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Surface anatomy leading to personalized surface applicator: 3D printing for brachytherapy of skin tumors

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Abstract: Radiation therapy of skin cancer using beta particles can be an interesting treatment when the lesion is very superficial. Due to their low penetration depth in tissue, beta particles can effectively protect underlying sensitive structures such as bone. 3D printing technology can be used to create applicators, for beta-emitters, that are made based on the individual shape and size of the tumor. The tumor-volume optimized applicator limits and shapes the beta radiation dose to the tumor surface anatomy while protecting healthy tissue nearby. This study illustrates the workflow to fabricate these tumor-specific applicators.

I. Introduction

Beta radiation therapy of skin tumors can be an option to treat very thin lesions, typically not more than 3-4 mm thick, and close to the skin surface [1]. Beta radiation, in contrast to the typically used gamma radiation, demonstrates a rapid dose falloff with a low penetration depth in tissue. Therefore, in the case of thin skin tumors where beta radiation can deliver enough dose in the target volume, sensitive bone and cartilage structures located right beneath the lesion can be well protected [1].

This feature has stimulated the development of therapeutic options based on beta radiation for use in skin cancer therapy [2-5]. The challenge in these methods is confining the radiation dose to the 2D surface anatomy of the tumor to protect healthy tissue around it.

To address this need, we have recently introduced the concept of utilizing brachytherapy for skin tumors using 3D printed applicators. The applicator uses a radioactive gel which consists of a beta emitting isotope (e.g., Y-90) mixed with gelatin. These applicators can be used in flat skin surfaces to shape the radiation beam based on the 2D shape of the tumor. A detailed description of the concept can be found in reference [6].

This study aims to illustrate the workflow of fabricating these personalized surface applicators, with a focus on feasibility and affordability for future use in routine clinical settings.

II. Material and methods

The workflow is presented in Fig. 1. For the current study, we used a smartphone (iPhone 6s, Apple Inc., USA) to take a photograph of the skin tumor surface drawn on the arm of a human phantom. An applicator was designed in CAD (SolidWorks 2018, Dassault Systèmes). Then, a 3D printer (Prusa i3, Prusa Research Czech Republic) was used to create the physical applicator out of Polyethylene terephthalate (PET) material.

The workflow starts with photography of the lesion surface on the skin that is subsequently used to define the tumor's contour and can be scaled up to include treatment margins (Fig 1, step 1+2). This contour is then used in SolidWorks to design an applicator with a customized cavity that provides the space for placing the radioactive gel (Fig 1, step 3+4). A holder is also designed according to the size of the applicator. The digital models are saved as STL files and converted to 3D printable G-code. The model is manufactured on a 3D printer by Fused Deposition Modeling (Fig 1, step 5). The cavity of the applicator is filled with the radioactive gel and hardened in the fridge for 30 minutes (Fig 1, step 6).

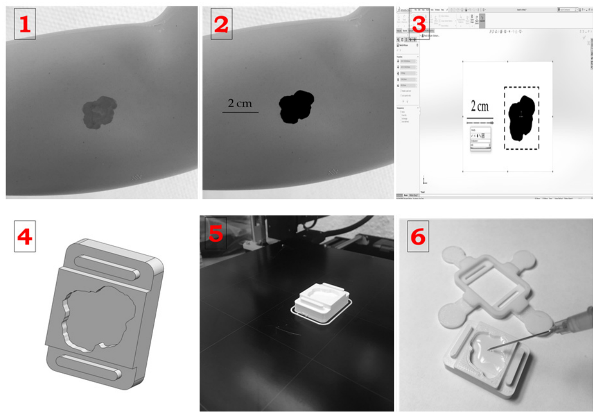

Figure 1: Workflow of creating the surface brachytherapy applicator based on the surface anatomy of a skin tumor

For the treatment, the holder is fixed on the skin surface, and then the applicator is placed to start the tumor irradiation. The treatment time depends on the tumor size, thickness, and also the type and activity of the radioisotope used inside the gelatin.

III. Results and discussion

The workflow for creating surface applicators based upon the information of the skin tumor surface anatomy is straightforward, and we believe that it is fast and can be provided at low cost. To estimate the amount of used filament and the printing time for different skin tumors, we repeated the process for different applicators' sizes. To

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this end, five different-sized applicators including their holders were designed with the cavity sizes ranging from 5×5 mm^2 to 25×25 mm^2. The results are presented in table 1. It took 23 to 65 minutes to print the applicators and holders, with a 90% fill density. The PET used for these models was in the range of 2.90 to 10.72 grams.

Table 1 Printing time and used PET filament for printing surface applicators, with different cavity sizes, and their holders

Cavity size (mm^2)	5×5	10×10	15×15	20×20	25×25
Printing time (min)	23	32	41	52	65
Used filament (g)	2.90	4.45	6.21	8.30	10.72

Total preparation of the customized applicators will take maximum of 2 hours to be ready to apply to the patients. Also, the cost of the used filament to print these applicators was in the range of 8 to 30 cents. Therefore, this workflow can be readily applied in routine clinical settings to create brachytherapy applicators for thin tumors as part of the total skin cancer treatment.

Due to the toxicity of ionizing radiation, the maximum possible dose should be delivered to the tumor volume plus margin with as little as possible exposure to the healthy tissue nearby. In the current external beam radiation therapy treatments, this is done through the use of multi-leaf collimators to shape the radiation beam. However, this issue has not been addressed in brachytherapy of skin tumors, partly due to technical challenges in shaping the radiation beam in the small field of views.

3D printed customized applicators, filled with beta-emitting radioactive gel could provide conformal brachytherapy of skin tumors by shaping the dose profile based on the 2D shape of the tumor. PET or other similar plastic materials used for 3D printing are suitable material for making such applicators. The mean range for beta particles of Y-90, as an example, in PET is around 3.5 mm according to continuous slowing down approximation (CSDA) [7]. CSDA is a good approximation of the mean path length traveled by beta particles. Therefore, when the Y-90 gel is housed inside the applicator made of PET, a significant part of the radiation dose will be absorbed within the 3-4 mm thickness of the applicator' body. This way, the radiation is directed through the opening of the applicator's cavity wherein the radioactive gel is placed. Additionally, when used as shielding for beta particles, low atomic-number of PET prevent consequent bremsstrahlung radiation.

IV. Conclusions

Using 3D printing technology, fabrication of tumor-specific surface applicators in a quick and affordable way is possible, supporting its use in regular clinical settings. As a subject for future work, and to make the whole process user-friendly, a program will need to be developed that generate the G-code of the applicators automatically and directly from the photograph of the skin tumor. 3D volumetric information of the skin tumor obtained by magnetic resonance imaging (MRI) and/or computed tomography (CT) should also be used as additional parameters in cases where intensity modulated brachytherapy of the skin tumor is indicated. This will also require additional work on dose simulation and calculation.

AUTHOR'S STATEMENT

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