Radiotherapy and Oncology 84 (2007) 34—39
www.thegreenjournal.com

Tomotherapy

An assessment of the use of skin flashes in helical tomotherapy using phantom and in-vivo dosimetry

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Abstract

***Background and purpose*: In helical tomotherapy the nature of the optimizing and planning systems allows the delivery of dose on the skin using a build-up compensating technique (skin flash). However, positioning errors or changes in the patient's contour can influence the correct dosage in these regions. This work studies the behavior of skin-flash regions using phantom and in-vivo dosimetry.**

***Materials and methods*: The dosimetric accuracy of the tomotherapy planning system in skin-flash regions is checked using film and TLD on phantom. Positioning errors are induced and the effect on the skin dose is investigated. Further a volume decrease is simulated using bolus material and the results are compared.**

***Results*: Results show that the tomotherapy planning system calculates dose on skin regions within 2 SD using TLD measurements. Film measurements show drops of dose of 2.8% and 26% for, respectively, a 5 mm and 10 mm mispositioning of the phantom towards air and a dose increase of 9% for a 5 mm shift towards tissue. These measurements are confirmed by TLD measurements. A simulated volume reduction shows a similar behavior with a 2.6% and 19.4% drop in dose, measured with TLDs.**

***Conclusion*: The tomotherapy system allows adequate planning and delivery of dose using skin flashes. However, exact positioning is crucial to deliver the dose at the exact location.**

Keywords: Tomotherapy; Skin dose; Volume reduction; Dosimetry

Helical tomotherapy (TomoTherapy Hi-Art system, Madison, US) is a treatment modality in radiotherapy in which intensity modulated radiotherapy (IMRT) is delivered in a helical fashion using a rotating 6 MV linac and simultaneously moving couch. Beam modulation is obtained by the use of a 64-leaf binary MLC. The combination of MLC, field width and table speed will give the ability of a high degree of dose distribution shaping [2,4,8,12].

Because of the high conformity and modulation of the dose distributions it is essential to use image guidance to position the patient correctly. This positioning has been integrated into the system by mounting a CT-detector opposite of the beam, allowing the beam to be used in acquiring a mega-voltage CT-scan of the patient prior treatment. By fusion of these acquired MV-images to the kV-planning images a positioning based on volumetric imaging can be performed, resulting in the high precision positioning required by this type of treatment [15].

However, since treatments can have fractionation schedules ranging up to several weeks it is possible that tumor volumes but also patient outer contours will change during this span of time [7,11,14]. Specifically in the case of head and neck tumors the target regions can be located close to or in some cases, including the skin region [4,5]. When the treatment progresses and the tumor reacts to treatment the patient will reduce in size, giving rise to changing dose distributions in the patient resulting from different depths in tissue traversed by the beam. In cases where the tumor is located in the center of the patient volume and at a significant distance from the skin this will result in a higher mean dose to the volume that can be checked using several techniques [3,11,17]. In specific cases where the skin is part of the treatment region a spatial displacement of this region could mean a significant change in skin dose since high dose gradients with the aim of compensating the natural dose build-up effect will exist in this region (the so-called 'skin flash'). It is important to determine the effect of a displacement of the skin contour to this skin flash and to assess in which cases this effect is significant enough to re-plan and re-image the patient.

The extreme caution that has to be taken to this problem originates from the specific design of the tomotherapy

0167-8140/$ - see front matter doi:10.1016/j.radonc.2007.06.003

system and will also ask extra attention in the planning phase of the treatment process. The tomotherapy treatment planning system (TPS) is an inverse-planning system based on a dynamically penalized likelihood optimization and performs dose-calculation based on a collapsed cone convolution algorithm [1,9,10,13]. The conversion between the planning CT Hounsfield Units and corresponding electron densities is performed using a user-defined conversion curve [3]. However, no use is made of a fixed patient skin threshold and dose is calculated in the entire CT-volume in the assumption that a wide enough range is covered by the conversion curve. This implies that dose outside of the skin contour will also be calculated according to the relative electron density (defined in the Image Value Density Table or IVDT) and dose will be visible in this region. The advantage of this approach is that the planning system is capable of depositing high doses on the skin. In conventional treatments using photon beams skin regions will always be liable to dose build-up/build-down effects that occur on tissue/air transitions [6]. Using an intensity modulated rotational treatment however, these transition effects can be compensated by the numerous tangential beams that cover the region.

Due to this compensation of build-up/down effects in planning, target contouring protocols will have to be adapted. When a contoured or generated planning target volume is partially located outside of the patient the system will try to dose this region adequately by compensating through tangential beam directions ('skin flash'). However, since clinical target delineation is often based on experience with surgery or conventional protocols where the skin-sparing effect is present, the transfer of these protocols to tomotherapy could lead to excessive skin reactions when applied without adaptation [5]. It is therefore essential that a good knowledge of the existence of skin flashes exists, even in the planning and contouring phase.

In the clinical cases where the dose prescription is, in fact, located on the skin (skin tumors,...) and the use of skin flashes are opportune several other problems have to be accounted for. The creation of the large gradient on a very specific location will ask very precise positioning of the skin region. Since in most clinical cases (especially head and neck) positioning will occur based on internal structures (spinal cord, bony structures), it has yet to be answered what the effect is on the skin flash when the positioning is not correct and if this could lead to severe under- or overdosage.

When contouring target volumes that are located close to the skin, another problem that can occur is that of patient skin shifting because of size increase or decrease. In head and neck cases with long fractionation schemes, weightloss or the reaction of the tumor to treatment can often decrease the circumference of the neck significantly in orders of magnitude of 1–2 cm. Since dose gradients are placed on the exact location of the target volumes, a shift in target volume would mean an irradiation plan that will agree less and less with the patients' anatomy when the treatment will go on. Other patients can develop oedema or inflammatory reactions causing the neck volume to increase.

In conventional fixed-isocenter treatments using fixed beams, an increase or decrease in volume would mean a decrease or increase in dose delivered by the beam transversing the skin at that point, relative to the change in percent depth dose (PDD) corresponding with the different equivalent depths the beam has to travel through. In helical rotational treatments however, the target volume is not located necessarily in the machine isocenter and it is not that straightforward to devise the correct effect on the dose deposition.

This work aims at investigating the effect of mispositioning of the skin on the dose delivered by means of skin flashes. At first the ability of the system in calculating and modeling skin dose is investigated on phantom by using film and thermoluminescent dosimetry (TLD). The effect of a shift in the skin contour is simulated spatially as well as in volume, and the effect on the skin dose is measured in order to define an action level for treatment re-planning.

Materials and methods

All TLD measurements were preformed using LiF pellets that were calibrated on the tomotherapy Hi-Art unit for doses ranging from 1.8 Gy over 2 to 2.35 Gy against ionization chamber measurements. Since the Hi-Art system does not use a flattening filter and does not allow for a sufficiently large flat field allowing batch calibration a flat field was created using intensity modulation. This field was checked using film and ionization chamber and proved to be homogeneous within 2%. Since the Hi-Art system is equipped with a 6 MV linac a test was performed by calibrating the TLDs on a regular 6 MV linac (BrainLAB NOVALIS), and comparing the calibration factors to those acquired on the Hi-Art unit.

Film measurements were performed using Kodak EDR2 film calibrated for the dose range from 60 to 250 cGy. For film calibration a fast calibration procedure was used and all measurements were checked against ionization chamber measurements (exradin A1SL, Standard Imaging, WI) [17]. Film calibration curves were obtained and used for optical density to dose conversion. All films originated from the same batch.

Before each measurement, the output of the machine was checked to be within 1% of the output defined in the planning model using a rotational calibration routine based on IC measurements (Standard Imaging Exradin A1SL) and detector readings [3].

To assess the ability of the tomotherapy planning system to correctly calculate the dose given to the skin when using a 'skin flash' a target region was delineated on a cylindrical phantom (Gammex RMI Inc., Middletown, USA), traversing the phantom outer contour with 1 mm (Fig. 1) as to include the skin as target. The phantom was transferred to the planning system and planned using a 2.5 cm field width, pitch of 0.3 and modulation factor of 2.0. The plan was optimized as to give a homogeneous dose of 2.0 Gy per fraction to the target region (Fig. 1).

In a first step, the local, spatial effect of the skin flash was investigated by measuring the in-air fluence of the delivered treatment by using an in-air film measurement. Since it is in the aim of this study to show that the use of a skin flash, being a local effect, will have to be investigated