SYSTEMATIC REVIEW

Helical tomotherapy planning for total marrow irradiation

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ABSTRACT

OBJECTIVE

To evaluate plan quality of helical tomotherapy (HT) planning for total marrow irradiation (TMI) in rando phantom then verify dose by optically stimulated luminescence (OSL).

METHODS

Helical tomotherapy treatment planning for TMI in rando phantom was performed. Target areas included cranium bone, spine, pelvis, sternum, and ribs with expanded margin 5.00 mm for planning target volume (PTV). Organs at risk (OARs) for radiation were right eye, left eye, right lung, left lung, liver, right kidney, left kidney, heart, brain, and bowel. Prescribe dose for volume 95% (D95) of PTV≥12.00 Gy in 6 fractions. Dose verification by OSL in rando phantom position at the spine, sternum, and both lungs.

RESULTS

From TMI planning the D95 of PTV was 12.06 Gy and median dose (D50) of right eye, left eye, right lung, left lung, liver, right kidney, left kidney, heart, brain, and bowel were 7.09 Gy 5.23 Gy, 5.14 Gy, 5.94 Gy, 6.01 Gy, 5.97 Gy, 6.22 Gy, 5.12 Gy, 7.44 Gy, 10.03, and 7.09 Gy respectively. Results from the dose verification, % dose differences from planning compared with OSL dose at spine, sternum, right lung, and left lung were -5.54%, -4.19%, 0.08%, and -0.37% respectively.

CONCLUSION

Helical tomotherapy planning for TMI achieves target coverage of PTV and can reduce mean dose of OARs to 57.33% of prescribed dose. The dose verification of tomotherapy planning by OSL is convenient and high precision by mean dose difference 3.48%.

INTRODUCTION

Hematologic malignancy is a type of cancer caused from the abnormality of bone marrow cells or the lymph nodes that can be found in children, adults, and elders, especially in the patient with low immunity and children with genetic deficiency.[1] As the cancer cells spread from bone marrow over the body, the irradiation technique used is called total body irradiation (TBI), where the whole body is the target volume.[2] Radiation therapy, however, can both damage cancer cells and suppress immunity before processing stem cell transplantation, non-involved organs such as the lungs, eyes, liver, and kidneys receive unnecessary radiation dose.[2] As the technique of intensity-modulated radiation therapy (IMRT) has been developed, total marrow irradiation (TMI) to minimize the target volume to cover only the specific area and limits the radiation dose to the adjacent organs is proposed and it has been studied as the option of TBI.[3]

TMI is still not considered as a standard treatment for hematologic malignancy.[4] Its efficacy has been reported firstly in a rando phantom using helical tomotherapy (HT) with a fixed field width.[5] In this study, dose verification by thermoluminescent dosimeter was also performed to confirm the dose of radiation.[5] Later, its preferred clinical outcomes were also reported in three patients with acute myeloid leukemia compared with TBI.[3] In 2007, an experiment of TMI together with total lymphatic irradiation (TMLI) in six patients with multiple myeloma was performed to limit the radiation dose to the other organs, it found that TMI reduced up to 51% of radiation compared with TBI.[6] A larger phase I trial was conducted in 2009 with acute myeloid leukemia, acute lymphoblastic leukemia, non-Hodgkin's lymphoma, and multiple myeloma, it showed that TMI using helical tomotherapy was clinically feasible.[7] In term of the technique of TMI planning, HT and volumetric modulated arc therapy (VMAT) was performed on a phantom in 2016, it found that both planning systems can create high-quality plans for TMI, with HT resulting in superior Organs at risk (OARs) sparing.[8] However, the quality of TMI planning can be various depending on the technique use, machine parameters e.g.field width (FW), modulation factor (MF), pitch factor (PF), and experiences of the planner.[5] Verification of treatment planning is, thus, required to ensure safety. The present study aimed to describe the treatment planning using helical tomotherapy that is able to irradiate to the complex and large size cancer continuously for 160 cm long to assess its feasibility on a rando phantom while the verification of TMI plan was also performed using the optically stimulated luminescence (OSL).

METHODS

STUDY DESIGN AND SIMULATION

This is an experimental study to describe the treatment planning using helical tomotherapy (Hi-ART, Accuray, USA) to assess its feasibility on a rando phantom (The Phantom Laboratory, USA) with the verification of TMI plan using the OSL. This phantom has a similar structure to that of humans. It can be separated into 2.50 cm slab thickness. Four OSL (InLight nanoDot, Landauer, USA.) was attached in the rando phantom at the spine, sternum, left lung, and right lung. The 5.00 mm slice thickness. CT images data set was acquired and transfer to the contouring workstation

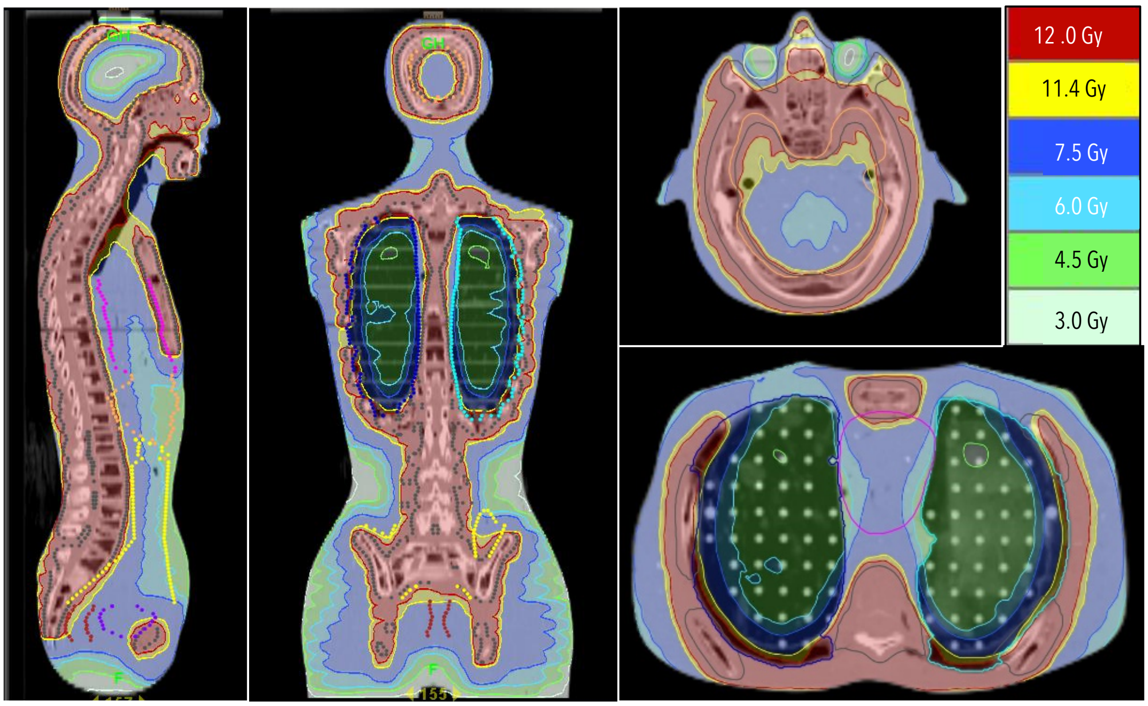

Figure 1. Dose distribution of helical tomotherapy planning for TMI in rando phantom.

(Oncentra Master Plan V.3.2., Nucletron). The present study was conducted at the Department of Radiology, Faculty of Medicine, Chiang Mai University, Thailand. It was conducted between August 2018 and November 2019.

STRUCTURE CONTOURING DOSE PRESCRIPTION

Gross tumor volume (GTV) is the total bones in the body. Planning target volume (PTV) is expanding GTV 5.00 mm on each side. OARs include lungs, eyes, kidneys, liver, heart, bowel, and brain. The prescription dose for volume 95% (D95) of PTV≥12.00 Gy in 6 fractions. For the OARs, following Marcantonini's study, the median dose (D50) of eyes, lungs, liver, heart, intestine, and brain should be lower than 6.00, 7.50, 7.50, 7.50, 8.00, 9.00, and 12.00 Gy respectively.[9]

HELICAL TOMOTHERAPY PLANNING

For helical tomotherapy planning using 6 MV photons, the machine parameters are dynamic jaw, field width=5.00 cm, modulation factor=2.50, and pitch factor=0.45. After the plan was compliant with the objective for PTV and OARs, the plan verification was processed. Verify the position of rando phantom before the irradiation by megavoltage computed tomography (MVCT) imaging. The plan was delivered for OSL dose measurement for three times. Thirty minutes after irradiation, the radiation dose from the sixteen OSL was readout.

ANALYSIS OF PLAN VERIFICATION

The percentage difference of radiation dose at each position in the rando phantom between the

Table 1. OARs dose from helical tomotherapy planning.

OARs	Constraint D_{50} (Gy)	Planning Dose (Gy)		
		D_{50}	D_{10}	D_{mean}
Brain	<12.00	10.03	12.48	9.30
Heart	<8.00	7.44	10.13	7.71
Right eye	<6.00	5.23	6.88	5.33
Left eye	<6.00	5.14	7.12	5.27
Right lung	<7.50	5.94	11.33	7.08
Left lung	<7.50	6.01	11.20	7.18
Right kidney	<7.50	6.22	9.27	7.08
Left kidney	<7.50	5.12	11.39	5.85
Liver	<7.50	5.97	8.72	6.45
Bowel	<9.00	7.09	11.00	7.49
Average				6.88

treatment planning calculation and OSL measurement using the equation shown in Box 1.

$$\%\text{Dose difference} = \frac{\text{Planning dose} - \text{Measure dose}}{\text{Measure dose}} \times 100$$

Box 1. Equation

RESULTS

Helical tomotherapy planning for TMI with the dynamic jaw, FW=5.00 cm, MF=2.50, and PF=0.45 use dose constraint of OARs, following the study of Marcantonini.[9] The obtained dose distribution in rando phantom is shown in Figure 1.

PLANNING DOSE AT THE TARGET VOLUME AND OARS

From dose-volume histogram (DVH) the D_{95}, D_{50}, dose received by 10% volume (D_{10}), mean dose (D_{mean}), and maximum dose (D_{max}) of PTV were 12.06 Gy, 12.64 Gy, 12.88 Gy, 12.60 Gy, and 14.35 Gy respectively. The volume received 110.00% of the prescription dose (V_{110}) and volume received

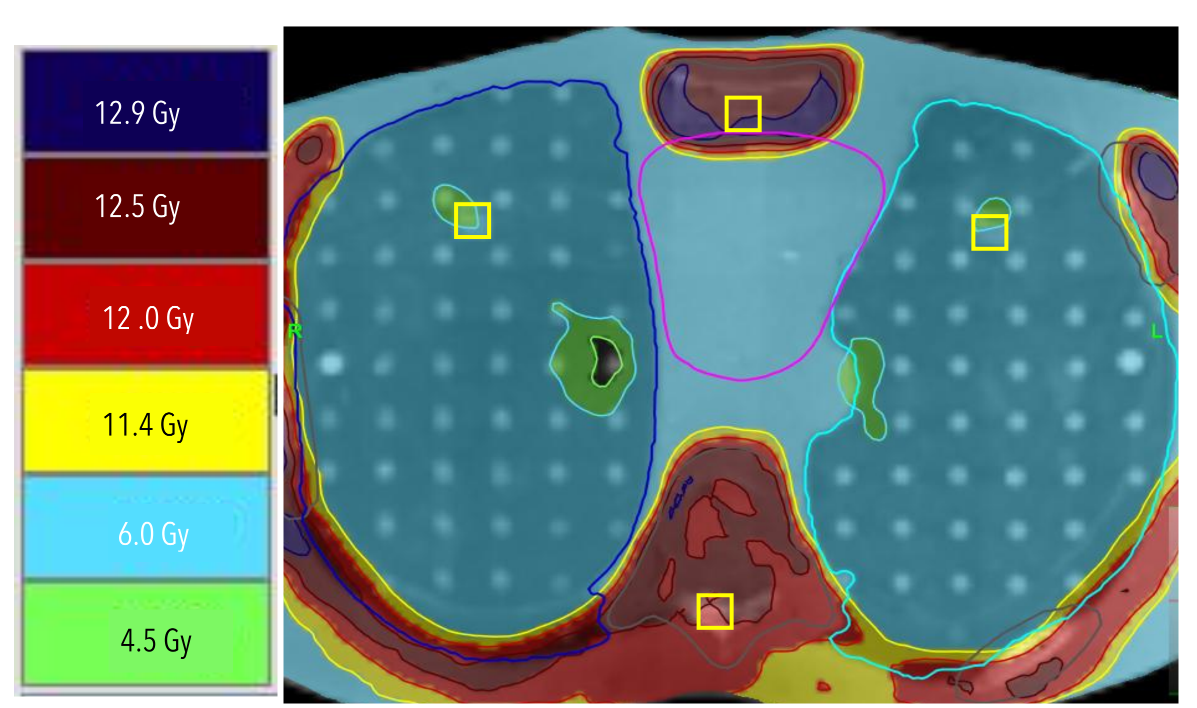

Figure 2. Dose distribution of helical tomotherapy planning for TMI in axial plane and the position of the four OSL in rando phantom.

93.00% of the prescription dose (V_{93}) of PTV were 1.80% and 99.08%, respectively. Planning dose at OARs, which include brain, heart, right and left eye, right and left lung, liver, and bowel are shown in Table 1.

PLANNING DOSE AT OSL

The calculation dose of helical tomotherapy planning for OSL position at spine, sternum, right lung, and left lung was 1253.00 cGy, 1293.67 cGy, 485.00 cGy, and 488.00 cGy respectively. Four OSL positions were shown in Figure 2.

MEASURED DOSE IN THE RANDO PHANTOM

OSL measured dose from the MVCT image procedure to verify the position of the rando phantom at the spine, sternum, right lung, and left lung was 1.80 cGy, 1.75 cGy, 1.80 cGy, and 1.65 cGy, respectively. The average of three times the dose measured with OSL from TMI plan delivery for 6 fractions at the spine, sternum, right lung, left lung were 1326.53, 1350.24, 484.63, and 489.83 cGy, respectively.

TMI PLANNING DOSE DEVIATION

The percentage difference between the planning calculation dose and OSL measured dose, at the spine, sternum, right lung, and left lung, were -5.54%, -4.19%, 0.08%, and -0.37%, respectively. The average difference was 3.48%.

DISCUSSION

This study on helical tomotherapy planning for TMI had the criteria D_{95} for PTV the same as that of the study by Schultheiss and Nalichowski.[6,8] The OARs had the dose constraints following the study of Marcantonini as the international dose constraints for TMI is still unavailable.[9] The helical tomotherapy in the present study was created for TMI in the rando phantom, which was similar to the study of Nalichowski.[8] The machine parameters for optimizing were the same, except PF which was 0.450 while that of Nalichowski was 0.287. The D_{95}, D_{mean}, and D_{10} of PTV in our study and that of Nalichowski were similar; the differences were less than 1.00%. D_{max} in our study was 2.00% lower.[8]

Helical tomotherapy for TMI minimizes radiation dose at OARs when compared to prescription dose. Our study was able to reduce the average OARs radiation dose to 57.33% (6.88 Gy) of the prescription dose. Nalichowski used PF=0.287 which better reduced the average OARs radiation dose to 43.00% (5.16 Gy). The dosimetric parameters at the organs of the present study and that of Nalichowski were different as the rando phantom had no internal organs, except bones and lungs. Consequently, the drawing of organs contour and volume relied on the individual physician which affected the dosimetric parameters of each organ.

Average dose at the lung in this study was 7.13 Gy, which was higher than that of Nalichawski's study (6.77 Gy) but lower than that of Losert study which irradiated with 6 isocenter VMAT and lung dose was about 10.00 Gy.[8,10] TMI dose verification using OSL in our study showed the low percentage dose deviation at both lungs as it was in the low dose gradient area. There was a high percentage of deviation at the spine and sternum as the OSL were in the high dose gradient area. The average percentage of deviation was corresponding to the study of Yuen and lower than that of Welliver's study which was 4.48%.[11,12]

In conclusion, helical tomotherapy plan in the present study was able to provide a quality and effective plan for TMI D_{95}, D_{50}, and D_{mean} of PTV was deviate from the prescription dose less than 5.50% and was able to reduce the radiation dose to OARs, which were brain, heart, eyes, lungs, kidneys, and bowel to 57.33% of the prescription dose. TMI with helical tomotherapy minimized radiation dose to OARs in the rando phantom which mitigated the possibility of severe adverse effects such as pneumonia, cataract, and the chance of secondary cancer. OSL was considered suitable and convenient to use for HT planning for TMI verification as it is small and can measure radiation dose at different positions at the same time with the error at the low dose gradient less than 1.00%, and at the high dose gradient area was less than 6.00%.

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