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The Bebig Valencia-type skin applicators: Dosimetric study and implementation of a dosimetric hybrid technique

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ABSTRACT

PURPOSE: To determine the relative dose rate distribution in water for the Bebig 20 mm and 30 mm skin applicators and report results in a form suitable for potential clinical use. Results for both skin applicators are also provided in the form of a hybrid Task Group 43 (TG-43) dosimetry technique. Furthermore, the radiation leakage around both skin applicators from the radiation protection point of view and the impact of the geometrical source position uncertainties are studied and reported.

METHODS AND MATERIALS: Monte Carlo simulations were performed using the MCNP 6.1 general purpose code, which was benchmarked against published dosimetry data for the Bebig Ir2.A85-2 high-dose-rate iridium-192 source, as well as the dosimetry data for the two Elekta skin applicators. Both Bebig skin applicators were modeled, and the dose rate distributions in a water phantom were calculated. The dosimetric quantities derived according to a hybrid TG-43 dosimetry technique are provided with their corresponding uncertainty values. The air kerma rate in air was simulated in the vicinity of each skin applicator to assess the radiation leakage.

RESULTS AND CONCLUSIONS: Results from the Monte Carlo simulations of both skin applicators are presented in the form of figures and relative dose rate tables, and additionally with the aid of the quantities defined in the hybrid TG-43 dosimetry technique and their corresponding uncertainty values. Their output factors, flatness, and penumbra values were found comparable to the Elekta skin applicators. The radiation shielding was evaluated to be adequate. The effect of potential uncertainties in source positioning on dosimetry should be investigated as part of applicator commissioning.

Keywords: Ir-192; Dosimetry; Skin applicators; TG-43; Monte Carlo

Purpose

Skin cancer is a very common malignancy worldwide, and its incidence continues to rise (1). The radionuclide-based brachytherapy with iridium-192 (^{192}Ir) is one of the well-established methods among radiation therapy modalities, which allows a hypofractionated approach with the advantages of fewer fractions and short treatment duration (1). It can be performed with the utilization of skin flabs, interstitially for deeper lesions, and with the aid of skin surface applicators for superficial lesions (1, 2). Eckert & Ziegler Bebig (Berlin, Germany) considers the utilization of the two new applicators in connection with their high-dose-rate (HDR) ^{192}Ir afterloading systems for the treatment of small and shallow lesions of the skin, with planning target volume (PTV) diameters of less than 2 cm for the Bebig Valencia type (BVH)-20, less than 3 cm for the BVH-30, and a depth of 0.3 cm with respect to the margins applied in the clinical practice (1).

This work presents the relative dosimetry data necessary for treatment planning in clinical applications of both skin

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Conflict of interest: Dr. Georgios Anagnostopoulos had an honorary contract with Eckert & Ziegler Bebig to perform this investigation. Michael Andrássy is the senior physicist of Eckert & Ziegler Bebig. Prof. Dr. Dimos Baltas reports no conflict of interest.

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applicators. The data sets were obtained by Monte Carlo (MC) simulations adhering to the methodology described by Granero *et al.* (2) for the two commercially available skin applicators. The applied hybrid Task Group 43 (TG-43) dosimetry technique was proposed by Rivard *et al.* (3). The radiation leakage study for both Bebig skin applicators was performed by additional MC simulations following the methodology described by Granero *et al.* (4). Following the recommendations in the American Association of Physicists in Medicine (AAPM) TG-43U1 report (5) and the joint AAPM and European Society for Radiotherapy and Oncology (ESTRO) High Energy Brachytherapy Source Dosimetry report (6), the dose rate uncertainties were assessed for all tabulated data sets provided in this work. Furthermore, additional MC simulations for specific source offset positions and the inherent applicator manufacturing tolerances were performed to investigate the impact on the uncertainty of the dose intended to deliver.

Methods and materials

Skin applicator and source characteristics

The information regarding source design details was provided by the manufacturer in the form of technical drawings together with the elemental composition and the mass density of the components of the Bebig Ir2.A85-2 HDR ^{192}Ir source (7).

For dosimetry benchmarking of the MC code, the dimensions of the commercially available Elekta skin applicators VH2 and VH3 were estimated by careful investigation of the high-resolution figure 1 in Granero *et al.* (2) and the information provided in that study. We have then verified the dimensions using the analytical method in Jeraj *et al.* (8). Furthermore, we adjusted the height of the conical filters in our MC simulations to reproduce the dose rate values at the depth of 0.3 cm, as these were given for both Elekta applicators in Granero *et al.* (2), within uncertainties regarding the MC results. The rest of the filter dimensions were defined accordingly. The elemental compositions, mass densities, and drawing details of the microSelectron v2 HDR (Elekta, Stockholm, Sweden) ^{192}Ir source used for the Elekta VH2 and VH3 benchmarking dosimetry were taken from the study of Daskalov *et al.* (9).

The new Valencia-type skin applicators, with reference to the technical documents submitted by Eckert & Ziegler Bebig, are cup shaped and made of the tungsten alloy Inermet 170 (90% W, 6% Ni, and 4% Cu; $\rho = 17.0$ g cm^{-3}) to confine the radiation to the intended area. The BVH-20 type has a cup opening with a diameter of 2 cm, covered by a flattening filter (also made of Inermet 170), and the BVH-30 type is the analog with 3 cm diameter as shown in Figs. 1 and 2. The source long axis is positioned parallel with respect to the treatment surface. It reaches the central

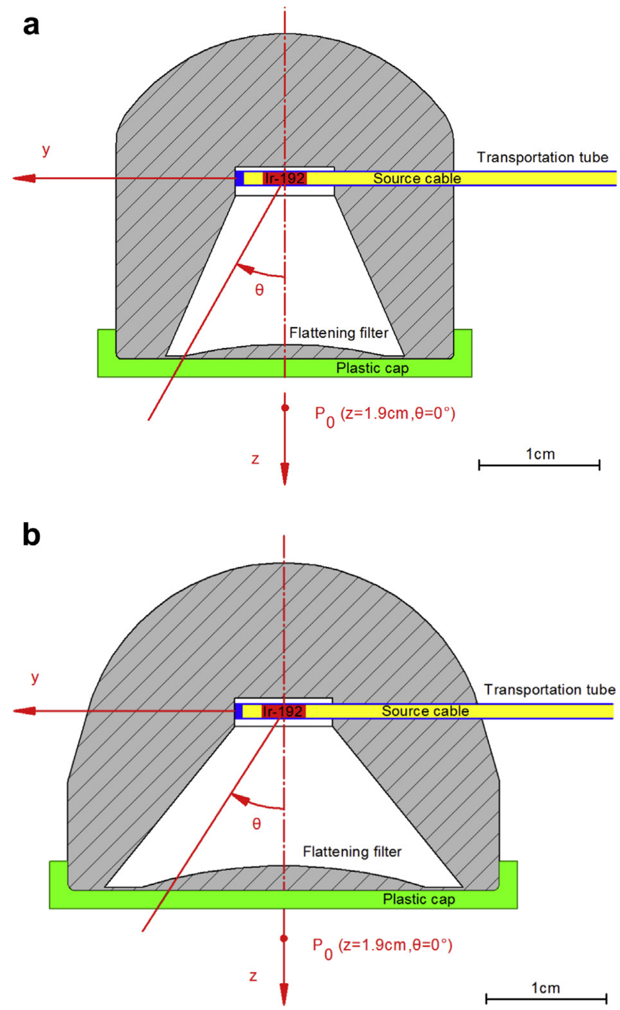

Fig. 1. The geometrical design of the Bebig (a) BVH-20 and (b) BVH-30 skin applicators with their corresponding flattening filters provided by the manufacturer. The coordinate origin depicts the position of the source center inside both skin applicators, and the point P_0 is the reference point in water along the z-axis of symmetry ($y = 0$ cm) in the depth of $d = 0.3$ cm ($z = 1.9$ cm). Ir-192 = iridium-192.

dwell position via a transportation tube made of AISI 304 stainless steel (69% Fe, 18.5% Cr, 9.5% Ni, 2% Mn, and 1% Si; $\rho = 7.9$ g cm^{-3}). Both skin applicators are provided with removable 0.1-cm thick protective plastic caps. In contact with the surface of the skin, the plastic caps provide electronic equilibrium and absorb secondary electrons originating from the applicator (10). These plastic caps are made of polyvinylidene fluoride (59.3% F, 37.5% C, and 3.2% H; $\rho = 1.78$ g cm^{-3}).

Monte Carlo simulations

All MC simulations in this work were performed using the MCNP6 v.1 general purpose MC radiation transport code (11), which is suitable for brachytherapy applications (12−15). The mcplib04 photoatomic cross-section library was used, which is based on the Lawrence Livermore