THE EFFICIENCY OF TOMOTHERAPY HD SYSTEM ON THE TREATMENT OF DIFFERENT CANCER LOCALIZATIONS

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Abstract: *Helical tomography is an intensively modulated radiation therapy that has a geometry similar to that of a computed tomography. The aim of this study is to demonstrate the feasibility of the Tomotherapy HD system for the treatment of various cancer localizations: breast, rhinopharynx and prostate. There are retrospectively selected the complex cases involving positively lymph-nodes according to the histopathological results. Advantages of tomotherapy include better conformity of treatment with low doses for the organs at risk (OARs) and fewer adverse reactions comparing with 3D conformal radiotherapy (3DCRT).*

INTRODUCTION

Helical tomotherapy (HT) is an intensity modulated radiation therapy (IMRT) delivery technique that was developed at the University of Wisconsin-Madison. This system combines IMRT treatment delivery and megavoltage computed tomography (MVCT) imaging capabilities. First unit was introduced in clinical use in 2003.(1) The tomotherapy system has a geometry that resembles that of a helical computed tomography (CT) scanner. The beam is generated by a 6 MV linear accelerator that continuously rotates around the patient while the couch is moving into the gantry.(2) This movement can be parameterized by a quantity known as pitch, as in spiral CT. However, in helical tomotherapy the value of the pitch is less than unity.

The source to axis distance (SAD) is 85 cm instead of the usual 100 cm for other systems. The gantry has an access bore with a diameter of 85 cm. Two independent jaws, integrated with the primary collimation, form the fan beam, both manufactured from an alloy containing 95% tungsten.(3,4) The maximum transverse dimension of the radiation field is of 40 cm (x axis). On the y axis three openings are commissioned: 5, 2.5 and 1 cm.

The beam is collimated by a multileaf collimator (MLC) consisting of 64 leaves, the projection of one leaf at the isocenter being of 6.25 mm.(2) The integrated MVCT imaging system consists of a conventional xenon ion chamber CT detector that is mounted on the gantry opposite to the beam-line. The imaging beam is produced at a lower quality/energy (3.5 MV) than the treatment beam. Measurements with ion chambers and gafchromic films estimated that the delivered dose of the MVCT is between 1 cGy and 4 cGy.(5)

PURPOSE

The purpose of this study is to prove our experience of using helical and direct Tomotherapy planning system to treat the cancer in three different localizations. Our system also has the option of direct IMRT treatment as an alternative to the helical tomotherapy planning. This static option is very useful for the treatment of different localizations like breast, in order to avoid high mean doses for the contralateral lung and breast, reducing the risk of a secondary malignancy.

MATERIALS AND METHODS

Tomotherapy HD (Accuray) system has been used in our radiotherapy department since august 2014, as a new tool for cancer treatment. Three patients with different locations were selected to demonstrate the effectiveness of the Tomotherapy HD system from our cancer treatment department. All the patients were scanned by using a large bore CT scanner (GE Optima) that has the same opening bore with that of the accelerator. Before the CT procedure, the patient with pelvis localization (prostate) was asked to fill his bladder by drinking 0.5 l of water. All patients were scanned in a supine position using different immobilization supports (Orfit). For the patient with head and neck cancer we used a thermoplastic mask in 3 points (Orfit). The selected slice thickness was of 2.5 mm over the region of interest.

The planning target volumes (PTVs) and the organs at risk (OARs) were delineated by our physicians using the dedicated software Artiview. Next, the CT images and associated contours were transferred to the Tomotherapy Treatment Planning System (TPS) using the digital imaging and communications on medicine (DICOM) protocol. The treatment plans were generated using a 5 cm field width (FW) and a modulation factor of 2 in order to obtain reasonable treatment times. All plans were optimized through inverse planning using the normal (axial matrix 256X256) calculation grid.

First case is a 61-year-old female diagnosed with invasive carcinoma of the left breast: cT3N1M0, HER2-positive. The patient underwent radical mastectomy + left axillary lymphadenectomy. All 17 resected axillary lymph nodes were invaded (+17/17). The prescribed doses were 45 Gy to the entire chest wall and to the supraclavicular lymph nodes (SCL) in 25 fractions and 50 Gy to the axillary lymph nodes in 25 fractions.

The second case is a 58-year-old female patient diagnosed with nasopharyngeal non-keratinized undifferentiated squamous cell carcinoma T4N3M0, stage IV B. The prescribed dose for the primary tumour was 70 Gy in 35 fractions. Bilateral

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neck lymph nodes (retropharyngeal and levels II, III, IV and V) were irradiated with a dose of 60 Gy in 30 fractions.

The third case is an 85-year-old male patient diagnosed with prostate adenocarcinoma cT3bNxMx. The prostate specific antigen (PSA) was of 75 ng/ml before starting radiotherapy, and the Gleason score 8 (5+3). The prescribed doses were 78 Gy in 39 fractions for the prostate, 56 Gy in 28 fractions for the seminal vesicles and 50.4 Gy in 28 fractions for the pelvic lymph nodes.

The plans were evaluated using the following parameters: the homogeneity index (HI), the mean and maximum doses for the OARs (parallel, serial). Dose homogeneity in the PTV is quantified by the HI, according to the International Commission on Radiation Units and Measurements (ICRU). The HI is defined as the greatest dose delivered to 2% of the target volume (D2%) minus the dose delivered to 98% of the target volume (D98%) divided by the median dose (Dmedian) of the PTV:

HI = D2% - D98%/Dmedian

Smaller values of HI correspond to a more homogeneous dose distribution in the PTV. A value of 0 corresponds to absolute homogeneity of dose within the planning target volume.(6)

RESULTS AND DISCUSSIONS

Figure no. 1 shows the distribution of the isodoses in the axial, coronal and sagittal planes and the dose-volume histograms (DHVs) for breast case selected for this study.

Figure no. 1. DVHs and isodose distributions for the breast representative patient

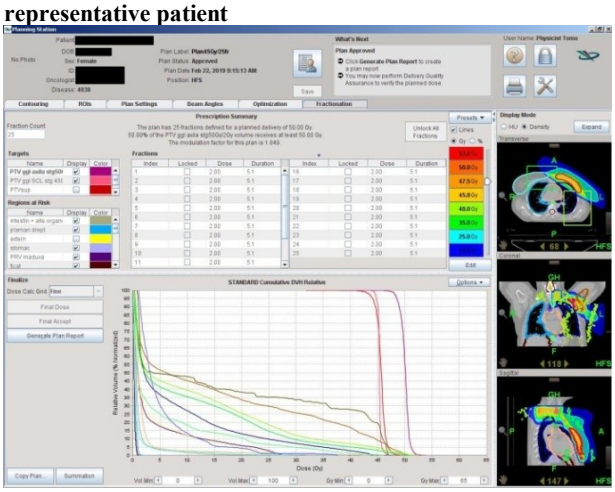

Table no. 1 summarises the mean, maximum and minimum doses (PTVmean, max and min) for the following targets: PTVchest wall, PTVaxillary and PTVsupraclavicular. In addition to these values D2%, D98% and Dmedian were determined for the three targets. The calculated HI values were close to 0, this fact meaning that a good homogeneity was obtained for all the three targets.

Table no. 1. Dose evaluation for the targets of the breast case

	Chest wall	Axillary lymph-nodes	Supraclavicular lymph-nodes
PTVmean (Gy)	45.59±0.93	50.00±0.86	45.32±0.33
PTVmax (Gy)	50.97±0.93	53.94±0.86	46.92±0.33
PTVmin (Gy)	40.85±0.93	45.90±.86	43.66±0.33
D2% (Gy)	47.53	51.59	46.23
D98%(Gy)	43.2	48.04	44.49
Dmedian (Gy)	45.66±0.93	50.09±0.86	45.32±0.86
HI	0.094	0.021	0.038

Evaluation parameters of OARs included the following: heart (Dmean, V30 and V40), left lung (Dmean, V5 and V20), right lung (Dmean), right breast (Dmean and V5) and spinal cord (Dmax and Dmean). Vx represents the proportion of volume under x Gy radiation from the total volume.(7) The above mentioned values are introduced in table no. 2.

Table no. 2. Dose evaluation for the OARs of the breast case

Organ	Project indicators	Results
Heart	Dmean (Gy) V30 (%) V40 (%)	1.99±1.51 1.01 0.27
Left lung (ipsilateral)	Dmean (Gy) V5 (%) V20 (%)	7.78±3.24 36.7 13
Right lung(contralateral)	Dmean (Gy)	0.41±0.25
Right breast	Dmean (Gy) V5 (%)	1.02±0.31 3.17
Spinal cord	Dmax (Gy) Dmean (Gy)	28.31±5.09 3.55

Analyzing the values of the indicators of the heart we can see that a value of the Dmean lower than 2 Gy and also the values of the V30 and V40, suggests that there is no cardiac toxicity for this patient. We also have obtained good results for the ispsilateral lung (Dmean<8 Gy and V20<20 %). For the right breast Dmean is less than 3 Gy, this being our limit in order to avoid the induction of a secondary malignancy in the contralateral breast. Usually, there is no problem with the limitation of the doses in the contralateral breast and lung when we use direct IMRT technique.

The side-effects of breast radiotherapy include lung and cardiac toxicity, especially when the left breast is irradiated. In order to reduce the incidence of late cardiac mortality after breast radiotherapy, our internal protocol does not allow a mean dose higher than 3 Gy. In addition to this, the mean dose for the ipsilateral lung is restricted to be lower than 10 Gy. We also add a more restricted limit to V20, according to the recommendations of the Radiation Therapy Oncology Group (RTOG).

The use of helical tomotherapy with the gantry rotating around the patient has some drawbacks for the breast irradiation such as the delivery of higher doses in the contralateral breast and lung.(8) In order to avoid this situation, for this case we used tomotherapy in fixed gantry positions (static delivery) as the couch moves through the gantry. This technique is similar to the standard tangential breast radiotherapy, the main advantage being a better control of the hot spots in order to reduce adverse effects (skin erythema). We use helical technique for the patients that have an irregular geometry of the thorax.

Figure no. 2. DVHs and isodose distributions for the head and neck patient

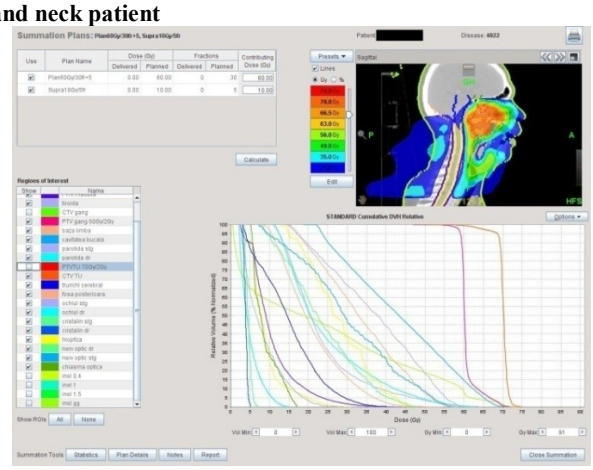

Figure no. 2 shows the distribution of the isodoses in

the sagittal plane and the dose-volume histograms for the summation of the two plans (plan plus boost) for the head and neck (H&N) case.

Table no. 3 summarises the mean, maximum and minimum doses (PTVmean, max and min) for the primary tumour (V=134.58 cm^3) and for the bilateral lymph nodes (V=279.92 cm^3). The values of D2%, D98% and Dmedian were determined for both targets. The calculated HI values were of 0.16, the obtained homogeneity being acceptable for this case. Due to the localization and to the big volume of the primary tumour, a trade-off was made between an acceptable homogeneity and acceptable values for the parameters used to evaluate the OARs.

Table no. 3. Dose evaluation for the targets of the head and neck case

	Primary tumour	Bilateral lymph-nodes
PTVmean (Gy)	69.84±2.36	60.82±2.31
PTVmax (Gy)	75.15±2.36	72.61±2.31
PTVmin (Gy)	50.21±2.36	46.86±2.31
D2% (Gy)	72.26	69.02
D98% (Gy)	60.99	58.4
Dmedian (Gy)	70.22±2.36	60.19±2.31
HI	0.16	0.17

In order to evaluate the OARs, the doses to proximal critical structures were analyzed: spinal cord (Dmax), brainstem (Dmax), left and right lens (Dmax), left and right optical nerves (Dmax), pituitary gland (Dmax), chiasm (Dmax), oral cavity (Dmax, Dmean). A planning risk volume (PRV) was created 3 mm around the spinal cord. Parotid sparing was analyzed using the mean dose and the dose to 33% and 66% of the parotid volume (D33, D66). The above mentioned values are introduced in table no. 4.

Table no. 4. Dose evaluation for the OARs of the head and neck case

Organ	Project indicators	Results
Spinal cord	Dmax (Gy)	31.03±4.61
PRV spinal cord	Dmax (Gy)	44.18±6.17
Brainstem	Dmax (Gy)	42.13±7.12
Left lens	Dmax (Gy)	6.2±0.74
Right lens	Dmax (Gy)	5.14±0.44
Left optical nerve	Dmax (Gy)	53.73±2.32
Right optical nerve	Dmax (Gy)	47.88±2.72
Pituitary gland	Dmax (Gy)	42.03±5.17
Chiasm	Dmax (Gy)	17.09±3.37
Oral cavity	Dmax (Gy) Dmean (Gy)	71.29±3.49 32.61±13.49
Left Parotid	Dmean (Gy) D33 (Gy) D66 (Gy)	23.46±15.27 24.15±15.27 17.85±15.27
Right Parotid	Dmean (Gy) D33 (Gy) D66 (Gy)	24.57±11.39 26.44±11.39 17.26±11.39

The maximum dose to the PRV of the spinal cord was limited to 50 Gy, and a maximum of 55 Gy is accepted for the brainstem. The high maximum doses obtained for the lens is a consequence of the extension of the primary target volume. Despite this, we were able to limit the maximum doses for the lens below 7 Gy (RTOG 0539), in order to avoid damaging them. For the optical nerves we constrained the maximum doses lower than 55 Gy, according to RTOG recommendations for H&N cancer. The mean doses below 26 Gy obtained for the parotid glands translated into meaningful reduction of xerostomia and improved quality of life for the treated patient. No hot spots higher than 103% of the prescribed dose for the primary target were allowed outside the targets.

Primary H&N tumours are often situated in close proximity to numerous critical structures, and delivering an adequate radiation dose to the primary and regional lymph-nodes requires special attention to protect the OARs. The treatment planning methods using external-beam radiotherapy have evolved from the traditional three-field technique in the early days to IMRT, and recently to the more efficient volumetric modulated arc therapy (VMAT) and helical tomotherapy.(9) Because helical tomotherapy is specifically developed for IMRT in combination with integrated image-guidance, it allows for precise dose distribution ("dose painting"), patient setup, and dose delivery.(10)

Many studies dosimetrically compared step-and-shoot Intensity Modulated Radiation Therapy (SS IMRT) with helical tomotherapy (HT) for patients with head and neck squamous cell carcinoma (HNSCC). All HT plans showed improvement in target coverage and homogeneity, and reduction in OAR doses compared to SS IMRT plans.(11)

Figure no. 3 shows the distribution of the isodoses in the sagittal plane and the dose-volume histograms for the summation of the two plans (plan plus boost) for the prostate case.

Figure no. 3. DVHs and isodose distributions for the prostate patient

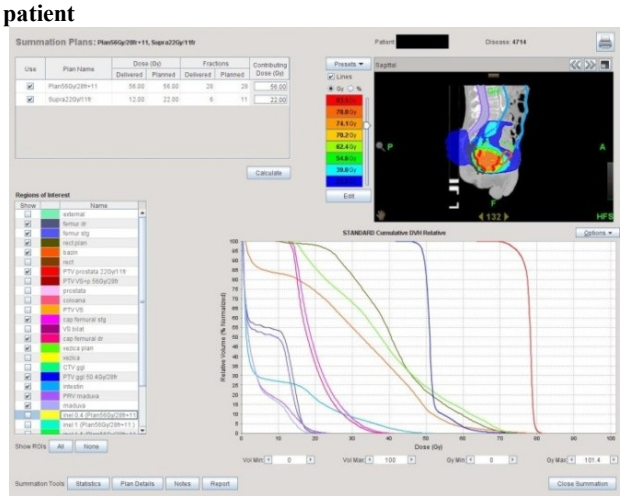

Table no. 5 summarises the mean, maximum and minimum doses (PTVmean, max and min) for the primary tumour (prostate) and for the pelvic lymph-nodes. The values of D2%, D98% and Dmedian were also determined for both targets. The dosimetric goal was to cover 95% of PTVs with at least 95% of the prescribed dose. The calculated HI value was of 0.09 for the primary tumour, revealing a very good homogeneity. The obtained HI value for the pelvic lymph-nodes was of 0.26.

Table no. 5. Dose evaluation for the targets of the prostate case

	Prostate	Pelvic lymph-nodes
PTVmean (Gy)	78.02±1.53	51.6±3.02
PTVmax (Gy)	81.63±1.53	74.61±3.02
PTVmin (Gy)	73.63±1.53	46.64±3.02
D2% (Gy)	79.81	61.6
D98% (Gy)	72.68	48.07
Dmedian (Gy)	78.22±1.53	50.95±3.02
HI	0.09	0.26

For the OARs the planning constraints were as follows: V30≤55% and V50≤15% for rectum, and V30≤60% and V50≤20% for bladder. For the intestinal cavity, the dose was reduced as low as possible. The femoral head DVH goal was V20<50%. Evaluation parameters of OARs included the following: rectum (Dmean, D35 and D15), bladder (Dmean, D35 and D15), intestinal cavity (Dmean), left and right femoral heads (Dmean and D25) and pelvic bones (Dmean). The above mentioned values are introduced in table no. 6.

Table no. 6. Dose evaluation for the OARs of the prostate case

Organ	Project indicators	Results
Rectum	Dmean (Gy) D35 (Gy) D15 (Gy)	40.52±10.09 43.7±10.09 54.84±10.09
Bladder	Dmean (Gy) D35 (Gy) D15 (Gy)	38.75±12.47 43.7±12.47 57.39±12.47
Intestinal cavity	Dmean (Gy)	8.04±3.21
Left femoral head	Dmean (Gy) D25 (Gy)	20.45±5.45 23.27±5.45
Right femoral head	Dmean (Gy) D25 (Gy)	19.46±5.22 22.14±5.22
Pelvic bones	Dmean (Gy)	31.17±12.54

Radiotherapy (RT) is one of the established primary modalities for treating prostate cancer. Approximately 30% of all prostate cancer patients who are treated with curative intent receive RT, most with external beam radiotherapy, and a substantial proportion will be cured.(12,13) Studies have shown that IMRT/IGRT allows significant escalation of radiation dose with excellent biochemical control of disease with the same or less treatment-related morbidity.(14,15) Drozdz S. et al. compared different image-guidance (IG) strategies for prostate cancer with IMRT using tomotherapy and linear accelerator (LINAC)-IMRT, and their impact on PTV margin reduction. Follow-up data showed reduced bladder toxicity in tomotherapy patients compared to LINAC-IMRT. In addition, IMRT delivered with helical tomotherapy helps to avoid hotspots in the bladder neck, a critical anatomic structure associated with post-RT urinary toxicity.(16)

CONCLUSIONS

Tomotherapy HD (Accuray) system has proved its feasibility and its advantages in terms of less adverse effects for our patients. Both treatment techniques (helical and static) have been very useful, offering to our team solutions for the diversity of cases that were in treatment in our radiotherapy department. Its Treatment Planning System (TPS) has a good control of the hot spots, in addition to a high conformity and homogeneity of the doses in the targets. For the OARs, we usually obtain values much lower than the limits recommended by RTOG. All these, make Tomotherapy HD system very useful for the treatment of difficult cases, when the trade-off between the tumour coverage and the protection of the OARs is critical.

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