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Bolus-dependent dosimetric effect of positioning errors for tangential scalp radiotherapy with helical tomotherapy

Eric Lobb, M.S.

Department of Radiation Oncology, St. Elizabeth Hospital Cancer Center, Appleton, WI

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ABSTRACT

The dosimetric effect of errors in patient position is studied on-phantom as a function of simulated bolus thickness to assess the need for bolus utilization in scalp radiotherapy with tomotherapy. A treatment plan is generated on a cylindrical phantom, mimicking a radiotherapy technique for the scalp utilizing primarily tangential beamlets. A planning target volume with embedded scalplike clinical target volumes (CTVs) is planned to a uniform dose of 200 cGy. Translational errors in phantom position are introduced in 1-mm increments and dose is recomputed from the original sinogram. For each error the maximum dose, minimum dose, clinical target dose homogeneity index (HI), and dose-volume histogram (DVH) are presented for simulated bolus thicknesses from 0 to 10 mm. Baseline HI values for all bolus thicknesses were in the 5.5 to 7.0 range, increasing to a maximum of 18.0 to 30.5 for the largest positioning errors when 0 to 2 mm of bolus is used. Utilizing 5 mm of bolus resulted in a maximum HI value of 9.5 for the largest positioning errors. Using 0 to 2 mm of bolus resulted in minimum and maximum dose values of 85% to 94% and 118% to 125% of the prescription dose, respectively. When using 5 mm of bolus these values were 98.5% and 109.5%. DVHs showed minimal changes in CTV dose coverage when using 5 mm of bolus, even for the largest positioning errors. CTV dose homogeneity becomes increasingly sensitive to errors in patient position as bolus thickness decreases when treating the scalp with primarily tangential beamlets. Performing a radial expansion of the scalp CTV into 5 mm of bolus material minimizes dosimetric sensitivity to errors in patient position as large as 5 mm and is therefore recommended.

Introduction

TomoTherapy (Accuray Incorporated, Madison, WI) has been shown to be an effective and well-suited platform for radiotherapy of the scalp.[1,2] Compared with conventional techniques, tomotherapy offers the advantage of a simplified patient setup and treatment delivery through the availability of on-board megavoltage computed tomography (MVCT) verification imaging and elimination of the need for complex multimodality beam matching.[3] Various treatment planning techniques have emerged that assist in generating a conformal, homogeneous dose to the scalp target volume while sparing the underlying brain tissue.[4,5]

Previous studies on treatment of the scalp with tomotherapy have demonstrated techniques both with and without the use of bolus.[1,2,4,5] The rationale presented for superficial radiotherapy without bolus is that rotational techniques offer the ability to deliver a therapeutic dose using beamlets tangential to the patient surface as opposed to conventional *en face* techniques that require an adequate perpendicular depth for dose buildup at the air-tissue interface.

Accuracy of the tomotherapy dose-computation algorithm for superficial applications has been previously studied. Ramsey *et al.*[6] found overprediction of superficial doses of 3% to 13% when comparing thermoluminescent dosimeter and film measurements to treatment planning system predictions, and Cheek *et al.*[7] reported similar findings using film techniques. Tournel *et al.*[8] reported agreement between measured and calculated doses within 1.7% to 4.3% using thermoluminescent dosimeter measurements on patients with head and neck cancer with superficial disease extent.

A consequence of relying on tangential beamlets for dose delivery is that dosimetry of the most superficial tissue becomes particularly sensitive to patient positioning errors.[8] Whereas conventional *en face* radiotherapy beams experience minor changes in radiological depth for small errors in patient positioning, tangential beamlets may fail to intercept the patient at all if the positioning error is perpendicular to the beamlet trajectory. Depending on the superficial extent of the disease and the dose level where the

Reprint requests to: Eric Lobb, M.S., Department of Radiation Oncology, St. Elizabeth Hospital Cancer Center, 1506 S. Oneida Street, Appleton, WI 54915.
E-mail: eclobb2@gmail.com

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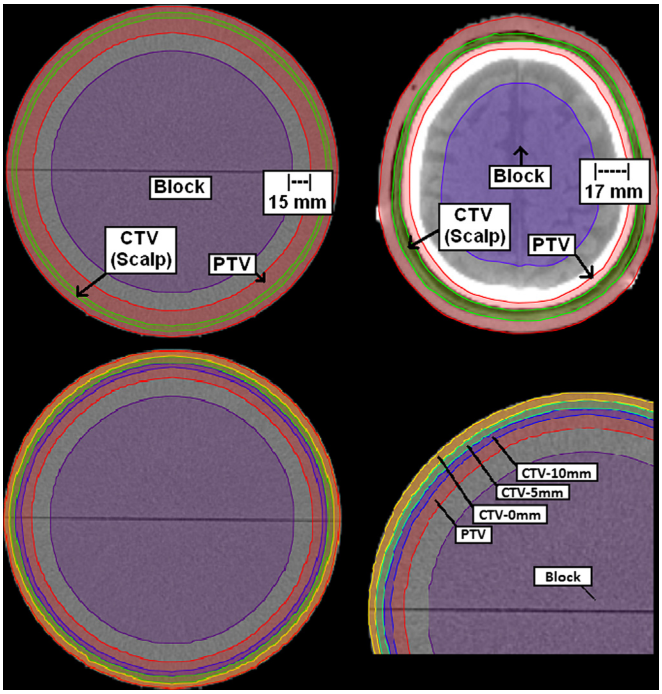

Fig. 1. Axial cross-section of the tomotherapy virtual water phantom (top-left) showing the PTV (red), CTV-5 mm (green), and complete block (purple) compared with a similar clinical example utilizing 7 mm of bolus (top-right); scalplike CTV structures with 0, 5, and 10 mm of separation from the external PTV border (bottom-left) with intermediate structures (1, 3, and 7 mm of separation) not shown, along with an enlarged view (bottom-right). (Color version of figure is available online.)

treatment's therapeutic aim becomes compromised, minor errors in patient positioning could lead to a clinically unacceptable loss of target dose. Additionally, symmetric anatomy such as the scalp will likely be irradiated with tangential beamlets from all sides such that a reduction in dose in one location will be accompanied by a dose increase in another, resulting in a more heterogeneous dose distribution compared with the treatment planning prediction.

Because the scalp typically has a thickness of only 4 to 6 mm and is by nature very superficial, uncertainty in surface dose may have a negative effect on the quality of a course of treatment. One method for mitigating this risk is to position the scalp at a deeper radiological depth through a radial expansion of the scalp clinical target volume (CTV). It is undesirable to perform this expansion into the air surrounding the superficial lesion, so bolus may be used to provide a physical media to expand into. This reduces exposure of the CTV to the uncertainties inherent in the dose-computation algorithm along with those introduced by errors in patient positioning.

The aim of this study was to quantitatively assess the dosimetric effect of positioning errors on superficial scalplike target volumes treated with highly tangential beamlets using the tomotherapy platform. Treatment plan robustness in terms of dosimetric sensitivity to intentionally introduced positioning errors is evaluated as a function of simulated bolus thickness to determine the optimal thickness of bolus, if any, to be used for these cases.

Methods and Materials

A tomotherapy treatment plan designed to mimic a scalp radiotherapy technique using primarily tangential beamlets was created on the tomotherapy virtual water phantom. Translational positioning errors were systematically introduced to assess the resulting dosimetric effect on the scalp CTV as a function of simulated bolus thickness of 0, 1, 2, 3, 5, 7, and 10 mm.

A kilovoltage computed tomography (kVCT) image of the phantom was acquired with a slice thickness of 2.50 mm using a General Electric LightSpeed RT CT simulator. Contouring of the planning target volume (PTV), CTV structures, and blocking structures was performed using an ADAC Pinnacle[3] (Philips Electronics, Amsterdam, The Netherlands) workstation. The PTV ring structure extended axially from the external surface of the phantom to a depth of 25 mm with a longitudinal length of 30 mm (12 CT slices). The blocking structure was created as a cylinder with a uniform inner separation from the target volume of 15 mm and longitudinal length of 55 mm (22 CT slices). Structure shapes and orientation are shown in Fig. 1 alongside a comparable clinical example.

Ring structures of uniform 5-mm axial thickness and 20-mm longitudinal length were created to represent scalp CTVs (Fig. 1). Each CTV was fully embedded within the PTV with varying amounts of radial separation from the external PTV and phantom surface. The separation from the external border simulated the application of bolus material of thickness equal to separation distances of 0 to 10 mm. The structures were named according to the thickness of bolus applied, *i.e.*, CTV-0 mm had no simulated bolus and directly abutted the outer border of the PTV structure and phantom surface, while CTV-10 mm had 10 mm of radial separation from the outer border, simulating the application of 10 mm of bolus material.

All CTV structures had an inner margin applied. Because a single PTV structure was used for planning, the inner margin thickness varied from 1 cm for the CTV-10 mm structure to 2 cm for the CTV-0 mm structure. The difference in absolute radial position of each CTV structure relative to the center of the phantom also resulted in variation in structure volumes. CTV-0 mm had the largest volume at 92.7 cm^3, whereas CTV-10 mm had the smallest volume at 86.4 cm^3. Though it would be ideal for each CTV to have the same position relative to the center of the phantom, it is the CTV-specific change in plan quality relative to the baseline treatment plan that is of interest. The locations and volumes of all structures were kept fixed relative to the phantom between the initial and recomputed dose distributions as positioning errors were introduced, and baseline dose distributions for each CTV structure were all of similar quality.

A contour intended to represent brain tissue was created by applying a uniform 7.5-mm axial margin to the blocking structure, positioning its outer border 7.5 mm from both the inner PTV border and the outer blocking structure border, similar to the clinical example shown in Fig. 1.

The prescription was specified as 200 cGy delivered to 95% of the PTV, with emphasis on achieving a homogenous dose distribution within the PTV such that minimum and maximum doses did not each vary by more than 2% between any 2 CTV structures in the baseline plan (Fig. 2). During fluence optimization, the blocking structure was specified as a complete block, disallowing the use of any beamlets that pass through it and forcing the use of beamlets tangential to the structure's surface. This is similar to the technique of contracting the brain contour by 5 to 10 mm and specifying the resulting structure as a complete block, as shown in the clinical example in Fig. 1.

Fluence optimization and final dose calculation were performed using the fine grid setting (0.254 cm × 0.254 cm) with a jaw width of 2.5 cm, pitch value of 0.287, and modulation factor value of 2.550.

After approval of the baseline treatment plan, a tomotherapy MVCT image of the phantom was acquired with a fine slice thickness of 2 mm and registered to the kVCT image. After alignment to the kVCT images, the entire phantom was scanned a second time so that the zero position of the phantom MVCT data set would be aligned with the planning kVCT image.

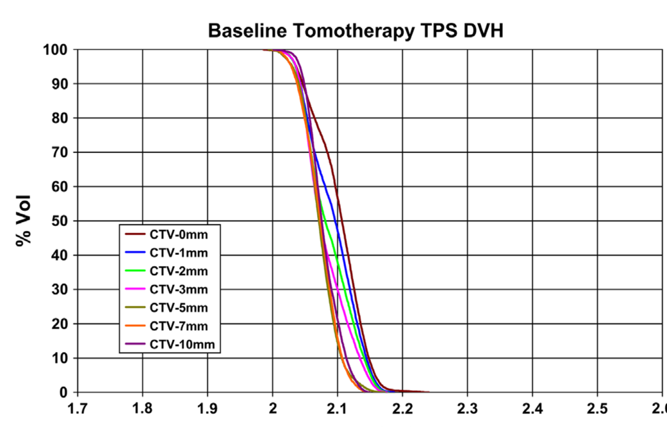

Fig. 2. Baseline dose-volume histogram from the tomotherapy treatment planning system showing each CTV structure. Abscissa scale is 1.7 to 2.6 Gy to emphasize DVH differences. (Color version of figure is available online.)