Impact of Intrafraction Patient Motion on Plan Dosimetry and Local Control in Lung SBRT

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INTRODUCTION

High fractional doses and steep gradients used in stereotactic body radiation therapy (SBRT) impose a need for effective motion management strategies. Robust immobilization systems and delivery techniques such as dose repainting and intrafraction repositioning, paired with a standard 5.0 mm planning target volume (PTV) margin have been used to guarantee adequate target coverage.

The purpose of this study is to assess the clinical robustness of our current protocols by measuring the effect of intrafraction patient motion on plan dosimetry and local control.

METHODS

Data were collected for 83 patients treated for non-small-cell lung cancer (NSCLC) with lung SBRT between 2018 and 2023. Prescription doses were 50-60 Gy to 95-99% iPTV in 5 fractions. Treatments used volumetric modulated arc therapy (VMAT) with 4D CBCT-guided repositioning between symmetric dose repaintings. Intrafraction repositioning shifts were collected for 395 fractions.

Patients were immobilized with a wing board, vacuum bag, and the respiratory belt for the Body Pro-Lok ONE™ system (BPL1, CQ Medical, Avondale, PA), which provided abdominal compression.

Dose perturbations were calculated for twelve cases with average 3D repositioning shifts ≥3.0 mm (3.0-5.6 mm) by applying shifts to half of each respective fraction and to entire fractions to simulate executed repositioning between repaintings and worst-case scenarios, respectively.

98%-100% internal gross tumor volume (iGTV) coverage doses and volume of lung receiving ≥5 Gy (V5, lung-iGTV) and ≥13.5 Gy (V13.5, lung-iGTV) were recorded.

Follow-up data were collected for 83 patients. The median follow-up interval was 19 months (4-66 months). The endpoint of interest was local control (LC) defined as freedom from local progression, determined by CT and/or PET/CT imaging.

RESULTS

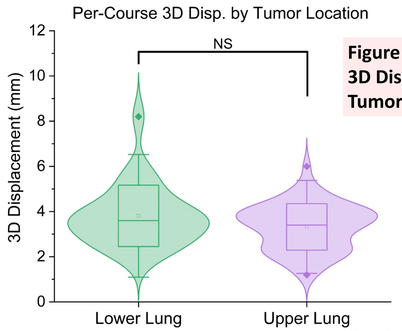


Figure 1: Course-Averaged 3D Displacement by Tumor Location

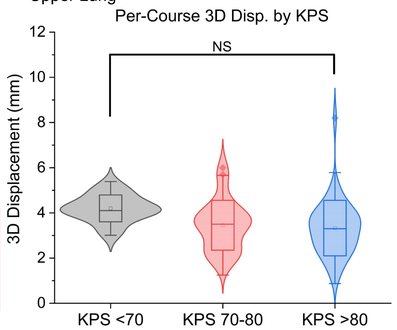


Figure 2: Course-Averaged 3D Displacement by Karnofsky Performance Status (KPS)

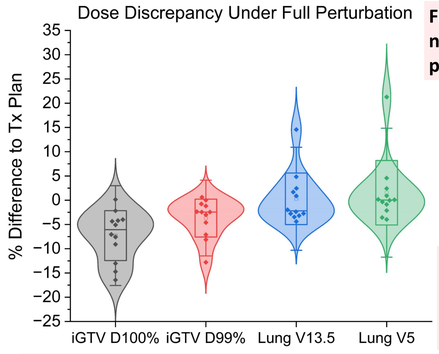


Figure 3: Percent differences to nominal plan metrics under positional perturbations.

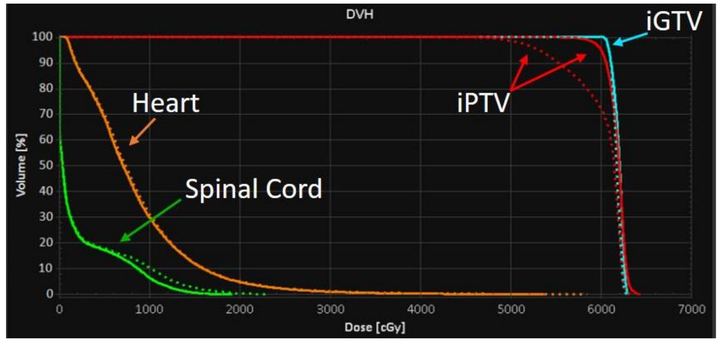
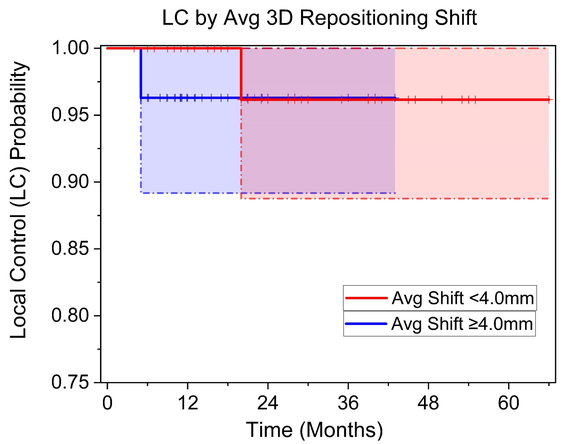


Figure 4: DVH for a representative case with large positional shifts. Dotted lines represent perturbed plan doses.



Time (months)	0	12	24	36	48	60
At-Risk, <4.0mm	54	39	25	19	10	1
At-Risk, ≥4.0mm	29	18	8	5	0	0

Figure 5: Kaplan-Meier plot of local control probability over time, separated by patients with course-averaged 3D shifts over or under 4.0mm.

The **average 3D repositioning shift was 3.5 mm (±1.7 mm) for all fractions**. 43 patients (50.5%) had course-averaged 3D repositioning shifts ≥3.5 mm. seventeen (20.0%) had total shifts >4.0 mm, and seven (8.2%) had average shifts ≥5.0 mm. There was no significant difference in repositioning by tumor location in the lung (Figure 1) or by Karnofsky Performance Status (KPS) at treatment (Figure 2).

Worst-case perturbed doses for average shifts ≥3.5 mm resulted in a mean **7.30% ± 5.14% decrease in iGTV minimum dose (range +0.16% to -13.03%).** There was no significant change in lung V5 and V13.5 (Figure 3). In one instance, the worst-case perturbation resulted in 100% iGTV coverage below prescription dose (Figure 4). However, this case had large average and single-fraction displacements of 5.6 mm and 8.6 mm, respectively, and was the only case which used a 3.0 mm PTV margin. **This was also one of two cases for which local control was not achieved.**

The overall **local control rate was 97.6% for all cases** (2 failures). The first instance of local failure was for a patient with the fourth largest average repositioning shifts in this study (5.6mm). A PET/CT at 8 months post-therapy demonstrated unchanged FDG avidity and increased size compared to previous imaging. The second instance of local failure was an in-field recurrence at 20 months post-therapy. The second patient had the smallest average 3D repositioning shift in this study (1.2mm).

CONCLUSIONS

All but one case maintained 100% iGTV coverage above the prescribed dose under positional perturbations, indicating that our standard 5.0 mm iPTV margin maintains ideal iGTV coverage. Furthermore, our >95% local control rate for cases requiring large average repositioning shifts indicates excellent clinical outcomes even in worst-case scenarios, which may corroborate safe reduction of standard planning margins.

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