ELSEVIER

CrossMark

BRACHYTHERAPY

Brachytherapy 14 (2015) 209–230

Heterogeneous dose calculations for Collaborative Ocular Melanoma Study eye plaques using actual seed configurations and Task Group Report 43 formalism

Christopher L. Deufel*, Keith M. Furutani

Department of Radiation Oncology, Mayo Clinic, Rochester, MN

ABSTRACT

PURPOSE: Collaborative Ocular Melanoma Study (COMS) eye plaques (EPs) contain silastic and Modulay materials that introduce 15–30% dose differences compared with all-water dosimetry. A Task Group Report 43 (TG43) dose rate calculation method is presented that includes silastic and Modulay heterogeneous effects, uses the actual plaque seed configuration, is not restricted to a particular commercial treatment planning system, and does not require purchase of additional software.

METHODS AND MATERIALS: Dose rate is calculated using TG43 formalism: $\dot{Dose}_{EP}(r,\theta) = S_K \Lambda \frac{G_L(r,\theta)}{G_L(r_0,\theta_0)} g_{EP}(r) F_{EP}(r,\theta)$, with revised radial dose, $g_{EP}(r)$, and anisotropy, $F_{EP}(r,\theta)$, functions specific to ^{125}I or ^{103}Pd seeds in COMS EPs. The EP signifies that the functions are specific to COMS EPs. The $g_{EP}(r)$ is obtained from Monte Carlo (MC) data for EPs that contain just a single center seed. The $F_{EP}(r,\theta)$ is obtained by performing a Nelder–Mead Simplex routine to find a least squares solution that minimizes differences between MC dose rate and $\dot{Dose}_{EP}(r,\theta)$.

RESULTS: The TG43 formalism calculations agree with MC results, for 10–22-mm ^{125}I and ^{103}Pd EPs, to within 2% along and near the plaque central axis and within 4% in the penumbra region for depths of 1 mm or greater. Methods and data are provided for COMS plaque calculations using seed models other than ^{125}I Model 6711 and ^{103}Pd Model 200. Because actual seed configurations are used in dose rate calculations, this formalism may also be used to estimate dosimetry for nonstandard seed loadings.

CONCLUSION: This manuscript enables the clinical user to perform accurate heterogeneity-corrected dose rate calculations for COMS EPs using TG43 formalism in a spreadsheet or commercial treatment planning system that has a TG43 line source geometry function calculation capabilities.

Keywords: COMS; Eye; Plaque; TG129; Uveal melanoma; Heterogeneous

Introduction

Brachytherapy treatment of ocular malignancies, including but not limited to uveal melanoma, is most commonly performed in North America with Collaborative Ocular Melanoma Study (COMS) eye plaques (EPs) (1). The COMS EPs are available in standard designs and sizes to accommodate a range of tumor dimensions (2). The COMS plaques are constructed using a high atomic number Modulay shell for shielding uninvolved regions of the eye and a silastic seed carrier for precisely positioning and securing seeds relative to each other and the scleral surface. The American Association of Physicists in Medicine (AAPM) Task Group Report 129 (TG129) and the American Brachytherapy Society provide a comprehensive review of COMS EP literature and guidance for clinical use (3, 4).

Heterogeneity-corrected delivered dose rate for ^{125}I and ^{103}Pd COMS plaques is approximately 15–30% lower than calculations that ignore the effects of the Modulay/silastic materials (5–8). The observed dose rate decrease is owing to Modulay and silastics' high density and atomic number relative to water. The dose rate decrease is measurably greater for ^{103}Pd than ^{125}I because the heterogeneous

Received 24 September 2014; received in revised form 28 October 2014; accepted 29 October 2014.

* Corresponding author. Department of Radiation Oncology, Mayo Clinic, Rochester, MN 55905. Tel.: +507-293-4019; fax: +507-284-0079.

E-mail address: deufel.christopher@mayo.edu (C.L. Deufel).

1538-4721/$ - see front matter
http://dx.doi.org/10.1016/j.brachy.2014.10.006

materials have a greater effect on lower energy photons. Dose rate decrease observed near the plaque central axis is primarily owing to attenuation from the silastic seed carrier, with magnitude that depends on the effective path length (6). The dose rate decrease observed outside the eye and near the Modulay collimating lip is caused primarily by obscured line of sight between the reference points and portions of seeds. Obscured line of sight occurs when Modulay material lies between a reference point and a radioactive seed, and thereby blocks transmission of radiation to the reference point. Source obscuring is most significant outside the eye ($R > 12.3$ mm) and also occurs for points inside the eye ($R < 12.3$ mm). For example, in Fig. 2 of TG129, a straight line drawn from the outside edge of an outermost seed through the point where the collimating lip touches outer sclera, extends into the eye, and therefore a portion of that seed is obscured by the collimating lip for some locations inside the eye. The magnitude of dose rate decrease owing to the source obscuring near the plaque lip depends on the relative locations of lip, reference point, and seeds. Overall scatter and interseed effects owing to to Modulay/silastic are relatively minor (6).

Several publications have proposed methods to estimate heterogeneity-corrected delivered dose rate for COMS EPs. The AAPM TG129 encouraged concurrent estimates of heterogeneity-corrected delivered dose rate to prepare for a transition to heterogeneity-corrected prescriptive goals. The report provides a method to calculate heterogeneity-corrected dose rate along central axis for implants using COMS plaques fully loaded with ^{125}I Model 6711 (Oncura, Arlington Heights, IL) or ^{103}Pd Model 200 (Theragenics, Buford, GA) seeds. The TG129 does not provide a mechanism for dose rate calculation off central axis. Furthermore, the TG129 provides no guidance on estimating the heterogeneity corrections for ^{125}I or ^{103}Pd seed models other than 6711 and 200. This is unfortunate for clinics, including ours, which use ^{125}I Model 2301 (Best Medical, Inc., Springfield, VA).

Rivard *et al.* (9) suggested a method for using a plaque loaded with just a single center seed to approximate published Monte Carlo (MC) data of 6711 fully loaded plaques. Each plaque, radionuclide, and model requires its own table, and MC data must be available for all variations. Such MC calculation capabilities are unfortunately not readily available in the typical clinic. The Tufts method uses a single-line geometry function to model particle streaming, and the attenuation/scatter correcting functions exhibit substantial variation over short distances (large first and second derivatives). Dose rate outside the plaque is very well modeled with the Tufts approach, but high-dose-rate gradients demand a very large table of anisotropy function points (i.e., 10,000) that is too large for some treatment planning systems (TPSs; e.g., Varian Brachytherapy Planning Version 11.0, Varian, Inc.,Palo Alto, CA). Tufts dose rate data are azimuthally (Φ, rotation about the plaque central axis) averaged, which obscures hot spots (~2% error at 2-mm depth, ~10% at inner sclera) (9).

Deufel *et al.* (10) proposed a dome geometry function, or dome particle streaming function, henceforth referred to as the Dome method that more accurately describes particle streaming and results in smoothly varying and small correction functions. Similar to the Tufts method, each plaque, radionuclide, and model requires its own table and the dose rate data are intrinsically azimuthally averaged. Unfortunately, geometry functions other than a point and line are not available in most, if not all, commercial TPSs.

Plaque Simulator (Eye Physics LLC, Los Alamitos, CA) software has provided heterogeneous EP dosimetry calculations for many years (11). The Plaque Simulator method requires modifications to the TG43 formula that are currently not available in commercial US Food and Drug Administration (FDA)—approved software. Furthermore, Plaque Simulator is neither FDA approved nor Conformité Européenne (CE) marked as a clinical TPS, currently requires Macintosh operating system, and the AAPM and American Brachytherapy Society do not recommend its clinical use as a primary dose calculation tool until it receives approval by the FDA (3).

This manuscript provides an EP method that the clinical physicist may use for heterogeneous dose rate calculations of COMS plaques with various ^{125}I or ^{103}Pd seed models using a typical FDA-approved TPS that has TG43 line source geometry function calculation capabilities (12). Tabulated data are provided for immediate clinical implementation. The EP method does not calculate heterogeneity-corrected dose rate outside the eye as well as the Tufts, Dome, and Plaque Simulator methods. Dose rate inside the eye, however, may be estimated with comparable accuracy. Moreover, the EP method overcomes three significant limitations of the Tufts, Dome, or Plaque Simulator methods: Dose rate calculations may be performed (*1*) using FDA-approved TPSs, including Varian Brachytherapy TPS; (*2*) for EPs loaded with sources other than ^{125}I Model 6711 and ^{103}Pd Model 200; and (*3*) for seed configurations different than standard COMS.

Methods and materials

Three coordinate systems are used in this manuscript (Fig. 1). First, a Cartesian coordinate system (X, Y, Z) in the plaque frame of reference is favored by MC and commercial TPSs as well as TG129 and COMS [see Fig. 2 of Ref. (3)]. The Cartesian origin is located at the intersection of the plaque central axis with the inner sclera of the eye. Second, a polar coordinate system in the seed frame of reference is used by TG43. The position of a reference point with respect to a radioactive seed is given by coordinates (r, θ), where θ is measured from the long axis of the seed (13). Third, a spherical coordinate system (R, Θ, Φ) is defined in the plaque frame of reference, with origin at the center of the eye (10). The spherical