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Technical Note

Introduction of novel 3D-printed superficial applicators for high−dose rate skin brachytherapy

Emma-Louise Jones*, Anna Tonino Baldion, Christopher Thomas, Tom Burrows, Nick Byrne, Victoria Newton, Sarah Aldridge

Department of Medical Physics, Guy's and St Thomas' NHS Foundation Trust, St Thomas' Hospital, London, UK

ABSTRACT

PURPOSE: Custom-made surface mold applicators often allow more flexibility when carrying out skin brachytherapy, particularly for small treatment areas with high surface obliquity. They can, however, be difficult to manufacture, particularly if there is a lack of experience in superficial high−dose rate brachytherapy techniques or with limited resources.

METHODS AND MATERIALS: We present a novel method of manufacturing superficial brachytherapy applicators utilizing three-dimensional (3D)−printing techniques. We describe the treatment planning process and the process of applicator manufacture.

RESULTS: The treatment planning process, with the introduction of a pre-plan, allows for an ''ideal'' catheter arrangement within an applicator to be determined, exploiting varying catheter orientations, heights, and curvatures if required. The pre-plan arrangement is then 3D printed to the exact specifications of the pre-plan applicator design. This results in improved target volume coverage and improved sparing of organs at risk.

CONCLUSIONS: Using a pre-plan technique for ideal catheter placement followed by automated 3D-printed applicator manufacture has greatly improved the entire process of superficial high−dose rate brachytherapy treatment. We are able to design and manufacture flexible, well-fitting, superior quality applicators resulting in a more efficient and improved patient pathway and patient experience.

Keywords: 3D-printed; Superficial; Applicators; Skin; High dose rate; HDR; Brachytherapy

Introduction

The radiotherapy department at St Thomas' hospital treats a number of nonmelanoma skin cancers, such as basal cell carcinoma (BCC) and squamous cell carcinoma (SCC), the incidence of which is high and increasing (1). SCC and BCC are predominantly treated through surgical excision, although other treatment options include cryotherapy, topical therapy, and photodynamic therapy. Indications for radiotherapy include superficial lesions where a better cosmetic result could be obtained with radiotherapy, lesions where surgery could cause significant loss of function, or where multiple lesions require treatment and surgery would be onerous for the patient. St Thomas' is a referral center for a skin lymphoma called mycosis fungoides (MF). MF is a rare cutaneous T-cell lymphoma, and most cases are relatively low grade with long survival (2, 3). MF patients are predominantly treated with topical therapy, photochemotherapy, and total skin electron beam therapy (4). However, after a course of total skin electron beam therapy, MF lesions continue to present on the skin surface as the disease progresses and these lesions often require additional superficial kilovoltage x-rays and/or electron beam radiotherapy. MF is very radiosensitive and low doses of radiotherapy can be used, the relatively low dose allows adjacent fields to be treated and recurrences to be retreated safely (5).

High−dose rate (HDR) brachytherapy can be an effective radiotherapy treatment technique for all these conditions as either primary treatment or for treatment of recurrences (6−8).

Many nonmelanoma skin cancers and MF lesions present in difficult to treat locations on the body. Successful utilization of HDR brachytherapy for superficial lesions delivered with purchasable HDR applicators, such as the Freiburg Flap (Elekta, Stockholm, Sweden), and custom-made surface molds have been described extensively in

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* Corresponding author. Department of Medical Physics, Guy's and St Thomas' NHS Foundation Trust, London, UK. Tel.: +44 20 7188 3785; fax: +44 20 7188 2107.

E-mail address: emma.jones@gstt.nhs.uk (E-L. Jones).

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the literature (9−12). Since 2014, HDR brachytherapy has been used at St Thomas' for BCC, SCC, and MF superficial lesions where conformal treatment and/or sparing of organs at risk (OAR) with the other available radiotherapy treatment modalities could not be achieved. This includes lesions in locations with significant surface obliquity (e.g., face) and lesions covering large treatment surface areas (e.g., limb). Although the number of referred cases was initially relatively low, with frequent gaps in between, the number of patients has increased rapidly in recent months as experience and confidence in the technique has grown.

Superficial HDR patients at St Thomas' hospital have predominantly been treated using the Freiburg Flap or custom-made surface molds. Particular success has been achieved at St Thomas' for the treatment of large area lesions on the limb, where brachytherapy has allowed for high surface dose with conformal shaping of dose around a circumference, while sparing tissues at depth. The Freiburg flap is fixed to an Aquaplast thermoplastic shell (Qfix, Avondale, PA), which has been moulded to the patient's anatomy in the mold room (Fig. 1a). However, in our limited experience, small area lesions, particularly those occurring on the face, have proved complicated to treat. Small area lesions, particularly those with irregular surface contour such as the nose, may benefit from multiplane and multidirectional catheter geometries and catheters of varying height above the skin surface, and this is difficult to achieve with the Freiburg Flap. Custom-made surface molds affixed to a patient shell often allow more flexibility in catheter arrangement (Fig. 1b); however, they are difficult to manufacture with sufficient quality when inexperienced in superficial HDR brachytherapy or with limited resources. It is our experience that custom-made surface molds require significant mold room time, experience, and expertise.

The custom-made surface molds are manufactured in the mold room using doric wax (Schottlander, Letchworth Garden City, UK). The wax is built up in layers on the surface of a patient face shell, and catheters, through which the HDR source travels to deliver the brachytherapy, are inserted between the layers, typically 1 cm above the shell surface.

In both the situations described, the brachytherapy applicator was manufactured before the planning CT scan was acquired. In the case of the custom-made surface molds, the patient must also submit to the mold room experience, which in the case of the face shell is not always well tolerated.

Despite there being a long history of effective HDR skin brachytherapy using existing superficial applicators, with excellent patient outcomes, there is potential for improved tumor coverage and sparing of organs at risk through pre-planning HDR skin brachytherapy and manufacturing the required applicator to the exact planning specifications. Pre-planning the "ideal" catheter arrangement is possible and readily achievable with most treatment planning systems (TPS), however, realizing that pre-plan arrangement in the manufacture of the mold is difficult to achieve accurately. Our experience has established that they cannot match pre-planned catheter arrangements precisely. If the catheters do not coincide accurately to the pre-plan catheter arrangement, the ability to shape the isodose distribution tightly around the target volume may be compromised. If air gaps are introduced at the custom-made surface mold manufacture, these will not be accounted for in the TPS, which does not take into account any heterogeneity, which in turn reduces the surface dose.

Purpose

In 2016, in an attempt to overcome some these issues, three-dimensional (3D)−printed superficial brachytherapy

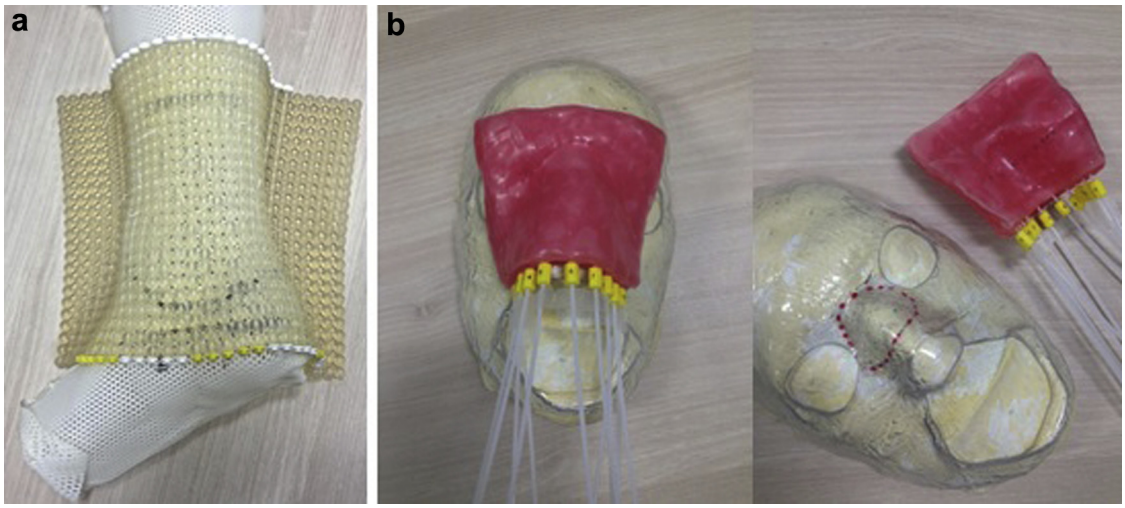

Fig. 1. (a) Freiburg flap brachytherapy applicator for limb lesion; (b) custom-made surface mold for facial lesion.