Enhanced Normal Lung Sparing In MRI-Guided Lung SBRT: A Systematic Comparison with CT-Guided Radiotherapy

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ABSTRACT

Purpose: MRI-guided lung SBRT has emerged as a novel treatment modality with the potential to enhance motion management and improve normal lung sparing. This retrospective study evaluates the extent of normal lung sparing achieved by real-time tracking and automatic gating with MRI-guided radiotherapy (MRgRT) and compares it with internal target volume (ITV)-based free-breathing CT-guided radiotherapy (CTgRT).

Methods: Lung cancer patients (n=214) treated on MRgRT or CTgRT systems between January 2020 and September 2023 were pooled and reviewed. A subset of patients treated to 50 Gy in 5 fractions were selected for analysis (MRgRT: n=28, CTgRT: n=28). The planning target volume (PTV) was designed as the GTV plus a 5 mm margin for MRgRT and the 4DCT internal target volume plus a 5 mm margin for CTgRT. The mean, standard deviation, and medians were calculated for tumor volumes, normal tissue dose metrics, and conformity. Differences in plan quality metrics between the two cohorts were assessed using a Wilcoxon rank sum test with a significance level of 0.05.

Results: The V20Gy for total and ipsilateral normal lung were significantly lower for MRgRT compared to CTgRT (3.91±2.49% vs. 6.44±3.75%, p=0.004; 7.70±4.88% vs. 12.8±7.25%, p=0.004). The contralateral normal lung V5Gy was higher for MRgRT compared to CTgRT (5.27±4.43% vs. 2.20±2.96%, p=0.002), and the dose conformality indices (CI100% and CI50%) were less conformal in MRgRT compared to CTgRT (1.15±0.15 vs. 1.003±0.065, p<0.001; 5.61±2.08 vs. 4.57±1.08, p=0.01).

Conclusion: MRgRT spares significantly more normal lung from higher doses than CTgRT, but with reduced conformality (likely due to the step-and-shoot IMRT used by MRgRT). The findings may guide modality selections: MRgRT may be advantageous for substantial organ motion, whereas CTgRT may offer superior plan quality when motion is minimal. Future work will evaluate whether the improved tissue sparing with MRgRT translates into better clinical outcomes.

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INTRODUCTION

Computed tomography-guided radiotherapy (CTgRT) has been the standard for conventional lung treatments, typically involving acquiring a 4DCT and contouring an internal target volume (ITV) to account for tumor motion. In recent years, magnetic resonance-guided radiotherapy (MRgRT) has emerged as a viable option for lung RT, as machines such as Viewray MRIdian enable live respiratory gating (RG). MRgRT with RG allows clinicians to treat targets only in a specific region of interest via real-time MR imaging guidance. MRgRT with RG allows for localization of volumes during treatment, which should allow for more accurate target volume delineation and less irradiation of normal lung tissue (Park et al. MRIdian). However, the presence of the MRI creates mechanical restrictions that limit the ViewRay to step-and-shoot IMRT. Though some studies have simulated plans to compare dosimetry, there has not been a retrospective analysis of dosimetry in clinically treated cases.

Purpose: The objective of this study was twofold: (1) quantify the dosimetric differences between MRgRT and CTgRT using actual treatment data and (2) use these treatment differences to inform modality decision-making. We addressed these objectives through a retrospective review of clinical cases treated at our institution to ensure objectivity in our analysis. We systematically selected cases treated in the last few years and compared their treatment plans to quantify their differences. To our knowledge, this is the first retrospective study of these differences in treated cases.

METHODS AND MATERIALS

Lung cancer patients (n=214) treated on MRgRT or CTgRT systems between January 2020 and September 2023 were pooled and reviewed. A subset of patients treated to 50 Gy in 5 fractions were selected for analysis (MRgRT: n=28, CTgRT: n=28) to ensure consistency in the planning techniques. The planning target volume (PTV) was designed as the gross tumor volume (GTV) plus a 5 mm margin for MRgRT, and the 4DCT internal target volume (ITV) plus a 5 mm margin for CTgRT. To compare normal tissue sparing, two physicians retrospectively contoured GTVs on the end-exhalation phase of the 4DCT for CTgRT cases since clinically, only an ITV is considered. The mean, standard deviation, and medians were calculated for tumor volumes, normal tissue dose metrics, and conformity (Table 1). Differences in plan quality metrics between the two cohorts were assessed using a Wilcoxon rank sum test with a significance level of 0.05. Figure 1 summarizes a flowchart of the study.

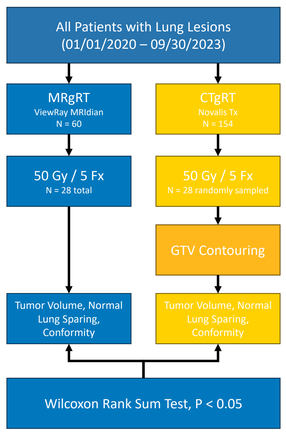

Fig. 1. Flowchart of the study design

Tbl. 1: Investigated dosimetric parameters

Parameter	Description
PTV/GTV Volumes	Volumes of the PTV and GTV
PTV/GTV V100%	Volume of each target receiving 100% of the Rx dose
R100% and R50%	Volumes of the 100% and 50% isodose contours
CI100% and CI50%	Ratios of R100% and R50% to the PTV volume
Total and Ipsilateral Normal Lung Dose	Normal lung is the lung volume subtracted by the GTV volume

RESULTS

Figure 2 shows an example of the retrospective contouring performed to obtain "normal lung" (total lung – GTV) for the CTgRT patients that were treated using an ITV.

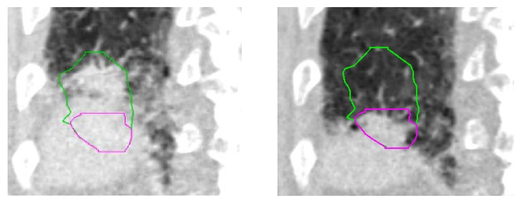

Fig. 2. (Left) ITV (green) contoured on the maximum intensity projection generated from the 4DCT and (Right) GTV (pink) contoured on the single-phase inhalation image

Based on the results shown in Figure 3, the total normal lung V20Gy and ipsilateral normal lung V20Gy were lower for MRgRT compared to CTgRT, but the contralateral normal lung V5Gy was higher for MRgRT compared to CTgRT. The dose was less conformal in MRgRT plans compared to CTgRT plans. These results help to quantify the benefits of normal tissue sparing with MRgRT, but illustrate that conformity may be slightly reduced, and dose to the contralateral lung may be slightly higher. This is likely due to the requirement of step-and-shoot IMRT. Given these results, patients with substantial motion may benefit from MRgRT, but tumors without significant motion may benefit from the higher plan quality offered by arc therapy with CTgRT.

Our CI50% constraints are related to the target volumes. Figure 4 shows the constraints on a scatter plot with the CI50% for each patient from both cohorts. From the MRgRT, 5 were within the ideal limit, 13 were within the tolerance limit, and 10 failed both constraints. From the CTgRT group, 19 were within the ideal limit, 2 were within the limit, and 7 failed both constraints.

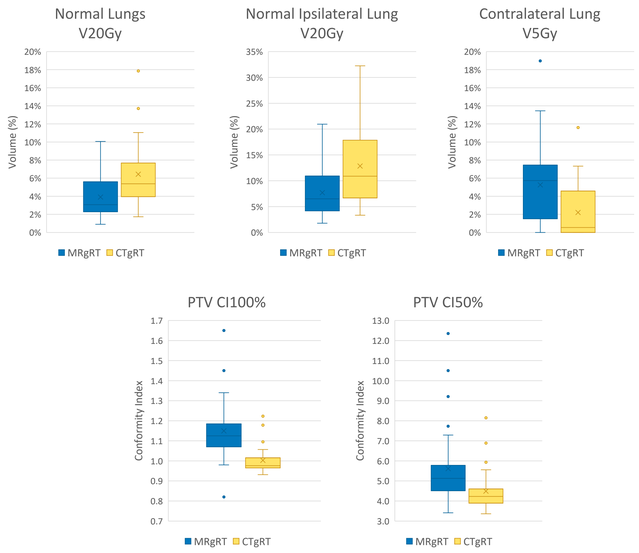

Fig. 3. Box and whisker plots summarizing key parameters between MRgRT and CTgRT treatment plans. All differences are statistically significant.

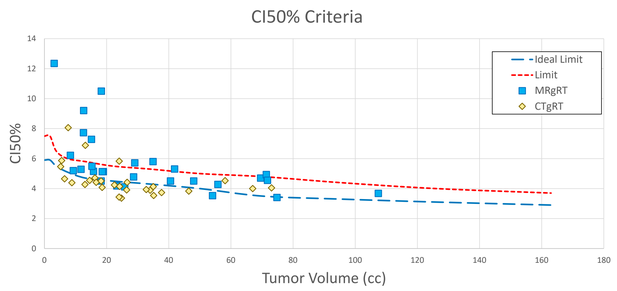

Fig. 4. Scatter plot of the CI50% for the MRgRT group (squares) and the CTgRT group (diamonds) with the ideal limit and limit (tolerance)

DISCUSSION

MRgRT offers great potential in normal tissue sparing for respiratory-gated lung treatments. As it has been increasingly employed in our clinic, we are continuously learning about its implications on treatment plans. In this study, we retrospectively analyzed lung radiotherapy plans delivered on the MRIdian and the Novalis Tx to determine the differences in the resulting plans. While we found that the normal tissue sparing was greatly improved for MR-linac plans, we noted other differences in the resulting treatment plans.

The contralateral lung doses were likely higher due to the limitations of the step-and-shoot IMRT planning technique employed by the MR-linac. These planning limitations may have encouraged planners to use beams that traverse the contralateral lung, whereas the more conformal VMAT plans used in the conventional linac group offered more conformity with partial arcs through the ipsilateral lung only. Our findings indicate that one should be mindful of placing beams through the contralateral lung when planning for MRgRT, and that perhaps constraints should be revised for MRgRT regarding conformity to ensure sparing of both lungs.

This study is mostly limited by the patient population in the MRgRT cohort. We have analyzed all the patients that were treated for lung SBRT with MRgRT at our institution. As time progresses, follow-up studies with larger cohorts will give us the ability to assess dosimetry in upper and lower lobe cases, which will impact tumor motion, and in medial and lateral cases, which will open our analysis to nearby OARs that depend on tumor location. Having more patients will also allow us to better match the tumor volumes and locations in each of these subgroups to obtain closer comparisons. Figure 5 shows how well-matched the GTV and PTV volumes were for this study. The findings of the present study are encouraging to initiate these suggested, larger follow-up studies.

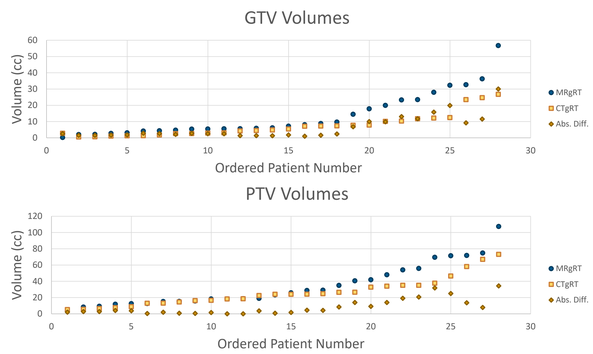

Fig. 5. Scatter plots of the (Top) GTV and (Bottom) PTV volumes for MRgRT and CTgRT patients ordered from smallest to largest. Diamonds show the absolute differences between the two.

CONCLUSIONS

The findings of this study should provide guiding information to clinicians choosing to plan a case on either an MR-linac or a conventional linac. Knowing the implications of dose to the normal organs and overall plan conformity can help decide if MRgRT is appropriate for a given patient. When organ motion is substantial, it may be advantageous to spare more normal lung with MRgRT. When organ motion is minimal, an ITV-based CTgRT approach may yield higher plan quality.

REFERENCES

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