Cancer/Radiothérapie 20 (2016) 205–209

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Technical Note

Three-dimensional customized bolus for intensity-modulated radiotherapy in a patient with Kimura's disease involving the auricle

Bolus personnalisé en trois dimensions pour radiothérapie avec modulation d'intensité chez un patient atteint de maladie de Kimura envahissant l'oreille

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ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form 3 November 2015
Accepted 10 November 2015

Keywords:
Customized bolus
3D printer
Kimura's disease

ABSTRACT

In radiotherapy, a commercial bolus often does not provide a suitable fit over irregular surfaces. To address this issue, we fabricated a customized bolus using 3D printing technology. The aim of our study was to evaluate the application of this 3D-printed bolus in a clinical setting. The patient was a 45-year-old man with recurrent Kimura's disease involving the auricle, receiving radiotherapy in our oncology department. A customized bolus, 5 mm in thickness, was fabricated based on reconstruction of computed tomography (CT) images. The bolus was printed on a Dimension 1200 series SST 3D printer. Repeat CT-based simulation indicated an acceptable fit of the 3D-printed bolus to the target region, with a maximum air gap of less than 5 mm at the tragus. Most of the surface area of the target region was covered by the 95% isodose line. The plan with the 3D-printed bolus improved target coverage compared to that without a bolus. And the plan with the 3D-printed bolus yielded comparable results to those with the paraffin wax bolus. In conclusion, a customized bolus using a 3D printer was successfully applied to an irregular surface.

Mots clés :
Imprimante 3D
Bolus individualisé
Maladie de Kimura
RCMI

RÉSUMÉ

En radiothérapie, un bolus commercial, souvent, ne fournit pas un ajustement approprié sur des surfaces irrégulières. Pour résoudre ce problème, nous avons fabriqué un bolus personnalisé en utilisant une technologie d'impression tridimensionnelle. L'objectif de notre étude était d'évaluer l'utilisation clinique de cette technologie. Le patient était un homme de 45 ans souffrant de la maladie de Kimura récidivante envahissant l'oreille. Un bolus personnalisé de 5 mm d'épaisseur a été fabriqué en utilisant une tomodensitométrie. Le bolus a été produit sur une imprimante série 1200 Dimension SST 3D. Les scanographies répétées ont montré un ajustement acceptable du bolus imprimé en trois dimensions sur la région cible, avec un intervalle d'air maximal de moins 5 mm au niveau du tragus. La plupart de la surface de la région cible a été couverte par l'isodose 95 %. La planification avec le bolus personnalisé imprimé en trois dimensions a amélioré la couverture cible par rapport à ce qui aurait été sans un bolus. Elle a donné des résultats comparables à ceux obtenus avec un bolus de cire de paraffine. En conclusion, un bolus personnalisée en utilisant une imprimante 3D a été appliqué avec succès à une surface irrégulière.

1. Introduction

Megavoltage photon beams are widely used in modern radiotherapy using a linear accelerator (i.e., LINAC system). The build-up of the megavoltage photon beam improves dose effectiveness for the treatment of deep-seated tumors, while sparing the skin. This

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http://dx.doi.org/10.1016/j.canrad.2015.11.003

skin-sparing effect, which reduces the effective dose delivered to the superficial tissues, however, can jeopardize target coverage in cases of superficial tumors. Therefore, a bolus is commonly used to enhance the surface dose of radiation in these cases.

Currently, the bolus that is commercially available is flat and, consequently, difficult to apply to irregular surfaces, such as the nose, ears, and scalp. The most important problem with a flat bolus is the formation of an air gap between the bolus and the skin, which further decreases the surface dose [1]. The use of a customized bolus has been proposed to enhance the homogeneity of electron radiotherapy dose for irregular surfaces [2]. Three-dimensional (3D) printing technologies can offer significant benefits to individualize the shape of a bolus to optimize the effectiveness of radiotherapy [3]. In our study, we fabricated a 3D-printed bolus for a patient with Kimura's disease involving the auricle, for whom a commercially available bolus could not be appropriately fitted. Our aim was to evaluate the possible application of our customized 3D-printed bolus in a clinical setting.

2. Materials and methods

2.1. Case report

A 45-year-old man with a history of Kimura's disease in the periauricular area since 2006 had undergone resection surgery three times and had received steroid therapy on an outpatient basis from 2006 to 2014. In July 2014, the patient received radiotherapy at the oncology clinic of the Yeungnam university medical center, in Daegu, Korea. The patient received a total dose of 30 Gy in 15 fractions using the 3D conformal technique. After 11 months of radiotherapy, he experienced an itching sensation and swelling in the same target area, and recurrence of the disease was confirmed by follow-up computed tomography (CT, Fig. 1). Re-irradiation using intensity-modulated radiotherapy (IMRT) was planned, using a total dose of 4000 cGy, which was higher than the previously delivered dose. As the tumor involved the periauricular area, including the external auditory canal, parotid bed, and auricle, a commercially available bolus was not suitable to enhance the surface dose of the radiotherapy. Therefore, a bolus was fabricated using paraffin wax for the initial treatment, up to 2000 cGy. After 3D printing technology was developed in our department, the treatment plan was modified to incorporate a 3D bolus with a subsequent 2000 cGy dose prescribed. The clinical target volume (CTV) was defined as the gross tumor volume (GTV) plus a 2 cm margin, with adjustment for anatomical barriers. The planning target volume (PTV) was obtained by a 5 mm expansion of CTV in all directions, except downward into the skin. This case study was approved by the patient verbal consent.

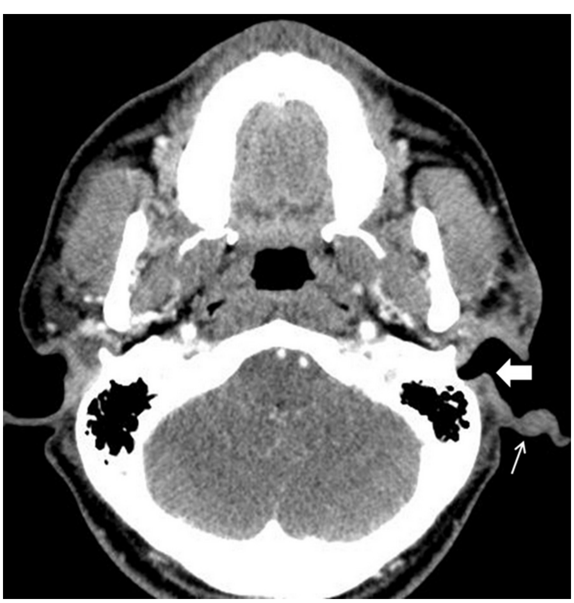

Fig. 1. Computed tomography image showing a tumor involving the auricle (shallow arrow) and extending into the external auditory canal (thick arrow) in a patient with Kimura's disease. In this case, the commercially available bolus may not be suitable to enhance the dose to the ear cavity and auricle given their irregular anatomic structure.

2.2. Three-dimensional printing

The 5 mm thick bolus was designed using Eclipse 8.6 system (Varian Medical Systems Inc., Palo Alto, CA), based on a simulation model of the PTV reconstructed from CT images. According to the treatment plan, the 5-mm bolus was sufficient to cover the PTV. DICOM images of the bolus structure were converted into a stereolithography file for 3D printing. The conversion was performed using 3D Slicer version 4.4 (http://www.slicer.org) with the SlicerRT toolkit [4]. The bolus was printed on a Dimension 1200 series SST printer (Stratasys, Eden Prairie, MN), with a layer thickness of 0.254 mm. ABSplus thermoplastic (Stratasys, Eden Prairie, MN) was used to fabricate the bolus based on its demonstrated effectiveness to enhance the radiotherapy dose in a previous phantom study [5].

2.3. Planning evaluation

A repeat CT simulation was performed with the 3D-printed bolus in place. The adjusted IMRT plan, based on the simulation outcomes for the 3D-printed bolus, was compared to the plan used with the paraffin wax bolus. To provide a control (i.e., no bolus condition) for the comparative analysis, a value of air (i.e., −1000) was assigned to a 3D-printed bolus. The prescription dose was normalized at $D_{50\%}$ (dose received by a 50% volume) as per the ICRU 83 recommendations [6]. The plans were optimized using the Anisotropic Analytical Algorithm, and the following dosimetric parameters were evaluated for each bolus condition: D_{max} (maximum dose), $V_{95\%}$ (volume receiving at least 95% of the prescription dose), $D_{98\%}$, and $D_{2\%}$ (minimum dose).

3. Results

3.1. Customized bolus fabricated using the 3-dimensional printer

The 3D-printed bolus with the patient setup is shown in Fig. 2. Fitting of the 3D-printed bolus, evaluated by CT simulation, shown in Fig. 3, indicated a maximum air gap of less than 5 mm at the tragus. The 3D-printed bolus was easily applied to the patient. However, the patient did report pain over the external ear canal, where the 3D-printed bolus contacted the area, with the problem resolved by smoothing its surface with sandpaper.

3.2. Plan and dosimetric results

Fig. 4 shows the isodose lines for the three IMRT plans: 3D-printed bolus, paraffin wax, and air. With the 3D-printed bolus, most of the surface area was covered by the 95% isodose line. A dose–volume histogram demonstrated improved PTV coverage with the 3D bolus compared to no bolus (Fig. 5). The dosimetric parameters are summarized in Table 1. Compared to the 3D-printed bolus, the plan without the bolus had lower $D_{2\%}$ and $V_{95\%}$ values. The plan with the 3D-printed bolus yielded comparable results to those with the paraffin wax bolus. However, areas of unwanted dose enhancement were identified with use of the paraffin wax bolus, due to the irregular thickness of the wax bolus and its coverage of an area larger than the PTV.