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Monte Carlo dosimetry of the eye plaque design used at the St. Erik Eye Hospital for ^{125}I brachytherapy

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ABSTRACT

PURPOSE: At St. Erik Eye Hospital in Stockholm, Sweden, ocular tumors of apical height above 6 mm are treated with brachytherapy, using iodine-125 seeds attached to a gold alloy plaque while the treatment planning is performed assuming homogeneous water surroundings. The aim of this work was to investigate the dose-modifying effects of the plaque and the seed fixating silicone rubber glue.

METHODS AND MATERIALS: The impact of the gold plaque and silicone rubber glue was studied with the Monte Carlo N-particle transport code, version 5.

RESULTS: For the 2 cm most proximal to the plaque surface along the plaque's central axis, the eyeball received 104.6–93.0% of the dose in all-water conditions.

CONCLUSIONS: The 0.3 mm thick layer of silicone rubber glue, used for seed fixation, attenuates photons little enough to allow characteristic X-rays from the gold alloy plaque to reach the eyeball. Close to the plaque, the dose rates were higher with the plaque and glue present, than in homogeneous water conditions. This is in contrast to what has been reported for more commonly used eye plaques, demonstrating the importance of investigating the dosimetry of individual treatment systems.

Keywords: Eye plaque; ^{125}I; Dosimetry; Monte Carlo simulations; Brachytherapy; Ocular melanoma

Introduction

Each year about 70–80 persons in Sweden are diagnosed with ocular melanoma. If enucleation of the affected eye can be avoided, the treatment is then brachytherapy, in which a radioactive plaque is attached to the part of sclera adjacent to the underlying ocular tumor. At the St. Erik Eye Hospital (Stockholm, Sweden), tumors with an apical height below 6 mm are treated with the β-ray emission from ruthenium-106. The limited range of β-rays makes them inappropriate for larger tumors because of high proximal sclera doses, where instead discrete iodine-125 (^{125}I) seeds arranged within a collimating metal plaque are used.

The Collaborative Ocular Melanoma Study (COMS) was initiated in 1985 to evaluate the effectiveness of radiotherapy for ocular melanoma. The COMS of patients with melanomas of apical height between 2.5 and 10.0 mm found no significant differences in survival rate between patients receiving ^{125}I brachytherapy and enucleation (1). However, eye-sparing brachytherapy often retains useful visual acuity and can thus lead to a better quality of life for the patient. COMS has established standardized ^{125}I gold plaques in different sizes, which are today in widespread clinical practice and are the most frequently used plaque models for eye brachytherapy (2).

At St. Erik's, custom-made gold plaques are used for ^{125}I eye brachytherapy. To the apex of the tumor, a dose of 80 Gy is prescribed, based on Task Group 43 (TG-43, of the American Association of Physicists in Medicine

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[AAPM]) assumptions. The COMS system uses silastic seed carriers that establish fixed seed positions and a distinct distance to the sclera, whereas seeds are attached manually to the St. Erik plaque using a thin layer of silicone rubber glue.

Dosimetry performed according to the dosimetry protocol published by the AAPM TG-43 (3, 4) is based on the dosimetric characteristics for a single seed, derived in a large homogeneous water volume. Because of the low energy of the photons emitted in the decay of ^{125}I (average, 28 keV), nonwater-equivalent materials in the vicinity of the seeds may considerably affect the dose distribution. An obvious concern in eye plaque therapy is the metal plaque to which the seeds are attached. The dose-modifying effects of backing materials of high atomic number have been investigated in several studies (5–13). For the 20 mm diameter COMS plaque loaded with ^{125}I seeds, the dose reduction is on the order of 13–14% at 10 mm depth from inner sclera, compared with TG-43 conditions (11, 14). Another plaque design, the Nag plaque, has similarities with the St. Erik plaque in that the seeds are manually glued instead of being positioned in a seed carrier (as for COMS plaques) (15, 16). They differ, however, in that the Nag plaque displaces the seeds 2 mm from sclera to avoid high-dose regions and reduce the tumor dose gradient.

To compare treatment outcomes and explain side effects from plaque therapy, accurate dosimetry is essential. The report from AAPM TG-129 (2) states that the resulting dose distributions are highly sensitive to the plaque design and the seed model used. This study was initiated to investigate the impact of the plaque and rubber glue heterogeneity of the St. Erik plaque on the dose distribution. Currently, AAPM TG-221 is reviewing the dosimetry of non-COMS plaques for ocular brachytherapy. The dosimetry of this plaque model has not been studied in detail before.

Methods and materials

Plaque and seeds

The CCB-type St. Erik plaque investigated in this study was modeled with a diameter of 20.0 mm, inner height of 5.0 mm, and thickness of 0.5 mm. The radius of curvature of the concave plaque surface is 11.8 mm. The design of the CCB plaque is shown in Fig. 1. It has been custom made by a goldsmith to replicate a ruthenium-106 plaque of CCB type (Eckert & Ziegler BEBIG GmbH, Berlin, Germany). In addition to the CCB plaque, plaques replicating the CCA, CCC, CIB, COB, and CCZ models have also been manufactured. The plaque consists of an 18-carat gold alloy. Because of lack of data on the elemental composition, alloy data were taken from the work on gold alloys in jewelry by Raub and Ott (17). The adopted alloy consisted of 75.0% gold, 15.5% silver, 9.0% copper, and 0.5% zinc by weight, with

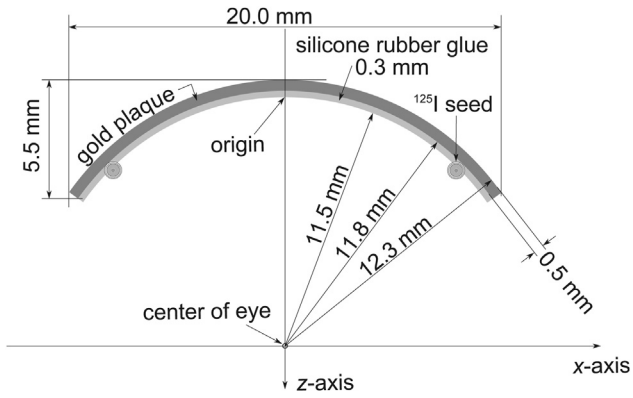

Fig. 1. A cross-sectional drawing of the CCB-type St. Erik plaque, showing the gold backing, silicone rubber layer, and two peripheral iodine-125 seeds. The origin is defined at the external rubber glue surface on the plaque's central axis. The seeds are included to show how they protrude from the glue layer.

a mass density of $\rho = 15.4$ g/cm^3. The seeds are manually attached to the plaque with rubber glue. As seen in Fig. 1, the glue does not fully cover the seeds. The distance between the outer sclera and the proximal protruding seed edge is uncertain. Because of this uncertainty, the origin of the coordinate system was set at the external rubber glue surface on the plaque's central axis (CAX) and not at the inner sclera as in the COMS reference coordinate system (2).

The seeds are arranged in a predetermined pattern specially designed for the CCB plaque (Fig. 2). The endpoint coordinates for each seed is given in Table 1 together with the angle φ, which is the angle between the positive x-axis and the line through the center of a seed and the origin, projected on the x–y plane. The 10 seeds are arranged with seven seeds close to the edge of the

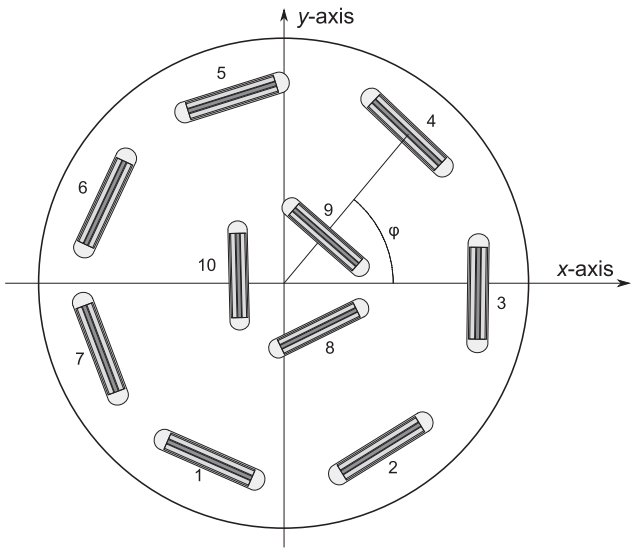

Fig. 2. Drawing of the seed positions in the 20.0 mm diameter CCB-type plaque. The figure also shows the angle φ, which is used in Table 1 along with the coordinates of each seed.