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Quantifying Lung Volume Change From Thoracic Radiation Therapy

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ABSTRACT

Purpose: To quantify changes in the lung volume due to irradiation.

Methods: Lung volumes from repeat 4D-CT scans were measured at two timepoints (simulation and twelve months post-RT) from 53 subjects treated for lung cancer. 16 subjects received standard fractionation (SFX) and 37 received SBRT. Volume change was tested statistically using linear mixed models. Three volume metrics, maximum inhale, nadir (or exhale), and tidal volumes, were collected from deep learning-based segmentations and reviewed visually. Test-retest reliability was analyzed using Intraclass Correlation Coefficient (ICC).

Results: Repeat scans showed high repeatability with maximum and nadir volumes ICC above 0.95. The SFX tidal volume post-RT was the least repeatable (ICC of 0.82). The irradiated lung for SFX patients was significantly smaller in maximum inhale and nadir volumes post-RT for all timepoints $p \leq 0.01$. The maximum lung volume averaged 2.33 +/- 0.67L pre-RT and 2.03 +/- 0.66L post-RT for the irradiated and 2.34 +/- 0.55L pre-RT to 2.45 +/- 0.5L post-RT for the contralateral lung. In SFX patients at all post-RT timepoints both these metrics where significantly smaller in the irradiated lung than the contralateral lung ($p \leq 0.01$). No SBRT comparison was significant (maximum lung volume averaged 2.41 +/- .76L pre-RT and 2.45+/- 0.83L post-RT for the irradiated and 2.40 +/- 0.64 pre-RT 2.48 +/- 0.79L post-RT for the contralateral lung).

Conclusions: Significant reductions in lung volumes were recorded in the treated lung. In the SFX group the maximum inhale and nadir treated lung volumes declined while the tidal volume did not, possibly to maintain pulmonary function. In SBRT patients a greater sample size is needed to test for smaller changes in volume. 4D-CT based volume metrics were highly repeatable, however more variable in tidal volume likely from differences in respiratory effort.

Disclosures:

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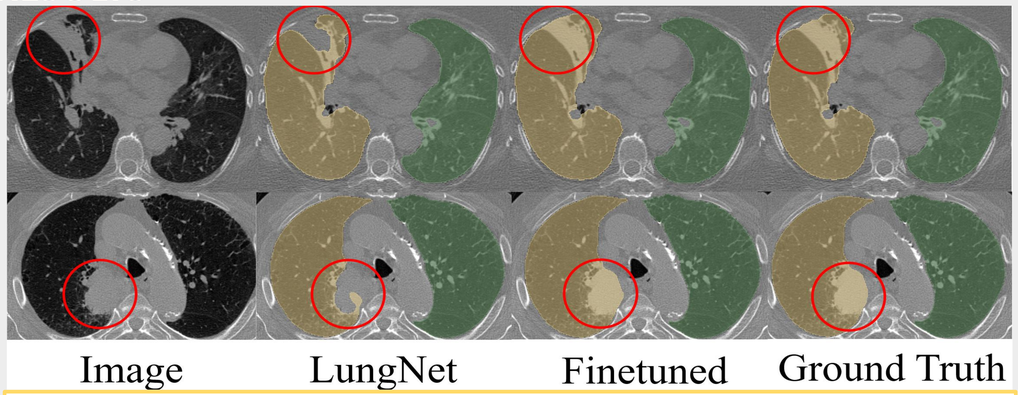
INTRODUCTION

- Lung volume change is an understood effect of thoracic radiation therapy but poorly quantified.
- Recent studies used radiation induce lung volume change to treat emphysema [1].
- 4D-CT used routinely but lung volume repeatability unknown.
- Changes in nadir and tidal volume as well as damage evolution have not been well investigated.

METHODS

- Subjects from NCT02843568 analyzed with two repeat 4D-CT scans at pre-RT and 3mo, 6mo and 12mo post-RT (8x)
- LungNet segmentation model finetuned to improve lung segmentations of lung tumors[2].
- Hemithorax segmented including tumors, radiation induced lung injury (RILI), and other lung abnormalities; excluded mediastinum and edema [3]. All segmentations were reviewed and corrected manually.
- Lung Volume is the sum of mask voxels multiplied by voxel volume. Nadir and maximum volume chosen from all phases.
- Lung parenchyma segmented by removing airway segmentation and voxels > -500 HU from lung segmentation.
- Repeatability reported with intraclass correlation coefficient, longitudinal results tested with linear mixed modeling.

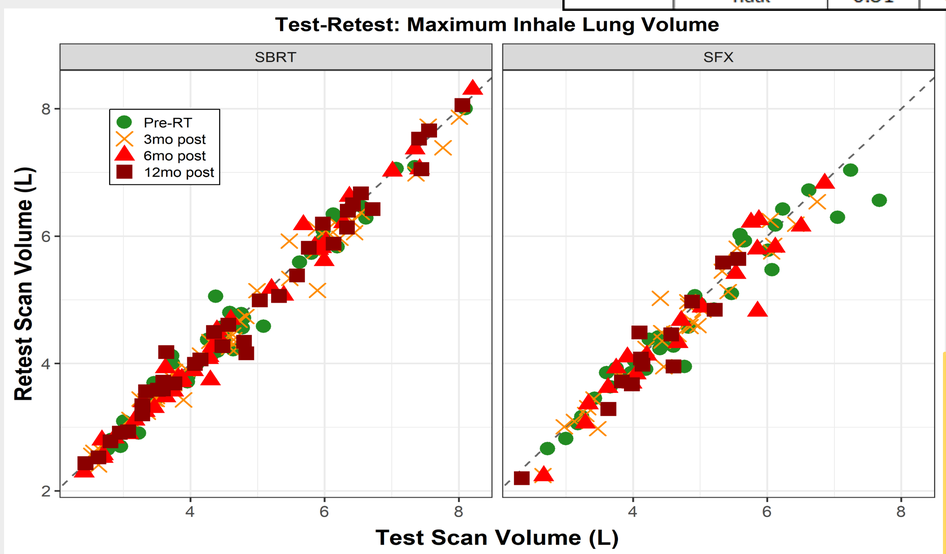
RESULTS



Takeaway 1: LungNet finetuning improved results in RILI and lung tumors. On worse cases dice improves from 0.88 to 0.92. Manual review is still necessary.

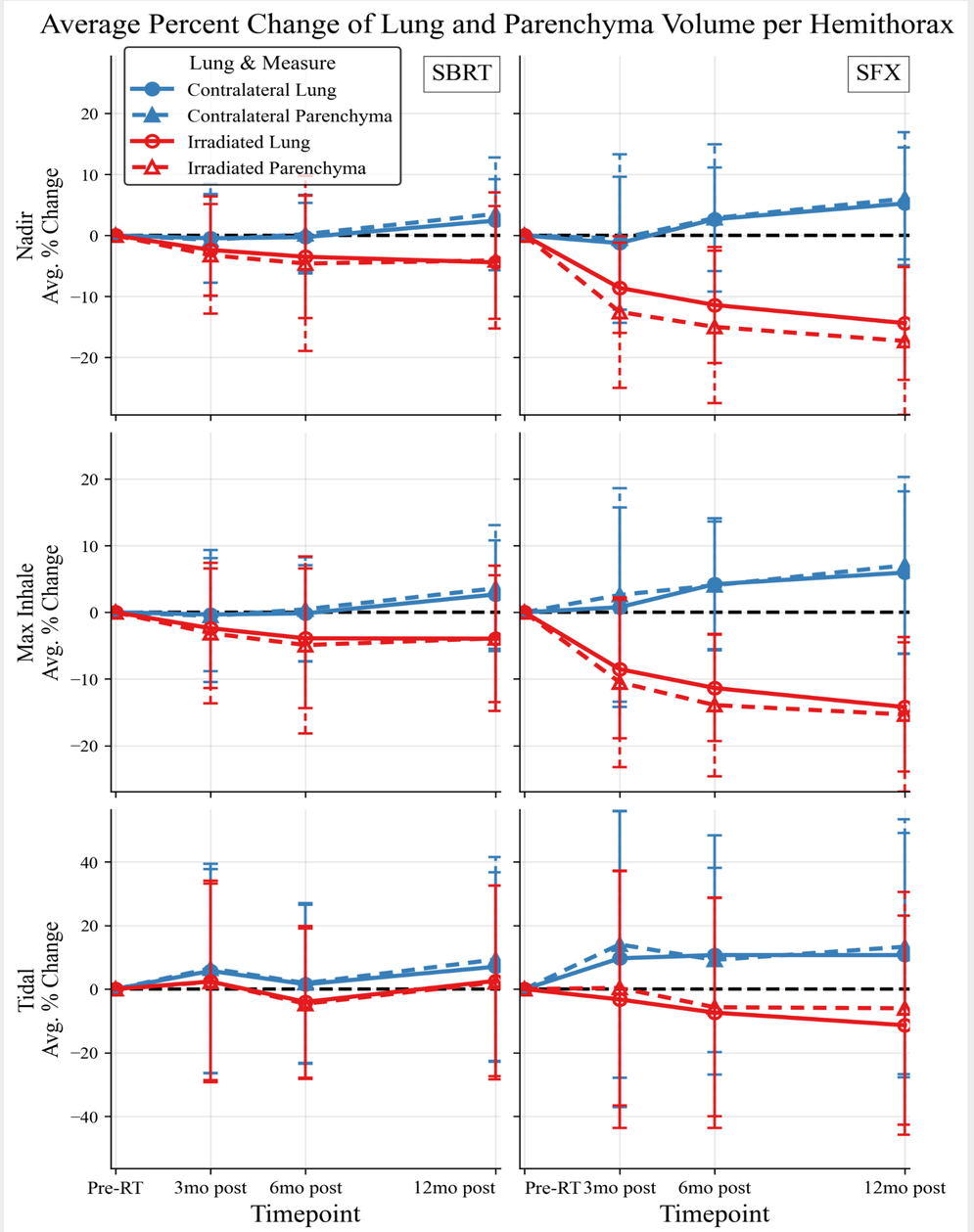
Subject Counts			
Timepoint	SBRT	SFX	Total
Pre-RT	49	28	77
3mo Post	46	25	71
6mo Post	40	18	58
12mo Post	37	16	53

ICC Values for Subgroups			
Timepoint	Measure	SBRT	SFX
Pre-RT	Maximum	0.98	0.97
	Nadir	0.99	0.99
	Tidal	0.91	0.84
3mo Post	Maximum	0.99	0.96
	Nadir	1.00	0.99
	Tidal	0.89	0.79
6mo Post	Maximum	1.00	0.98
	Nadir	1.00	0.99
	Tidal	0.97	0.83
12mo Post	Maximum	0.99	0.95
	Nadir	1.00	0.99
	Tidal	0.91	0.82



Takeaway 2: 4D-CT lung volume measurements are highly repeatable at the same timepoint, after a five minute "coffee-break" length gap, as evidenced by ICC values > 0.80. SFX is less repeatable than SBRT.

- Tidal volume is the least repeatable metric.



Takeaway 3: Nadir and maximum lung volume significantly decreases in the irradiated lung at post-RT timepoints for SFX subjects. Lung volume changes from SBRT not significant.

- SBRT to SFX significantly different in treated lung at all post-RT timepoints.
- Compensatory effect in contralateral lung that is not significantly different then pre-RT.
- Tidal volume shows same trend but is not significantly different.
- Post-RT timepoints are not significantly different then each other.
- Parenchyma segmentation had greater changes than lung segmentations.

CONCLUSIONS

1. Finetuning improves lung segmentation performance on subjects with high tumor burden or post-RT tissue change.
2. 4D-CT measures of lung volume are highly repeatable.
3. Lung volumes changes after irradiation, much more in SFX patients compared to SBRT. Damage evolves after irradiation as damage evolves.

DISCUSSION

- Lung segmentation remains difficult in the presence of RILI and large tumors, segmentation errors have large impacts on interpretation.
- Lung volume changes can be extracted using routine 4D-CT images. No additional images are needed to capture these metrics.
- Volume change may be an indicator of the normal tissue toxicity; further work is needed to correlate volume changes with RT dose and toxicity.

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