Diagnostic CT-based treatment planning of bone metastases for simulation free MR-guided online adaptive radiotherapy

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ABSTRACT

In standard computed tomography (CT) Treatment planning, the workflow takes 1-2 weeks before the treatment is delivered to patients with bone metastasis. Our study aims to expedite the treatment process for these patients with urgent needs by eliminating the need for simulation. Five bony metastatic patients with diagnostic CT scans, simulation CT scans, and MR scans will be examined. If the analyzed data correlates to that of the simulation adaptive plan, we hypothesize our findings will support the feasibility of simulation-free MR-linac treatment. These results would lead to a quicker workflow for bony metastasis patients, and increase staff efficiency by reducing overall workload. Furthermore, we believe that future research regarding MR-linac simulation-free treatment could be expanded to include a variety of disease sites.

INTRODUCTION

Simple treatment approaches, such as 2D simulation, direct, or parallel-opposed fields, could be used for palliative cases. However, these approaches often over-irradiate surrounding healthy tissues and lead to a higher chance of late toxicity and complications. Highly conformal treatment techniques, such as IMRT, are preferred in modern radiotherapy for treating palliative bony metastases for better tumor control and healthy tissue sparing. The standard radiation therapy (RT) workflow includes diagnostic imaging, RT consultation, simulation CT, treatment planning, quality assurance, and treatment delivery. This workflow can take up to a week before patients with bone metastasis can receive treatment. These patients often present with urgent needs due to obstructions and pain. Additionally, the patient's anatomy can change drastically during this time. For this reason, accelerated bone metastasis planning reduces treatment time.

In standard CT treatment planning, there is a lack of precision in identifying tumor location compared to MR-Linac treatment planning, which offers better bony and soft-tissue target delineation. As a result, a reduction of planning target volume (PTV) margins can be obtained. The Monaco treatment planning system with the Elekta Unity, a 1.5 Tesla MR-Linac, will be used to create a reference plan based on the diagnostic CT and will be compared to a standard simulation CT treatment plan. The adapt-to-shape (ATS) technique compares the two plans for target-dose conformality, dose to critical structures, and acceptable isocenter shifts. The purpose of our study is to investigate the feasibility of CT simulation-free treatment for bony metastasis using the MR-Linac online adaptive planning.

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METHODS AND MATERIALS

Materials:

- Elekta Unity 1.5 Tesla
- Five bony metastasis patients (areas of treatment including the left femur, sacrum, right sacrum, left ischium, and right iliac)
- Monaco treatment planning system
- 5 Diagnostic CT scans, simulation CT scans, and MRI scans

Methods:

- The simulation CT and the diagnostic CT will be fused to retrieve the original contours as well as the target volumes. Once the fusion is done an IMRT reference plan can be created on the diagnostic CT scan.
- Afterward using both the diagnostic CT and the simulation CT scans the dose will be calculated and verification of the diagnostic CT reference plan will be done.
- The diagnostic CT reference plan will then be fused onto the patient MR images where an adaptive plan will be created using the adapt to shape (ATS) technique.
- The plan quality of the adaptive plans will then be evaluated in terms of the isocenter shift, target coverage, and critical structure constraints.

RESULTS

Comparison between diagnostic CT reference plan and simulation CT plan

For all five cases individual diagnostic CT reference plans were created. Each of these reference plans had a simulation CT comparison plan that were computed to determine the similarities between target coverage and clinical objectives. Chart 1. Illustrates the target coverage percent difference between the reference plans and comparison plans varied between 0% - <2%. Overall target coverage was met for the different disease sites within their respective reference and comparison plans. Table 1 displays the different clinical goal values between the diagnostic CT plan and the simulation CT plan. These clinical goals include maximum dose objectives and OAR constraints. For all plans clinical goals were met, however doses varied slightly between the comparison and reference plans.

Comparison between diagnostic CT reference plan and MR Adaptive plan

Chart 2 shows the target coverage for both plans with differences of less than 2%. In comparing both target coverage objectives set for the five cases, both the diagnostic CT reference plans and the MR adaptive plans met these requirements. Table 2 represents the different clinical goal criteria of both the reference CT plan and the MR adaptive plan. For both plans, clinical objectives were mostly achieved except for the right sacrum case in which the sacral nerves Dmax < 1200 cGy objective varied by only 1%.

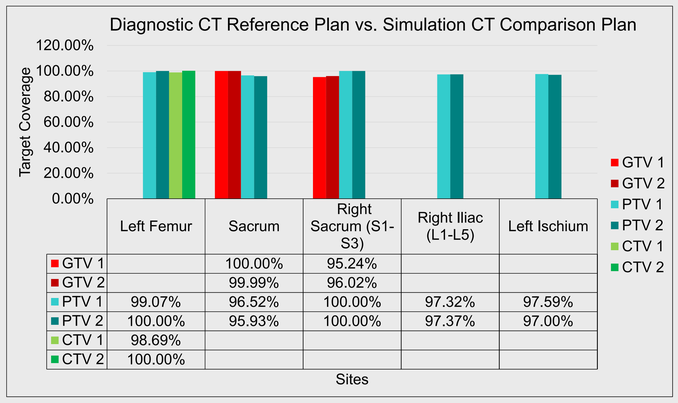

Chart 1. Comparison of Diagnostic CT reference plans (1) and Simulation CT comparison plans (2) target coverage

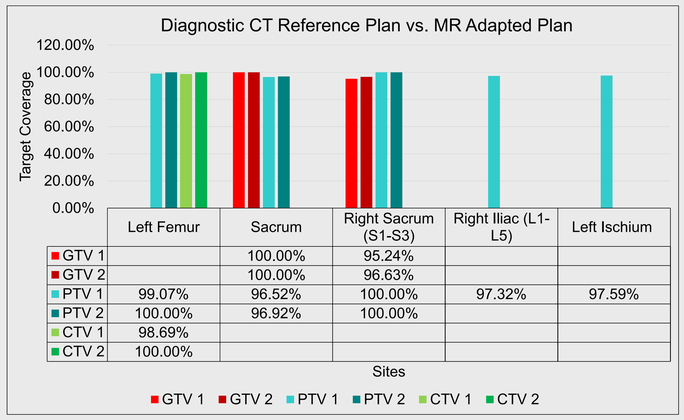

Chart 2. Comparison of Diagnostic CT reference plans (1) and MR Adaptive plans (2) target coverage

Treatment Site	Clinical Goals	Reference Plan	Comparison Plan
Left Femur	PTV D0.1cm^3< 920 cGy	909.3 cGy	912.1 cGy
Right Iliac (L1-L5)	Spinal cord D0.1cm^3<2000 cGy	565.0 cGy	104.7 cGy
	Nerve roots D0.1cm^3<3900 cGy	2049.2 cGy	2051.2 cGy
Right Sacrum	Cauda/Sacral Plexus Dmax < 1600 cGy	1590.0 cGy	1554.0 cGy
	Spinal cord Dmax < 800 cGy	40.5 cGy	39.8 cGy
	Bowel bag Dmax < 800 cGy	676.8 cGy	687.3 cGy
	Femoral heads Dmax < 800 cGy	13.2 cGy	13.4 cGy
	Right Kidney V800cGy < 33%	0.00 %	0.00 %
	Right Kidney V500cGy < 50 cm^3	0.00 cm^3	0.00 cm^3
	Liver V700cGy < 1000 cm^3	0.00 cm^3	0.00 cm^3
Right Sacrum (S1-S3)	GTV Dmax <2100 cGy	1919.8 cGy	1910.2 cGy
	Sacral nerves Dmax < 1200 cGy	1187.4 cGy	1190.2 cGy
	PRV_Nerves_0.3 Dmax < 1400 cGy	1361.1 cGy	1368.2 cGy
	PRV_Nerves_0.5 Dmax < 1600 cGy	1574.1 cGy	1544.9 cGy
Left Ischium	Bladder V1500 cGy <10%	1.75%	0.87 %
	Rectum V1500 cGy <10%	4.09%	11.24 %
	Left Femur V2000 cGy <20%	8.02%	15.30%

Table 1. Comparison of clinical goals between diagnostic CT reference plans and simulation CT comparison plans.

Treatment Site	Clinical Goals	Reference Plan	MR Adaptive Plan
Left Femur	PTV D0.1cm^3< 920 cGy	909.3 cGy	911.3 cGy
Right Iliac (L1-L5)	Spinal cord D0.1cm^3<2000 cGy	565.0 cGy	
	Nerve roots D0.1cm^3<3900 cGy	2049.2 cGy	
Right Sacrum	Cauda/Sacral Plexus Dmax < 1600 cGy	1590.0 cGy	1573.9 cGy
	Spinal cord Dmax < 800 cGy	40.5 cGy	39.5 cGy
	Bowel bag Dmax < 800 cGy	676.8 cGy	678.0 cGy
	Femoral heads Dmax < 800 cGy	13.2 cGy	12.9 cGy
	Right Kidney V800cGy < 33%	0.00 %	0.00 %
	Right Kidney V500cGy < 50 cm^3	0.00 cm^3	0.00 cm^3
	Liver V700cGy < 1000 cm^3	0.00 cm^3	0.00 cm^3
Right Sacrum (S1-S3)	GTV Dmax <2100 cGy	1919.8 cGy	1910.5 cGy
	Sacral nerves Dmax < 1200 cGy	1187.4 cGy	1211.8 cGy
	PRV_Nerves_0.3 Dmax < 1400 cGy	1361.1 cGy	1399.2 cGy
	PRV_Nerves_0.5 Dmax < 1600 cGy	1574.1 cGy	1576.9 cGy
Left Ischium	Bladder V1500 cGy <10%	1.75%	
	Rectum V1500 cGy <10%	4.09%	
	Left Femur V2000 cGy <20%	8.02%	

Table 2. Comparison of clinical goals between diagnostic CT reference plans and MR adaptive plans.

Treatment Site	Isocenter Shifts		
Coordinates	x	y	z
Left Femur	0.96	-3.80	-0.25
Right Iliac (L1-L5)			
Right Sacrum	-0.63	-1.14	0.56
Right Sacrum (S1-S3)	-0.68	-0.05	0.21
Left Ischium			

Table 3. Isocenter Shift information for MR adaptive plans.

DISCUSSION

Evaluation of diagnostic CT reference plan and simulation CT plan comparison

From our data collection, it is relevant to note the correlation between the reference and comparison plans. Both plans showed similar trends in target objectives and OAR constraints proving that it is practical to create a treatable plan on the diagnostic CT. Therefore, by creating this reference plan that is comparable to that of the simulation CT, simulation for bony metastasis patients could be eliminated.

Evaluation of diagnostic CT reference plan and MR Adaptive plan comparison

Based on the above findings, it is feasible to use a diagnostic CT to create a reference plan that will be adapted to the MRI. The clinical criteria for the ATS plans were mostly met as shown in the data collected in both the charts and tables. Table 3 shows the isocenter shifts for each one of the cases and all of them were within the tolerance of <5cm in each direction. The data collected comparing the OAR constraints, target coverage, and isocenter shifts all support the possibility of foregoing the simulation process of bony metastasis patients

Limitations

For this study one of the limitations encountered was the deformation of the diagnostic CT structures onto the MRI scan. Due to the size of the diagnostic CT the deformation algorithm could not accurately deform these contours onto the MRI scan. The planner could manually adjust the contours from the diagnostic CT to the MRI. However, in the case of this study to save time the structures from the simulation CT were deformed onto the MRI. Therefore, a better deformation algorithm would be required to have a more efficient workflow. Another limitation that could possibly affect this study would be the use of only five cases. By having more cases the information provided within this study would be better reinforced.

CONCLUSIONS

- The aim of this study was to demonstrate the feasibility of a simulation free workflow for bony metastasis patients by utilizing the Elekta Unity MR-linac. The relative discrepancies between the diagnostic and simulation comparison plans proves that it is possible to create a reference plan using a diagnostic CT.
- Our outcomes show that by using the ATS technique, the reference diagnostic CT plan can be adequately adapted to the MRI scan to create a plan that meets required dosimetric criteria, such as target coverage and OAR constraints. Therefore, by introducing this simulation-free workflow, bony metastasis patients would be able to receive treatment sooner with a similar plan quality.
- In conclusion, this study encourages further inquiry into the possibility of MR-linac simulation-free treatment for a variety of treatment sites.