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BRACHYTHERAPY

MRI-based treatment planning and dose delivery verification for intraocular melanoma brachytherapy

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ABSTRACT

PURPOSE: Episcleral plaque brachytherapy (EPB) planning is conventionally based on approximations of the implant geometry with no volumetric imaging following plaque implantation. We have developed an MRI-based technique for EPB treatment planning and dose delivery verification based on the actual patient-specific geometry.

METHODS AND MATERIALS: MR images of 6 patients, prescribed 85 Gy over 96 hours from Collaborative Ocular Melanoma Study−based EPB, were acquired before and after implantation. Preimplant and postimplant scans were used to generate ''preplans'' and ''postplans'', respectively. In the preplans, a digital plaque model was positioned relative to the tumor, sclera, and nerve. In the postplans, the same plaque model was positioned based on the imaged plaque. Plaque position, point doses, percentage of tumor volume receiving 85 Gy (V_{100}), and dose to 100% of tumor volume (D_{min}) were compared between preplans and postplans. All isodose plans were computed using TG-43 formalism with no heterogeneity corrections.

RESULTS: Shifts and tilts of the plaque ranged from 1.4 to 8.6 mm and 1.0 to 3.8 mm, respectively. V_{100} was ≥97% for 4 patients. D_{min} for preplans and postplans ranged from 83 to 118 Gy and 45 to 110 Gy, respectively. Point doses for tumor apex and base were all found to decrease from the preimplant to the postimplant plan, with mean differences of 16.7 ± 8.6% and 30.5 ± 11.3%, respectively.

CONCLUSIONS: By implementing MRI for EPB, we eliminate reliance on approximations of the eye and tumor shape and the assumption of idealized plaque placement. With MRI, one can perform preimplant as well as postimplant imaging, facilitating EPB treatment planning based on the actual patient-specific geometry and dose-delivery verification based on the imaged plaque position.

Keywords: Ocular; Melanoma; Brachytherapy; Magnetic resonance imaging; Dosimetry

Introduction

Melanoma of the uveal layer, which includes the choroid, ciliary body, and the iris, is the most common primary intraocular cancer (1). Treatment options include enucleation and globe-sparing irradiation techniques such as charged particle therapy, stereotactic radiotherapy, and more commonly, episcleral plaque brachytherapy (EPB) (2). Iodine-125 (I-125) EPB was evaluated by the Collaborative Ocular Melanoma Study (COMS) trial for medium-sized tumors and was found to be as effective as enucleation in terms of disease-specific and overall survival, with the additional benefits of eye and some vision preservation (3).

A COMS-based approach for treating uveal melanoma patients via EPB with I-125 seeds is used at our institution; outcomes for over 500 patients treated between 1996 and

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Conflicts of interest: none.

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2011 have been reported by Badiyan et al. (4). This approach utilizes ophthalmic information, that is, ultrasound (U/S) A- and B-mode imaging, fundus photographs, and retinal diagrams, to create a two-dimensional (2D) representation of the tumor and its relationship to critical structures on a standard model of the eye. The ophthalmic information provides the tumor apex height, basal dimensions, distances to critical structures, tumor shape, and its location in the eye. The tumor is typically represented on the 2D standard eye model diagram as an oblate spheroid shape of apical height and width. The plaque is generally represented as being positioned symmetrically about the tumor and appositioned to the sclera which is defined to have a uniform thickness of 1 mm. Points of interest (POIs), for example, tumor apex, prescription depth, optic disc, fovea, and lens, are identified on the cross-sectional diagram of the standard eye, and the coordinates of these points are calculated in the eye-plaque coordinate frame, where all points lie in a single plane. Isodoses are calculated using a radiation therapy treatment planning system (TPS) and displayed relative to the points of interest by manually superimposing a transparency printout of the isodose lines onto the cross-sectional diagram. With this approach, the information used for EPB treatment planning does not utilize volumetric imaging methods that are standard of care for the radiation therapy of other tumor sites. A limitation of the 2D method is that the resulting dosimetry is based on a generalized approximation of the treatment geometry that may not accurately represent the patient-specific geometry of the tumor and of the ocular anatomy, for example, mushroom-shaped versus the more classic dome-shaped tumors, scleral thickness, and proximity of tumor to optic nerve sheath.

A three-dimensional (3D) representation of the eye was generated by the Plaque Simulator (PS) software, developed by Astrahan et al. (5). The PS software generates an interactive, translucent, 3D model of a patient's eye and tumor based on composite information from multiple imaging sources, that is, CT or MRI to determine the dimensions of the eye, U/S imaging to determine the dimensions of the tumor, and fundus photographs that are mapped onto the retinal and tumor surfaces. However, the 3D information provided by the PS software is limited since it does not directly use the volumetric image data to represent the patient's ocular anatomy and tumor.

Others have developed a 3D-based approach using conventional TPSs and CT imaging to generate a reference eye geometry for EPB isodose planning (6–8). Gagne *et al.* described how funduscopic images are used to aid the contouring of normal tissue volumes on the CT including the ciliary body, cornea, eyelid, lacrimal gland, lens, and optic nerve, as well as identifying dose points for the foveola and optic disc. However, due to the poor soft tissue contrast of CT, the tumor contour was still limited to an ellipsoidal shape based on tumor apex and basal dimensions provided by the ophthalmic examination.

An alternative to CT is the use of MRI for volumetric imaging of uveal melanomas because MRI has excellent soft tissue contrast (9–11). Daftari *et al.* found that 3D T_2-weighted fast spin echo MR imaging at 1.5-T yielded accurate volumetric measurements and additional information regarding tumor shape compared to more conventional imaging techniques, for example, U/S and trans-scleral illumination (9). In addition, MRI does not suffer from severe streaking artifacts that can obscure the ocular anatomy, as with CT, due to the low magnetic susceptibility of the gold alloy plaque. Thus, MRI has a unique advantage over CT in that one can image with the plaque in place which allows for treatment dose verification (12). MR imaging of the implanted plaque at 1.5-T was proposed by Houdek *et al.* in 1989 and evaluated for 1 patient, demonstrating the feasibility of postimplant MR imaging for 3D visualization of the ocular anatomy, tumor, and plaque position with adequate spatial resolution (12). However, other than verification via U/S by the ophthalmologist immediately after plaque implantation, the acquisition of volumetric image data sets of the implant is not commonly done for EPB, unlike other tumor sites receiving brachytherapy, for example postimplant CT or MR imaging of permanent prostate seed implants. Thus, EPB dosimetry has been historically based on approximated treatment geometries generated from preimplant imaging information. In this work, we describe the implementation of MR imaging for EPB, eliminating both the reliance on approximations of the ocular anatomy and tumor shape as well as the assumption of idealized plaque placement. We demonstrate how preimplant and postimplant MR imaging can facilitate EPB treatment planning based on the actual patient-specific geometry and dose delivery verification based on the imaged plaque position. Furthermore, we demonstrate how all of this can be accomplished using a conventional TPS.

Methods and materials

Six patients were enrolled in a prospective clinical trial approved by the Washington University Human Research Protection Office to evaluate the utility of preimplant and postimplant MRI. Patients were prescribed 85 Gy over 96 hours from COMS-based EPB with I-125 seeds. The plaque size and prescription depth were based on tumor basal dimensions and apex heights, respectively, as determined by U/S imaging and fundus photography. The seed activity to deliver 85 Gy at a prescribed depth along the central axis of the plaque was calculated based on TG-43 isotropic point source formalism, where all activated seeds were set to uniform strength (13). In the case of notched plaques, certain seeds were set to zero strength to simulate the location of the notch.

For all patients, MRI was performed on a 1.5-T scanner (Intera, Philips Medical Systems, Inc, Cleveland, Ohio) in 2 sessions, that is, about 1 week prior to implantation and postimplantation with the plaque in place. Plaque implants