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Comparison of intensity-modulated radiotherapy and volumetric-modulated arc therapy dose measurement for head and neck cancer using optical stimulated luminescence dosimeter

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ABSTRACT

The in-vivo dose distributions of intensity-modulated radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT), a newly developed technique, for head and neck cancer have been investigated for several years. The present study used a head-and-neck RANDO phantom to simulate the clinical conditions of nasopharyngeal carcinoma and compare the radiation doses between VMAT and IMRT. Three types of planning target volume (PTV) profiles were targeted by reducing the PTV surface margin by 0, 3, and 5 mm. An optically stimulated luminescence dosimeter was used to measure the surface doses. The results revealed that VMAT provided on average 16.8–13.8% lower surface doses within the PTV target areas than IMRT. When the PTV margin was reduced by 0 mm, the surface doses for IMRT reached their maximum value, accounting for 75.1% of its prescribed dose (Dp); however, the Dp value of VMAT was only 61.1%. When the PTV margin was reduced by 3 or 5 mm, the surface doses decreased considerably. The observed surface doses were insufficient when the tumours invaded the body surface; however, VMAT exerted larger skin-sparing effects than IMRT when the tumours away from the skin. These results suggest that the skin doses for these two techniques are insufficient for surface tumours. Notably, VMAT can provide lower skin doses for deep tumours.

1. Introduction

Compared with intensity-modulated radiotherapy (IMRT), volumetric-modulated arc therapy (VMAT), also called RapidArc, is a newly developed treatment technique. Several studies have reported that for carcinomas such as head and neck, prostate, lung, intracranial, and endometrial cancers, VMAT has several advantages over IMRT, including short treatment time (Johnston et al., 2011; Oliver et al., 2009; Teoh et al., 2011) , uniform target dose distribution, enhanced dose-sparing effects on organs at risk (OARs), and efficient use of monitor units (MUs); thus, the MUs of VMAT are substantially lower than those of IMRT (Rao et al., 2010), thereby rendering VMAT a rapid, safe, and accurate treatment technique (Verbakel et al., 2009).

Several studies have reported the use of IMRT for treating head and neck cancers, particularly nasopharyngeal carcinoma (NPC) (Kam et al., 2004; Lee et al., 2002; Tham et al., 2009). After VMAT was approved by the US Food and Drug Administration in 2008, recent studies have compared the plan quality, delivery efficiency, and accuracy of VMAT delivery and existing therapy techniques such as three-dimensional conformal radiotherapy, IMRT, and tomotherapy (Palma et al., 2008; Rao et al., 2010; Vanetti et al., 2009; Verbakel et al., 2009). Numerous studies have evaluated the skin doses for IMRT for treating carcinomas (Fischbach et al., 2013; Rudat et al., 2014). However, the surface doses for VMAT for treating patients with head and neck carcinoma are yet to be evaluated. Furthermore, whether the skin doses can reach or exceed the prescribed dose (Dp) and cause skin damages when the tumour is close the skin remains a major concern.

To prevent neck lymph node metastasis in patients with NPC, the radiotherapy range usually includes the primary tumour and lymph node of the neck. Nevertheless, because the neck lymph node is the treatment location closest to the skin and severe skin reactions easily occur in this gland when patients with NPC receive radiation therapy. Moreover, the skin surface has substantial changes in dose due to the lack of charged particle equilibrium. These uncertainties regarding

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dose calculation results are the critical clinical concerns. To avoid the uncertainties regarding surface area calculation in treatment planning systems (TPS), therapy TPS often reduces the planning target volume (PTV) margin, which can effectively reduce the surface doses but may affect the radiation doses in the shallow lymph glands.

Optically stimulated luminescence dosimeters (OSLDs) are widely used as personal dosimetry badges and for in vivo skin dose measurements in radiotherapy. Compared with a thermoluminescent dosimeter (TLD), the OSLD possesses the advantage of repeated readouts following a single radiation exposure. The present study used a RANDO phantom to simulate a patient's clinical conditions of NPC and measured the skin surface doses and target doses using an OSLD. Because of the size limitation of OSLD, the conventional OSLD (even a nanoDot OSLD) cannot be placed in the RANDO phantom for absorbed dose determination, thus restricting its use. Therefore, the OSLD material was cut into smaller disks and dose determination tests are performed using a Microstar reader. We adopted two different treatment techniques (IMRT and VMAT) and reduced the PTV margins by 0, 3, and 5 mm. This simulation was conducted to elucidate the most favourable therapy for obtaining adequate PTV coverage and lower skin doses after neck lymph node irradiation.

2. Materials and methods

A head-and-neck anthropomorphic RANDO phantom was used to simulate the clinical conditions of patients with NPC, followed by the execution of VMAT and IMRT. Similar to the practical radiotherapy, the treatment planning was carried out by an experienced radiation therapist and a medical physicist. The study targeted three types of PTV profile by reducing the PTV margins by 0 mm (i.e. without margin reductions), 3 mm, and 5 mm for measuring the effectiveness of treatment planning and surface doses. These data may provide a reference for skin dose determination in patients with head and neck carcinoma and may facilitate highly accurate clinical judgements in clinical practice.

2.1. Standard source

First, the dose output of a 6-MV linear accelerator was calibrated to ensure dose accuracy throughout the study. We used 6-MV photon beams of Varian 21EX and Elekta Synergy linear accelerators as the standard source. The applied calibration conditions are outlined as follows: source-to-axis distance (SAD) was 100 cm; the field size was 10×10 cm^2; the solid water phantom was placed under the gantry head; and a 0.6-cm^3 Farmer-type ion chamber (A19; Standard Imaging, USA) connected with a PTW electrometer (MAX4000, Standard Imaging, USA) were placed at the isocenter. The output dose (1 MU=1 cGy) was calibrated under these conditions with temperature and pressure corrections. The tolerance, flatness, and symmetry of the dose output were within 2%, 3%, and 2% (for depth=10 cm; field size=80%), respectively. The Farmer-type ion chamber together with PTW electrometer was used to measure the charge, which was further converted into dose.

2.2. Thermoluminescent dosimeter

We used a round sheet TLD-100H (LiF:Mg, Cu, P materials; size=4.5 mm×0.8 mm; density=2.64 g/cm^3; weight=28 mg). The effective atomic number was tissue equivalent (Z_{eff}=8.2). The OSLD dose results were validated using the TLD. No fading phenomenon was observed at room temperature, and the linear dose range was 1 μGy to 10 Gy. The TLD was used for dose measurement because of its high repeatability and accuracy, reusability, and small size.

To ensure the dose accuracy, the dose output was calibrated before dose measurement. The calibration procedures were performed to ensure dose accuracy and dose sensitivity. The ionisation chamber was used to measure the dose output before TLD measurement, to verify the stability of the linear accelerators. Moreover, these TLDs must undergo annealing procedures to remove background signals. We constructed a dose-response curve for 50 pieces of TLD-100H and performed a blind test. The scatter dose from the background signals was ignored.

2.3. Optically stimulated luminescence dosimeter

The original OSLD is in the form of a long strip (Al_2O_3:C; Nagase Landauer Company, Japan). For inserting the OSLD into the hole in the RANDO phantom, we cut the strip OSLD into multiple smaller disks with identical size (diameter=4 mm; thickness=0.3 mm). No weight normalization was performed for each OSLD since we assume each OSLD is identical in weight. The effective atomic number (Z=11.2) of OSLD is not tissue-equivalent, no correction was made considering the Z number in this study. Because the Compton scattering dominates at our irradiated energy level (6-MV photon beams), we consider the sensitivity of energy response to the Z number is small (Mobit et al., 2006; Reft, 2009). It's worth noting that the dose response and sensitivity of each OSLD varied because of the slight differences in the amount of impurities in each OSLD. Therefore, a repeatability test was performed for all OSLDs before dose measurement to eliminate the unsuitable dosimeters with larger errors.

Total 200 OSLDs were examined for the repeatability test. Before the procedure of selections, the OSLDs were irradiated with a visible light of high intensity for 24 h to remove background signals. To prevent the fading phenomenon, the readout process was completed within 3 days after OSLD exposure to radiation. Such exposure and readout procedures were repeated four times to obtain the average values, standard deviations, and coefficient of variation (CV). Note that annealing process was performed for each OSLD after irradiation to ensure perfect sensitivity, although OSLDs can provide accumulated dose measurements.

2.4. Dosimeter distribution of RANDO phantom

The RANDO phantom was used in the present study for surface dose and internal dose measurements and for comparing the dose distributions of different radiotherapy techniques. The derived dose distribution can be divided into two parts: surface distribution (for the skin surface of the neck lymph node) and internal distribution. Moreover, to understand the contribution of scatter doses, dose measurement for critical organs, such as the lens, is essential. Furthermore, we explored whether the reduction of the PTV margins results in tumour underdose.

A total of 36 OSLDs were placed on the bilateral neck position within PTV range and the lens, upper cheek, lower cheek, upper neck, middle neck, and lower neck. The dose readouts of right and left sides were averaged. To measure the tumour dose, we placed the OSLDs on the internal central neck and bilateral target position. The distances between the measurement point and the right and left surfaces were 3.1 and 2.75 cm, respectively.

2.5. Treatment planning design

The RANDO phantom was scanned by a Computed tomography (CT) scanner and the CT images were then fed into the treatment planning system. Two treatment techniques with three different PTV margins were developed to generate six treatment plans in this study.

For IMRT, a 6-MV photon beam produced by the Varian linear accelerator together with 60 pairs of multileaf collimator (MLC) leaves was used. Step-and-shoot IMRT plans were generated using the Pinnacle^3 treatment planning system version 8.0 (Philips Medical, Madison, WI, USA). An isodose curve was constructed for the PTV margins that were used in the treatment planning to simulate NPC;