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Investigating Dose Sensitivity to Landmark Error and Clinical Workflow Practices Following Lung SBRT.

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Introduction

With an increase in early detection pathways and advances in cancer treatments, patients with several different types of cancer are living longer. As a result, more patients are returning for treatment of recurrences or secondary cancer making accurate dose accumulation more important.

Stereotactic Body Radiation Therapy (SBRT) of the lung can cause large deformations in the months following treatment. These deformations can lead to significant anatomical changes which make accurate dose accumulation for retreatment challenging. With significant anatomical changes deformable image registration (DIR) has the potential to increase registration accuracy over rigid registration. The accuracy of dose accumulation relies on the image registration, but the relationship between geometric registration error and dose error is not well characterized.

This study investigates the effect of different DIR methods on landmark error and dose error.

Conclusions

No significant difference was seen between software systems or rigid registration starting locations. Relative dose errors decreased as distance from PTV increased in accordance with dose fall off. For distance bins further from the PTV, greater landmark error led to greater dose error which was mitigated through user revision. A clinical workflow utilizing user adjusted DIR could reduce dose error particularly at increased distances from the PTV for challenging retreatment dose accumulation.

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METHODS AND MATERIALS

- Ten patients treated with lung SBRT (45-60Gy/4-5Fx) received a planning CT, and 3- Month, 6-month and 12-month follow-up CTs.
- Up to 30 landmark points were defined within 5cm of the planning target volume (PTV) by physician consensus. Figure 1 shows an example point.
- Two commercially available DIR software systems were used to rigidly register the images by two starting locations: spine and carina.
- DIR was then performed using the system default settings
- One user then performed additional revisions to the DIR for each rigid image.
- The rigid and deformable registrations were used to transfer the dose to the 12 month follow up image.
- Relative dose error was calculated at each of the landmark points between the planning and transferred dose on the follow up image.
- Linear mixed effects modeling in R was conducted to determine significant interactions with relative dose error among software system, rigid starting location, registration method, landmark error, and binned 1cm distances 0 to 5 cm from PTV.

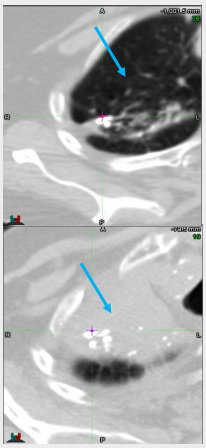

Figure 1: Example of a consensus landmark point at treatment planning (red) and at 12 month follow up (purple). Large anatomical changes post treatment can make registration challenging example lung collapsed or fibrotic as seen with the blue arrow above.

Table 1: Average residual landmark registration error (mm) following deformable registration for system 1 using the carina rigid registration as a starting point.

	Default Registration	User Adjusted
Month 3	4.16 ± 3.42	3.94 ± 1.16
Month 6	10.43 ± 4.43	7.67 ± 2.16
Month 12	11.23 ± 5.23	9.04 ± 2.94

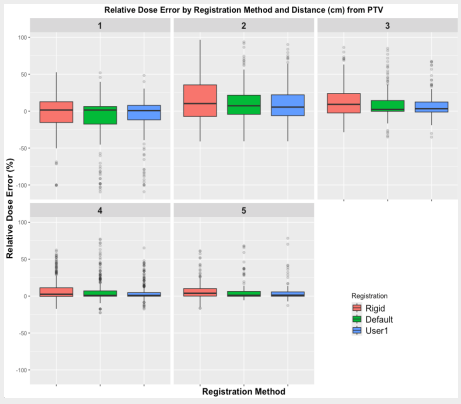

Figure 2: Relative dose error vs registration method stratified by distance in cm from the PTV. Within in 1cm of the PTV, all methods appear to perform similarly. Beginning after 1cm the deformable registration begins to perform better than rigid registration with the user modified performing better than default registration as distance increases.

RESULTS

- Landmark error increased longitudinally in time post treatment. The average error across all patients post treatment for 3 months, 6 months, and 12 months for system 1 can be seen in Table 1. Standard deviation of average values is provided.
- The absolute average dose error and landmark error for system 1 and system 2 across all points and registrations are summarized in Table 2.
- Main effects for the system and rigid starting location all had p-values > 0.093, while distance from PTV and landmark error were significant with p-values <0.001.
- Interactions among the distance from PTV, landmark error and registration type were significant with p-values < 0.05 to < 0.01.

Table 2: Comparison of the average dose error (Gy) and landmark error (mm) for each system stratified by rigid registration starting point- spine or carina, and registration method. Average standard deviation is provided.

	Spine					
	Rigid Registration		Default DIR		User Adjusted DIR	
	Absolute Dose Error (Gy)	Landmark Error (mm)	Absolute Dose Error (Gy)	Landmark Error (mm)	Absolute Dose Error (Gy)	Landmark Error (mm)
System 1	4.28 ± 10.23	14.17 ± 5.88	2.32 ± 9.77	11.55 ± 8.48	2.23 ± 7.46	9.86 ± 5.42
System 2	4.20 ± 9.94	14.03 ± 5.83	2.78 ± 9.76	11.35 ± 7.18	2.43 ± 9.64	11.17 ± 7.07

	Carina					
	Rigid Registration		Default DIR		User Adjusted DIR	
	Absolute Dose Error (Gy)	Landmark Error (mm)	Absolute Dose Error (Gy)	Landmark Error (mm)	Absolute Dose Error (Gy)	Landmark Error (mm)
System 1	4.48 ± 10.34	13.07 ± 5.79	2.49 ± 10.08	11.23 ± 7.97	0.53 ± 7.85	9.04 ± 5.58
System 2	3.83 ± 9.73	13.67 ± 5.43	2.70 ± 9.81	11.09 ± 7.05	2.46 ± 9.64	10.66 ± 6.86

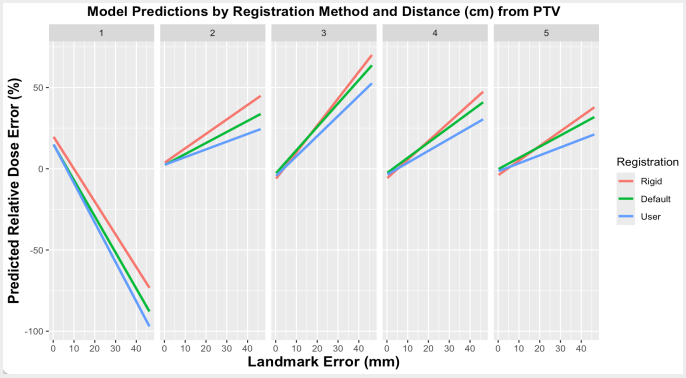

Figure 3: Linear mixed effects model predictions for relative dose error vs landmark error stratified by distance in cm from the PTV. Within in 1cm of the PTV, model appears to underestimate the dose with increasing landmark error. At further distances from the PTV, there is a positive direct correlation between dose error and landmark error with the user adjusted DIR registration showing the least dose error.

DISCUSSION

This study was performed using a small data set and results should be validated in a larger dataset. The amount of deformation caused by prior radiation may depend on dose, treatment technique and patient factors not considered here. In addition, deformations might increase beyond one year. Anatomical deformation are particularly relevant for lung targets but other deformations, such as positional, might be different for other organs. In addition only one user with over 5 years experience performed the deformable registration adjustments. Further study should investigate how user experience impacts registration performance.