRI sequence protocols make it difficult to localize each seed implanted into the prostate and periprostatic tissues and perform postimplant dosimetric analysis.

Precise dosimetric evaluation of prostate implants is crucial for assessing the adequacy of the treatment

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Conflict of interest: SJF is a cofounder of C4 Imaging, LLC. All other authors declare no conflicts of interest.

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delivered and thus for ensuring the highest probability of cure. Therefore, current brachytherapy guidelines recently published by the American College of Radiology and the American Brachytherapy Society recommend the fusion of MRI with CT for postimplant dosimetry (6, 7). However, the inadequacies of MRI−CT fusion registration have led to active investigations of seed localization using MRI only (8−12).

To facilitate seed localization by MRI, a cobalt chloride complex contrast (C4) agent was developed that generates a positive signal under MRI (13). The C4 solution is embedded within a polymer capsule of dimensions identical to those of standard seed spacers and placed adjacently to a seed within a strand to enable seed localization under MRI (13). A previous study showed that the dose anisotropy of a single ^{125}I seed was unaffected by the C4 MRI marker and that subsequent imaging of the C4 MRI marker was unaffected by high-dose radiation exposure (14). However, the volumetric dosimetric effects of C4 MRI markers in a standard brachytherapy implant are unknown. Hence, the purpose of this study was to analyze the volumetric dosimetric impact of C4 MRI markers/spacers and conventional markers adjacent to ^{103}Pd, ^{125}I, and ^{131}Cs sources in the context of permanent prostate brachytherapy. Dose perturbations by spacers surrounding a single seed are also presented and compared with dose perturbations based on variations in seed design end-weld thicknesses.

Methods and materials

Monte Carlo (MC) simulations were performed using v1.40 of the MCNP5 radiation transport code. Three different low-energy photon-emitting radionuclide sources were examined: ^{103}Pd model 200 (Theragenics Corporation, Buford, GA), ^{125}I model 6711 (GE Healthcare, Chalfont St. Giles, UK [a unit of General Electric Company]), and ^{131}Cs model CS-1 Rev2 (IsoRay Medical, Inc., Richland, WA). Standard source component configurations and material compositions have been described and benchmarked elsewhere (15).

Three different brachytherapy source spacers were evaluated: "conventional," C4, and C40 spacers. Conventional spacers were simulated using a 90%/10% molar concentrations of polyglycolic acid/poly L-lactic acid ($C_2H_2O_2$/CH_3O_2) having a mass density of 1.5 g/cm^3. To our knowledge, there are no other spacer types available. C4 spacers consisted of a polyether ether ketone shell ($C_{19}H_{12}O_3$; 1.32 g/cm^3) surrounding a C4 $(CoCl_2)_{0.8}(C_2H_5NO_2)_{0.2}$ (1.01 g/cm^3; Fig. 1) (13, 16). As patients have not yet been implanted with the C4 spacers, consideration for the influence on a higher contrast loading was examined. Specifically, spacers having a C4 agent loading 10 times higher were labeled as C40. These hypothetical C40 spacers were identical to the C4 spacers except that the cobalt chloride complex density was increased to 1.10 g/cm^3. The spacer lengths and diameters were modeled as 0.55 cm and 0.08 cm, respectively.

Photon energies and intensities for each radionuclide source were simulated using data from the U.S. National Nuclear Data Center (17). The MCPLIB04 photon cross-section library DLC-220 was applied for photon-only radiation transport calculations. Owing to the short range of secondary charged particles, energy fluence kerma tallies were used to estimate absorbed dose (*F4). The *F4 tally estimator output (mega electron volts per square centimeter) was converted to absorbed dose (mega electron volts per grams) using mass energy absorption coefficients μ_{en}/ρ (square centimeters per gram) (18). Two simulation geometries were designed to examine volumetric dose distributions: (*1*) single-source simulations showing the influence of adjacent spacers and manufacturing variations and (*2*) multiple source implants simulating clinical cases as described in the following sections.

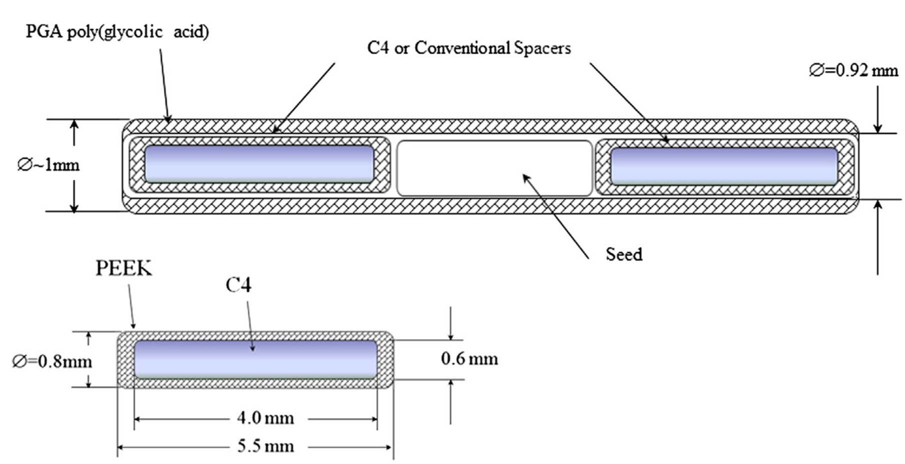

Fig. 1. Schematic representation of a seed with adjacent C4 spacers (MRI markers) as simulated using MC methods for radiation transport simulations. C4 detail illustrates the spacer composition and dimensions. C4 = cobalt chloride complex contrast; MC = Monte Carlo; PEEK = polyether ether ketone.