Dosimetric Impact of Diaphragm Motion and Dynamic MLC Interplay in Lower Thoracic Spine Radiosurgery

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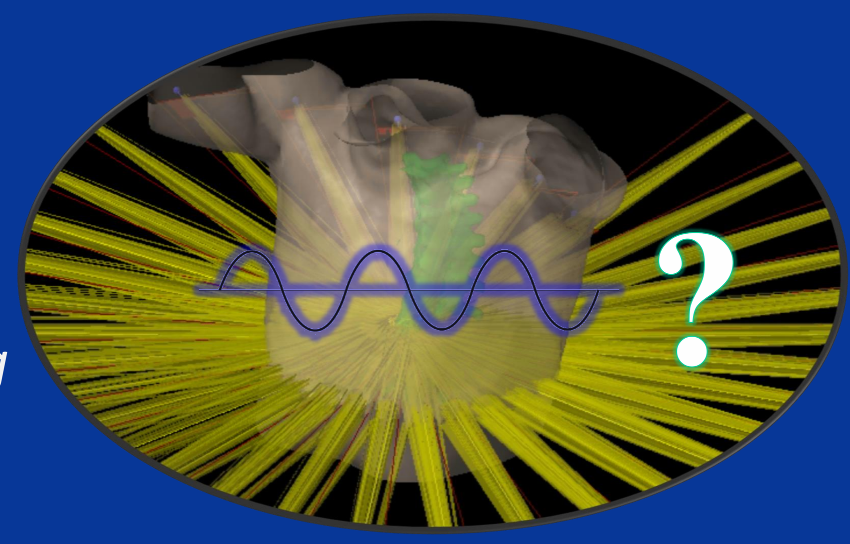

BACKGROUND

- The close proximity of the organ at risk (spinal cord) to the planning target volume (PTV) during spine radiosurgery (SRS) demands high dose gradients (up to 4 Gy/mm), accurate dose calculation and delivery
- A free-breathing CT (FBCT), which is a snapshot of the patient, is often utilized for treatment planning
- However, for SRS treatment of lower thoracic vertebrae at the level of diaphragm, the diaphragm motion may have an impact on the dose calculation or delivery accuracy

PURPOSE / OBJECTIVE

- The aim of this study was to evaluate the dosimetric impact of breathing motion in lower thoracic spine SRS where it interplays with beam delivery

MATERIAL & METHODS

- In this IRB approved study, five past cases with both FBCT and 4DCT image datasets available were selected. PTV and spinal cord volumes were defined at the level between T9 and T11
- For each case, an IMRT plan composing of 9 posterior and posterior-oblique beams and a VMAT plan composing of 2-3 full arcs were generated on FBCT
- The dose distribution was re-calculated on the average CT (AVGCT) and the two extreme phases (PH0%CT and PH50%CT). The two extreme phases represent the possible scenarios of FBCT snapshots
- For IMRT plans, each beam was divided into 25-83 subfields based on total monitor units, dose rate, and timestamp relative to the breathing trace, using in-house software
- Similarly, each arc of VMAT plans was divided into sub-arcs using native tools in planning system (**Figure 1**)

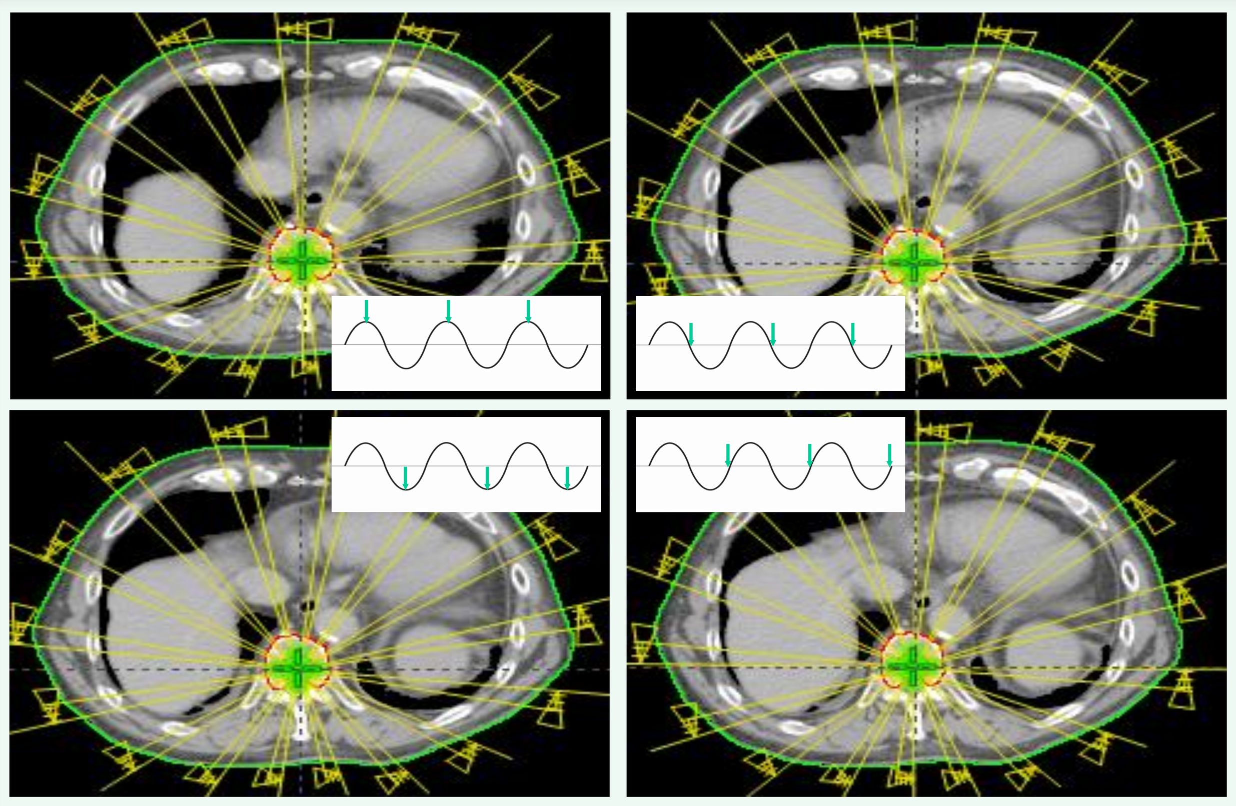

Figure 1: Illustration of sub-arcs sorting onto 4 phases. The subsequent doses distribution of each phase were added to generate composite dose on 4D plans

- Dose distributions from each subfield were recalculated onto the corresponding phased CT images. A 4D IMRT plan and a 4D VMAT plan, which is a composite of all subfields doses, were generated for each case
- Dose volume metrics evaluated were $D_{98\%}$, $D_{95\%}$, $D_{2\%}$, V_{Rx} for PTV, and $D_{10\%}$, $D_{0.35cc}$, $D_{0.035cc}$ for spinal cord

RESULTS & DISCUSSIONS

- Differences were observed between the dose volume metrics calculated on FBCT and other images (PH0%CT, PH50%CT, AVGCT), but no correlation between them

  ⟶ Dose calculation based on FBCT is arbitrary. It depends on where the diaphragm is during acquisition of FBCT

- The absolute differences between 4D plan dose and dose calculated on AVGCT were small (**Table 1**)

  ⟶ Dose calculation on AVGCT is equivalent to 4D calculation

Table 1 Difference in dose volume metrics between 4D and AVG plans (D in Gy, V in %), suggesting dose calculation on AVGCT is equivalent to 4D calculation.

	PTV $D_{98\%}$	PTV $D_{95\%}$	PTV $D_{2\%}$	PTV V_{Rx}	Cord $D_{10\%}$	Cord $D_{0.35cc}$	Cord $D_{0.035cc}$
Mean	0.01	0.01	0.01	0.16	0.01	-0.01	-0.04
Std Dev	0.01	0.01	0.02	0.30	0.01	0.03	0.14

- When comparing dose calculated on FBCT, PH0%CT, and PH50%CT to AVGCT, the largest percent changes in D98%, D95% and D2% to PTV for IMRT plans were 4.3%, 4.3% and 2.9%, respectively. Corresponding differences were larger for VMAT at 6.0%, 5.9% and 5.1%, respectively

  ⟶ Dose predicted on FBCT is not equivalent to 4D calculation

- A worst case scenario was presented in **Figure 2**, where the diaphragm was at deep inhalation during FBCT. V_{Rx} in the FBCT plan was over-estimated by 3.2% with IMRT and 40.7% with VMAT (**Figure 3** and **Figure 4**)

  ⟶ Actual PTV coverage *could* be dramatically different from planned coverage based on FBCT

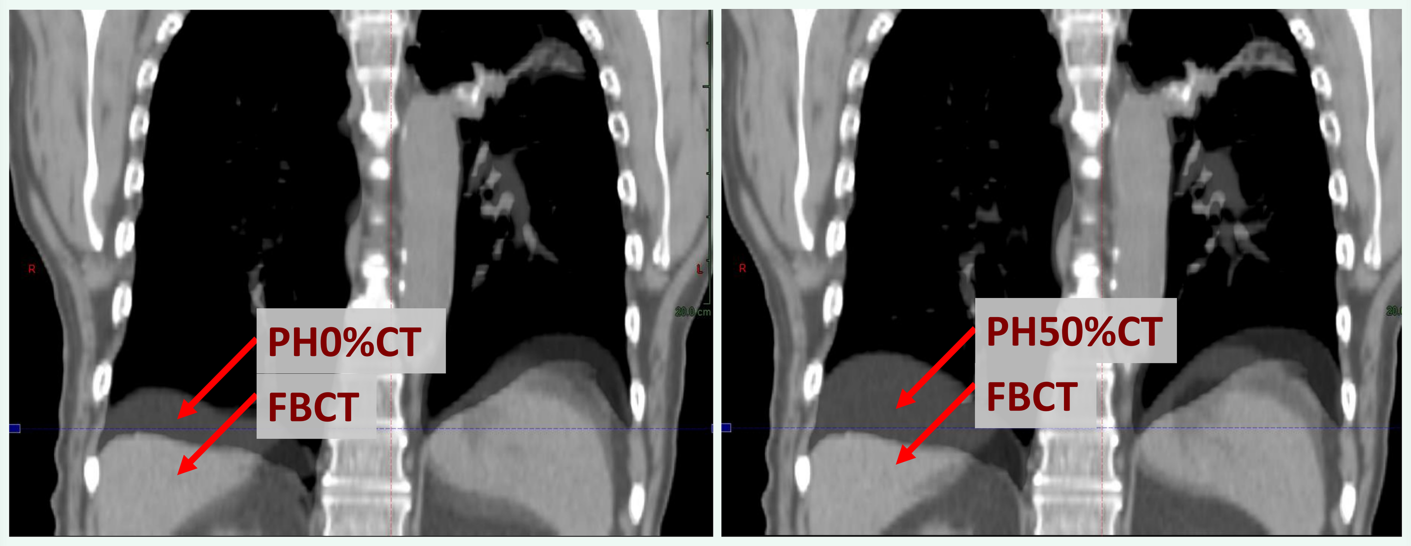

Figure 2: One example case where the FBCT was acquired during a deep inhalation, resulting in the diaphragm being more inferior than that when 4DCT was acquired. DVH comparisons based on FBCT and AVGCT were shown in Figure 3 and Figure 4.

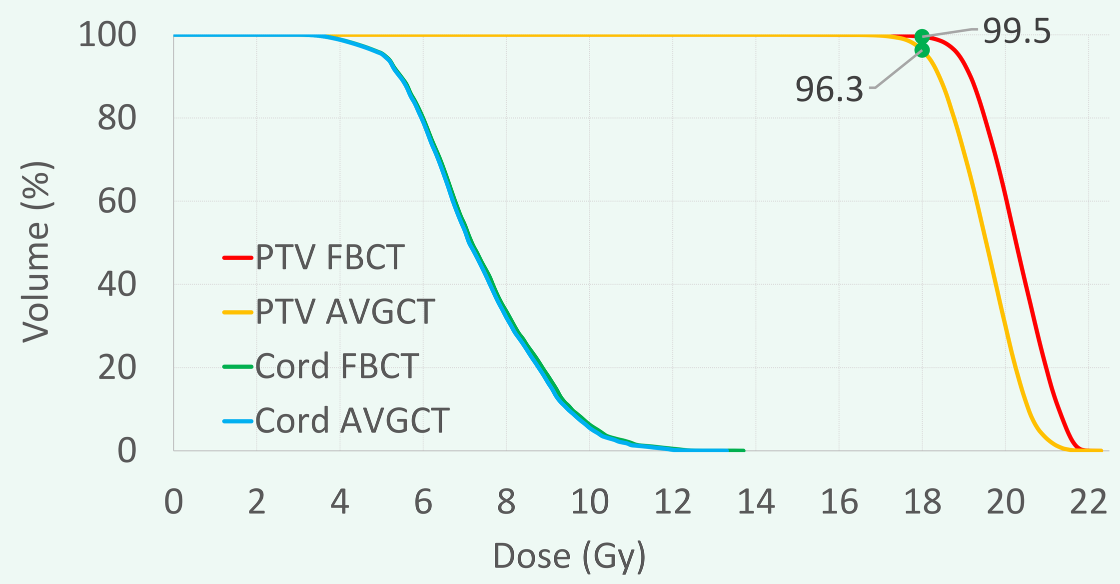

Figure 3: IMRT plan DVH comparison for the case shown in Figure 2. Prescription coverage (V_{Rx}) is 99.5% based on FBCT versus 96.3% based on AVGCT

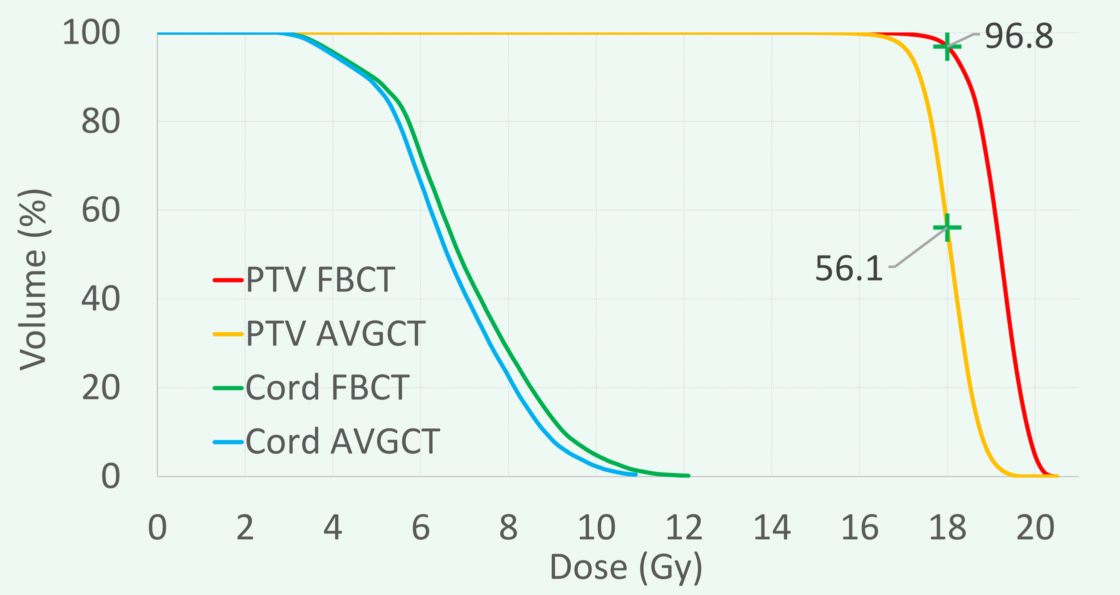

Figure 4: VMAT plan DVH comparison for the case shown in Figure 2. Prescription coverage (V_{Rx}) is 96.8% based on FBCT versus 56.1% based on AVGCT

- For spinal cord, when comparing dose calculated on FBCT to AVGCT, the average changes (± standard deviation) in $D_{10\%}$, $D_{0.35cc}$ and $D_{0.035cc}$ for IMRT plans were 0.08 ±0.18, 0.04 ±0.15 and 0.14, ±0.39 Gy, respectively, and 0.21 ±0.24, 0.29 ±0.38 and 0.29 ±0.34 Gy for VMAT plans
  - In the worst case scenario shown in Figure 2, the changes in $D_{10\%}$, $D_{0.35cc}$, $D_{0.035cc}$ for IMRT plans were 0.09, 0.09 and 0.17 Gy, respectively, and 0.42 , 0.43 and 0.65 Gy for VMAT plans

  ⟶ Safer to keep spinal cord dose at least 0.5 Gy below the tolerance dose during planning

- IMRT technique showed smaller deviation than VMAT in both PTV and OAR dose volume metrics mainly due to posterior and posterior-oblique beam arrangement

SUMMARY / CONCLUSION

- Due to interplay between diaphragm motion and dynamic MLC, the **use of FBCT for treatment planning in lower thoracic spine SRS could lead to deviations between planned and delivered dose, especially in the context of VMAT delivery**
- **Dose calculation on AVGCT was found to be consistent to that on 4DCT** for both IMRT and VMAT delivery
- **Planning on AVGCT is recommended for cases where diaphragm is in beam's path**
- In principle, other motion management methods such as slow CT acquisition and abdominal compression could also reduce the deviation between planned and delivered dose