Physics and Imaging in Radiation Oncology 4 (2017) 22–25

Contents lists available at ScienceDirect

Physics and Imaging in Radiation Oncology

journal homepage: www.elsevier.com/locate/phro

Short Communication

Volumetric modulated arc therapy based total body irradiation: Workflow and clinical experience with an indexed rotational immobilization system

Luo Ouyang[a,b], Michael Folkerts[a], You Zhang[a], Brian Hrycushko[a], Richard Lamphier[a], Pam Lee[a], Eric Chambers[a], Ezequiel Ramirez[a], Robert Reynolds[a], Yulong Yan[a], Steve B. Jiang[a], Robert Timmerman[a], Neil Desai[a], Ramzi Abdulrahman[a,c], Xuejun Gu[a,*]

[a] Department of Radiation Oncology, The University of Texas Southwestern Medical Center, Dallas, TX 75390, USA
[b] Department of Radiation Oncology, Torrance Memorial Medical Center, Torrance, CA 90505, USA
[c] Department of Radiation Oncology, Texas Tech University Health Science Center, Lubbock, TX 79415, USA

ARTICLE INFO

Keywords:
Total body irradiation
Volumetric modulated arc therapy
Immobilization system

ABSTRACT

An indexed rotational immobilization system was developed for supine total body irradiation (TBI). Treatment plans had multi-isocentric volumetric modulated arc therapy (VMAT) beams to the upper body and parallel-opposed fields to the lower body, with a 12 Gy prescription dose to > 90% of the body and mean lung dose ~8 Gy. In the end-to-end test, point dose measurements had < 10% error. Compared to conventional TBI, the VMAT-based TBI technique increased the mean dose to the body by ~1.0–1.5 Gy and decreased the mean dose to the lung by ~1.0–1.5 Gy. Overall treatment time was ~1.5 h, similar to conventional TBI.

1. Introduction

Total body irradiation (TBI) is a conditioning regimen in conjunction with chemotherapy in patients undergoing bone marrow transplantation for leukemia and lymphoma [1–3]. To effectively eradicate residual tumors and suppress the immune system in the whole body, TBI requires: 1) a uniform dose across the body (variation within ± 10%); 2) a reduced dose to the lungs; 3) a low dose rate of ~5–15 cGy/min [4].

Conventional TBI (cTBI) techniques adopt large treatment fields with lung blocks to irradiate the patient's entire body in a standing or lying-on-the-side position at an extended source-to-skin distance, e.g. 5 m, which requires costly, large-sized linear accelerator (LINAC) vaults [4,5]. Moreover, both positions are exhausting for immunocompromised patients undergoing chemotherapy. The overall treatment time is often extended because of compliance issues. Floor cTBI techniques [6–10] have been developed, though the prone position could be challenging for adult patients and even dangerous for sedated pediatric patients. Recently developed Tomotherapy [11] and volumetric modulated therapy (VMAT) [12] techniques allow TBI treatment to be administered in a supine position, however, patients have to be positioned twice in one treatment because of couch limitations. In this study, we report an indexed rotational immobilization system (IRIS)-assisted VMAT-TBI treatment technique (IRIS-VMAT-TBI), which allows delivering multi-isocenter plans without re-positioning patients.

2. Material and methods

2.1. Indexed rotatable immobilization system (IRIS)

The IRIS was designed to overcome couch length limits to treat patients without repositioning. The system comprised a rotational platform, a patient-immobilizing body frame, and a beam-spoiler attachment (sees Fig. S1 in the Supplementary Material). The rotational platform includes 1) a base plate locked to the CT and LINAC couches using an Exact Lock Bar®; 2) a top plate that supported and secured the immobilizing body frame; 3) a rotating disc that enables the top plate to rotate around a pivot point. Two pegs are used to securely lock both plates at each end to prevent unnecessary inter-plate motion after alignment. The removable beam spoiler is attached to the foot end of the rotational platform to enhance the skin dose to the lower body. The IRIS was constructed with central line shift < 2 mm after a 180° rotation.

2.2. IRIS-VMAT-TBI treatment workflow

During simulation, the IRIS was aligned and anchored to the CT

* Corresponding author.
E-mail address: xuejun.gu@utsouthwestern.edu (X. Gu).

https://doi.org/10.1016/j.phro.2017.11.002
Received 27 May 2017; Received in revised form 19 November 2017; Accepted 19 November 2017

couch. The patient was immobilized in a supine position in a Vac-Lok bag with arms along the body. A setup reference point was marked with three radiopaque ball bearings (BBs) on patient's chest level serving as the origin of the patient's setup coordinate system. The patient was first scanned from the head to the upper thighs in the head-first-supine (HFS) position, followed by a 180° rotation, and then scanned from the feet to the upper thighs in the feet-first-supine (FFS) position. Two CT scans were concatenated using the DICOMan^{TX} [13] software package to form a whole body CT dataset and transferred to the Pinnacle treatment planning system (TPS) (Philips Medical Systems, USA).

IRIS-VMAT-TBI plans were generated in Pinnacle including three VMAT sections (head-and-neck, chest, and pelvis) and two to three AP-PA sections (upper, middle, and lower legs). Between neighboring VMAT sections, we used a 5-cm field overlap at iso-center plane to account for the beam divergence. The collimator angle for VMAT arcs is set at 0°. For AP/PA beams, the collimator angle was set to 90° to insert "field-in-field" MLC sequences to remove hotspots at the junction area. Such a plan beam configuration can be applied to patients with heights up to 3 m. A patient in 2.2 m height was treated using the beam configuration as described. For patients with larger separation (> 40 cm), two lateral isocenters are used in chest and pelvic regions. IRIS-VMAT-TBI plans were generated using the Pinnacle collapsed cone convolution algorithm with heterogeneity correction.

A treatment dry-run was performed without patient before the first fraction to verify collision clearance and prepare isocenter shifts spreadsheet for treatment. Patient-specific IMRT quality assurance (QA) was also performed on solid water slabs with an ion-chamber and a film for each section, with passing criteria as < 5% point dose error and a ≥90% gamma passing rate using 5 mm/3% gamma criteria. So far, all treated patient plans have met these criteria.

During treatment, the patient was immobilized and aligned with lasers and field crosshair. Cone beam CT images were acquired near chest for alignment. After alignment, arc beams are delivered sequentially with planned couch shifts. After VMAT treatment, IRIS is rotated 180° around the pivotal point to treat the lower body.

2.3. End-to-end test

An end-to-end test was performed to assess the overall workflow and dosimetric accuracy on a total body phantom, comprising a Rando phantom and solid water slabs. Optically simulated luminescent dosimeters (OSLDs) were placed on multiple surface spots to measure the skin dose. An EBT3 film was placed between the solid water slabs to evaluate the planar dose distribution on IRIS rotational junction.

2.4. Treatment plan dosimetric evaluation

We compared dose distributions and dose volume histogram parameters (DVH) between the IRIS-VMAT-TBI technique and a conventional standing TBI technique for dosimetric evaluation. Retrospectively, standing cTBI plans were generated using the patients' CT images where the beam isocenter was placed on the mid-plane at the umbilicus level, 550 cm away from the LINAC source. Lead compensators of different thicknesses were simulated to compensate for body thickness variations. Cerrobend lung blocks with a transmission factor of 62.5% were simulated based on lung contours from the patients' CT images. The plan dose was calculated with an in-house Monte Carlo (MC) dose engine [14]. Dosimetric parameters such as D_{99} and D_1 (minimal dose received by 99% and 1% of PTV-lung/PTV-body volume), and the mean dose for both PTV-lung and PTV-body were compared. Here, PTV-lung was defined as a patient's lung volume contracting by 10 mm from the chest wall, and the PTV-body was the total body volume contracting by 3 mm from the exterior skin and excluding the lung.

2.5. Treatment delivery robustness and efficiency evaluation

To evaluate the variation in the delivered dose, we decomposed the setup uncertainties into two parts: 1) global setup uncertainties at initial patient positioning; 2) regional setup uncertainties between two abutting fields after couch shift. Setup uncertainties were simulated in TPS by shifting isocenters. Global setup uncertainties were simulated in three translational directions by 5 or 10 mm, while regional setup uncertainties were in a lateral direction by shifting chest isocenters 5 mm and in a longitudinal direction by shifting upper leg isocenters 5–10 mm. These relative shifts were intentionally selected to evaluate the dosimetric errors for fields with high modulation in the lung region and the IRIS rotation in the pelvic and upper leg regions.

Patient setup and plan delivery times were recorded for all eight patients treated with IRIS-VMAT-TBI. The setup time included the initial setup and the couch-shift time. The plan delivery time is "beam-on" time only. Treatment times of eight randomly selected cTBI standing patients were collected for comparison.

3. Results

The OSLD measurements in the total body phantom showed that the dose in regions of the head-and-neck (2.03 Gy), chest (1.90 Gy), pelvis (2.12 Gy), and upper legs (2.19 Gy) deviated from the fractional prescription 2.00 Gy dose by 1.4%, −5.2%, 6.1%, and 9.3%, respectively. Analysis of the "pelvis-upper leg-junction" film showed dose deviation within ± 15% of the prescription.

Eight patients were treated with IRIS-VMAT-TBI. The sample patient dose distribution is illustrated in Fig. 1. The sagittal and axial views at the chest level showed that IRIS-VMAT-TBI preserved the prescription dose to the chest wall, while cTBI exhibited a much lower chest wall dose due to beam attenuation of the lung blocks. DVH curves indicated that IRIS-VMAT-TBI body dose was higher than that of cTBI (Fig. 1c).

For all eight patients, the use of IRIS-VMAT-TBI increased the PTV-body dose in D_{99} (10.6 ± 0.5 Gy vs. 8.6 ± 0.3 Gy, $p < .001$), D_1 (15.7 ± 0.9 Gy vs. 13.6 ± 0.3 Gy, $p < .001$), and mean dose (12.8 ± 0.6 Gy vs. 11.5 ± 0.2 Gy $p < .001$). IRIS-VMAT-TBI showed a decreased PTV-lung dose with respect to D_{99} (6.4 ± 0.5 Gy vs. 8.0 ± 1.4 Gy, $p = .005$), D_1 (10.5 ± 1.0 Gy vs. 11.0 ± 0.3 Gy, $p = .05$), and mean dose (7.9 ± 0.5 Gy vs. 8.8 ± 0.2 Gy, $p < .001$).

Absolute percentage dose differences in the dosimetric parameters of eight patients with global isocenter shifts were listed in Table S1 in the Supplementary Material. Most dosimetric parameters, D_1, D_{99}, and mean dose of the PTVs demonstrated changes less than 15%, indicating their insensitivity to the global setup uncertainties. D_1 of the PTV-lung was found to be the most sensitive dosimetric parameter with an increase from ≤15% to 35%. These large changes might be caused by the sharp dose fall-off along the PTV_lung boundary.

The absolute percentage dose difference caused by the lateral regional shift between the two chest isocenters was minor. With a 5 mm lateral shift uncertainty, the percent dose changes for all eight patient plans were < 5%. The superior shift of upper leg isocenter introduced hot spots in the junction region, while the inferior shifts led to cold spots. A 5 mm shift uncertainty introduced a dose difference of < 10%, while a 10 mm shift caused dose differences of < 25%.

The treatment time for the eight IRIS-VMAT-TBI patients and the eight randomly selected cTBI patients were reported in Table S2 in the Supplementary Material. The average IRIS-VMAT-TBI beam-on time was 25.3 ± 3.7 min and the setup time was 54.3 ± 17.8 min. The average cTBI beam-on time was 21.9 ± 0.9 min and the setup time was 60.4 ± 17.2 min. Because of its multi-isocentric nature, IRIS-VMAT-TBI exhibited a longer beam-on time than cTBI. However, the simplified IRIS-VMAT-TBI setup time was shorter than that of cTBI because of the elimination of the lung block/compensator setup and the AP/PA duo patient positioning. Overall, the total machine time for IRIS-VMAT-TBI (79.5 ± 17.7 min) was comparable to that of cTBI (82.2 ± 17.6 min).