Design of a Module-Type Radioactive Applicator Using Monte-Carlo Simulation for Skin Cancer

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1. Introduction

Historically, external beam radiation therapy (EBRT) has been an efficient method for the treatment of skin cancers such as basal cell carcinoma and squamous cell carcinoma [1]. However, EBRT involves superficial X-rays or electron therapy. Moreover, EBRT is expensive and less accessible due to the requirement of high-value equipment and facilities. Brachytherapy can be a preferable alternative because of its usability. In addition, brachytherapy may be the best option for detecting shallow and widespread lesions or lesions at anatomic sites (for example, hand and full scalp). When compared with tele-therapy, the dose distribution in brachytherapy is more suitable for tumor coverage and reduction of normal tissue complications [2-3]. However, one challenge in skin brachytherapy is accurately and reproducibly positioning the applicators with good conformity on the irregular shape of a tumor [3]. For safe and effective skin treatment, the applicator should stick to the irregular skin surface without gaps between the applicators, while being stable and providing reproducible results throughout the affected regions [3]. Therefore, this study aims to design and optimize a module-type applicator for skin tumors that is easy to handle and can deliver homogenous doses.

2. Methods and Results

2.1 Design and Evaluation of applicator using MCNP6

Figure 1 shows the schematic of the applicator (cylindrical and hexagonal model). The inner part of the applicator comprises radionuclides, an acrylate plate, and an aluminum plate. The outer part was made of stainless steel. The thickness of the radioactive source was 0.3 mm. The diameter of the cylindrical model was 11 mm, and the length of the diagonal line of the hexagonal model was 11 mm. The stainless steel window film (0.1 mm thickness) below the radioactive source was added to encapsulate the inner part. To block beta rays, the thickness of the acrylate plate was taken to be 2.0 mm; similarly, to block secondary X-rays, the thickness of the aluminum plate was taken to be 2.0 mm. The inner components were encapsulated by stainless steel (height: 8 mm, wall thicknesses: 0.5, 1, 2 mm). A gap effect was evaluated according to the wall thickness of the stainless steel. The characteristics of the radioactive sources used in the present study are listed in Table 1. The dose distribution and uniformity for each applicator design were calculated in a flat water phantom that was placed at a depth of 2.5 mm. The dose uniformity is defined as the ratio of the area bounded by 80% isodose curve to the area bounded by 10% isodose curve. To achieve statistical accuracy (error < 2%) in the dose profile, 10^9 histories of the transported particles were considered.

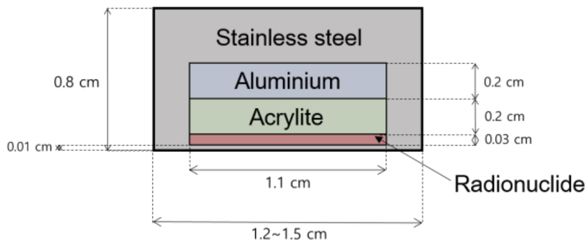

Fig. 1. Schematic (cross-section) of the radioactive module applicator

Table I: Characteristics of the radionuclides

Radionuclide	Emission energy (MeV)	Half-life
^{32}P	1.710	14.29 days
^{48}V	0.696	16 days
$^{90}Sr/^{90}Y$	0.546/2.484	28.2 years /2.67 days

2.2 Results

Figure 2 shows the trans-axial dose profile at a depth of 2.5 mm, for the designed applicators. The minimum percent doses caused by the gaps between the neighboring applicators for the hexagonal model were 96.7% (^{32}P), 85.8% (^{48}V), and 93.9% ($^{90}Sr/^{90}Y$). For the cylindrical model, the minimum percent doses were 69.3% (^{32}P), 57.3% (^{48}V), and 68.1% ($^{90}Sr/^{90}Y$).

Table II: Uniformity of applicators at a depth of 2.5 mm for various geometries, radioactive sources and wall thicknesses

Cylindrical			
Wall thickness	0.5 mm	1 mm	2 mm
^{32}P	0.278	0.230	0.189
^{48}V	0.249	0.220	0.184
$^{90}Sr/^{90}Y$	0.266	0.215	0.178

Hexagonal			
Wall thickness	0.5 mm	1 mm	2 mm
^{32}P	0.511	0.483	0.345
^{48}V	0.466	0.335	0.244
$^{90}Sr/^{90}Y$	0.499	0.447	0.300

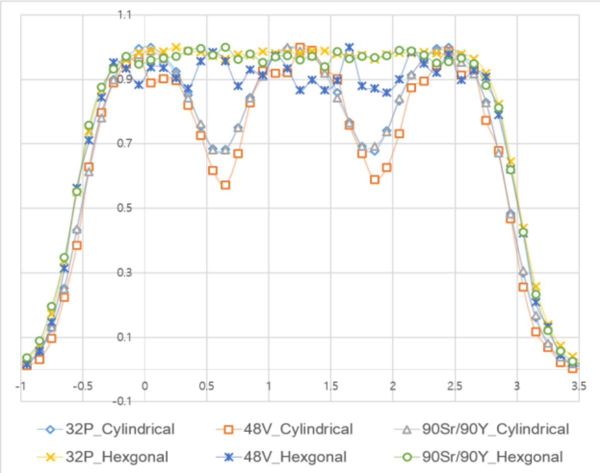

Fig. 2. Trans-axial dose profile of the cylindrical and hexagonal models (0.5 mm wall thickness), for various radioactive sources at a depth of 2.5 mm.

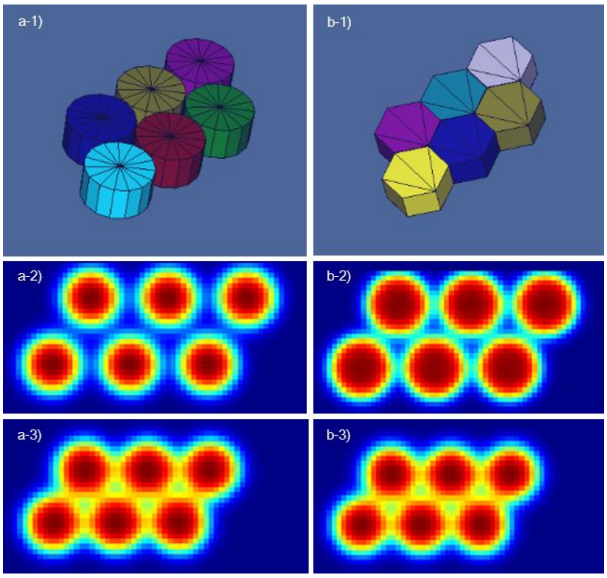

Fig. 3. In MCNP6 simulations, a-1) and b-1) show the 3D shapes of six applicators. a-2) and a-3) show the dose distribution of cylindrical models using ^{32}P, for wall thicknesses of 2 mm and 0.5 mm, respectively. b-2) and b-3) show the dose distribution of hexagonal models using ^{32}P, for wall thicknesses of 2 mm and 0.5 mm, respectively.

Table 2 shows the dose uniformity of the applicators at a depth of 2.5 mm for various radionuclides, applicator models, and wall thicknesses. It was confirmed that the dose uniformity of hexagonal models was better than that of the cylindrical models. In addition, the dose uniformity increased for both models when the wall thickness was decreased. Figure 3 shows the dose distribution of the applicators at a depth of 2.5 mm, for various wall thicknesses and applicator models. It was confirmed that the dose distributions of hexagonal models were more uniform than those of cylindrical ones.

3. Conclusions

In this study, module-type radioactive applicators were designed and evaluated using MCNP6 simulation for patient-specific brachytherapy. For cylindrical and hexagonal models, the dose distribution was calculated in a flat water phantom using various beta emitters. In all cases, the hexagonal models showed a better dose distribution. Furthermore, as the thickness of encapsulation decreased, the dose uniformity increased because of decreased gaps between neighboring applicators. In conclusion, a hexagonal applicator with a wall thickness of 0.5 mm could be a good alternative for brachytherapy of skin cancer.

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