Dosimetric evaluation of deformable image registration error using 4DCT-MRI datasets

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Motivation and Objective

To evaluate the dosimetric impact of deformable image registration error by utilizing 4DCT-MRI images with predefined ground-truth motions field

- Deformable image registration (DIR) is irreplaceable for 4D dose calculation
- Any geometric errors from estimated deformable vector fields (DVFs) can directly lead to error in accumulated dose distribution
- Quantifying DIR error is imperative but difficult due to the lack of DVF ground-truth.

Methods and Materials

- 9 synthetic 4DCT-MRI datasets were generated by image warping: 3 liver patients geometries with 3 sets of deformable motion from 4DMRI
- The Velocity™ B-splines DIR applied for estimating motion from 4DCT-MRI with ROI of full patient or just liver
- Geometric error was quantified by the differences of estimated DVFs and corresponding ground-truth DVFs.
- Dosimetric assessment was performed by analyzing the differences between estimated plans and ground truth 4D plans
- Comparisons of such effects were conducted for single- and multi-field scanned proton therapy treatment plans using either single or re-scanned dose delivery

Results and Discussion

- DVF-error magnitudes are 1.3±2.1 / 3.2±3.4 / 2.5±3.5 mm inside liver, for the initial motion being 3.1±1.4 / 8.1±2.9 / 8.4±3.5 mm, (averaged over phases and patient geometries)
- For single-field-no-rescan scenario, interplay effects in PTV (D5-D95) are 2.3±3.3 / 6.0±3.8 / 6.1±4.5 % under-estimated. The volumes receiving point-to-point absolute dose difference >10% located more outside PTV, with 10.8±2.1 / 24.4±4.4 / 26.1±5.2 % in the 10mm-extended-PTV.
- For multi-field-rescan scenario: difference in D5-D95 reduces to 0.1±0.7 / 1.5±1.1 / 1.9±1.8 %. The max error within 3% can be achieved for all investigated cases. Less than 6.0±2.5 % / 14.8±2.8 / 19.0±5.2 % volume in the 10mm-extended-PTV receive absolute dose difference >10%.

Conclusion

The DIR error of Velocity™ was quantitatively estimated. The dosimetric impact of the DIR uncertainty is pronounced for local dose distribution especially outside PTV, but rather limited on the plan statistical quantities inside PTV, especially when motion mitigation approach is applied.

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