Deformable Dose Accumulation Evaluation with Spatial Corrective Guidance Using Subregion Analysis

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2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

Background

- Re-irradiation is increasingly used, and deciding whether it is safe depends on the cumulative dose delivered to organs at risk across all courses.[1]
- Estimating that dose means mapping the prior dose onto the current anatomy, often by deformable image registration, which is uncertain and can place the prior dose in the wrong part of the organ.[2,3]
- Current validation reports whole-organ agreement, confirming that the contours overlap and the whole-organ dose is consistent on average, but not that the dose is preserved at the correct location within the organ. Whether the accumulated dose is spatially trustworthy remains unaddressed.
- We developed a framework that localizes this error, independent of the deformation, by comparing the accumulation against an estimate of the prior dose built from the organ's own geometry, using single registration data.

Materials/ Methods

- The organ is subdivided into axial levels and angular sectors from each contour's own geometry, position along the organ and angle around it, so the same location is identified on both scans independent of the deformation. For our study, we divided the esophagus contours using the parameter of 5 axial levels × 4 sectors.

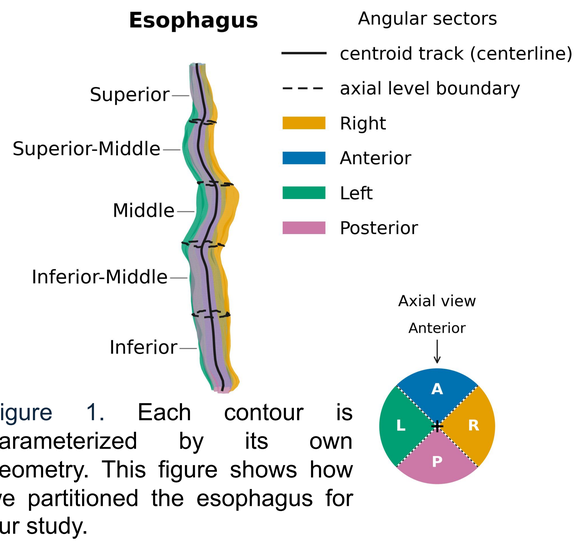

Figure 1. Each contour is parameterized by its own geometry. This figure shows how we partitioned the esophagus for our study.

- In each subregion, the framework compares two estimates of the prior dose, the deformed dose carried by the registration and a geometric reference read from the prior scan at the matching position, and reports their signed difference.
- Subregions of opposite sign cancel when averaged over the whole organ. Each case is summarized by the largest subregion discrepancy (MaxSR, with its anatomical label) and an error-cancellation index measuring how much of it the whole-organ mean hides. MaxSR was compared against the metrics current practice already uses, contour overlap (Dice, HD95) and whole-organ mean and maximum dose differences.
- Applied to 65 patients with thoracic re-irradiation[4]. Patients were split by MaxSR into spatially clean vs. flagged subgroups, and the composite mean dose's prediction of grade ≥ 2 esophagitis was compared across subgroups.

Results

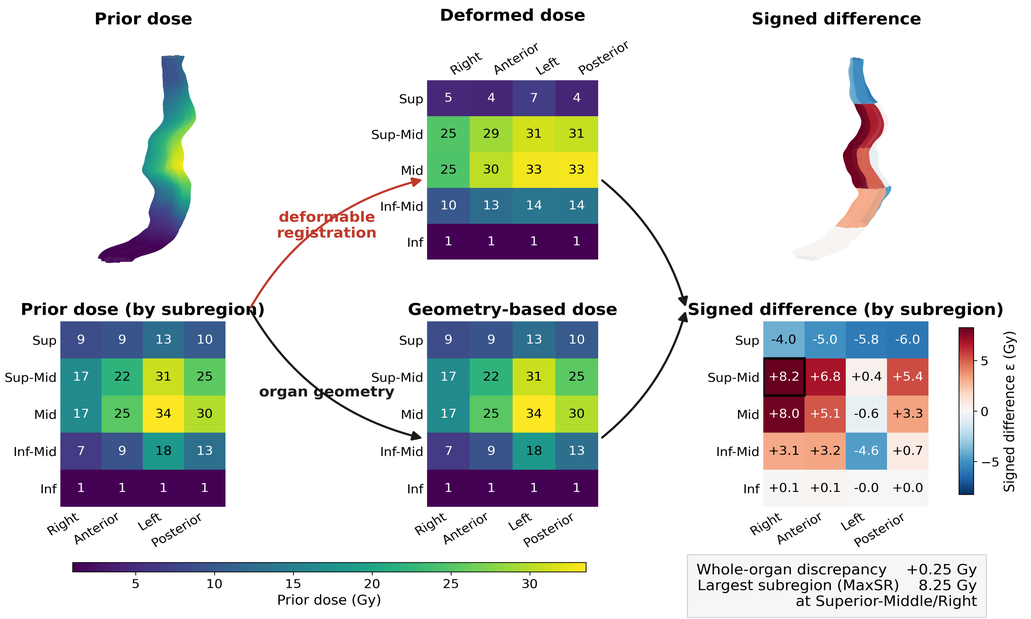

Figure 2. The framework applied to one accumulation. The prior dose is estimated two ways, deformed onto the current anatomy by deformable registration and rebuilt from the organ's own geometry, and their signed difference (deformed minus geometry) is resolved over five axial levels and four sectors. Here the whole-organ discrepancy is negligible at +0.25 Gy, yet the largest subregion reaches 8.25 Gy on the superior-middle right wall (outlined), the localized error that whole-organ agreement conceals.

- Figure 2 shows a representative case passing whole-organ review at +0.25 Gy while carrying 8.25 Gy on the superior-middle right wall, where opposing-sign subregions cancelled to the near-zero whole-organ value.
- Conventional agreement did not capture localized error. At a whole-organ mean dose difference below 0.5 Gy, dose pairs matched on Dice at 0.71 ± 0.02 still reached MaxSR near 13 Gy, so neither summary bounded the localized error (Figure 3). Dice did not differ between the flagged and clean groups (p = 0.75), and a median 47% (IQR 29 to 69%) of subregion error magnitude was masked by cancellation in the whole-organ mean.
- Across 65 patients with 17 esophagitis events, composite mean dose predicted grade ≥2 acute esophagitis in the spatially clean subgroup (AUC 0.818, 95% CI 0.566 to 0.983) but not in the flagged subgroup (0.526, 0.298 to 0.750), with the full cohort intermediate (0.727, 0.584 to 0.854).

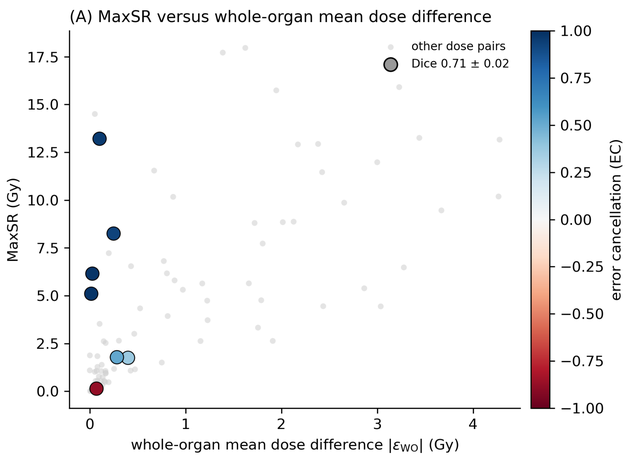

Figure 3. Maximum subregion discrepancy (MaxSR) against the absolute whole-organ mean dose difference for all dose pairs (grey). Dose pairs matched on Dice (0.71 ± 0.02) with a whole-organ difference under 0.5 Gy are enlarged and colored by the error-cancellation index. Their maximum subregion dose difference metric spread across 0.2-13 Gy.

Conclusions

- Whole-organ agreement can hide localized error. Accumulations matching on whole-organ mean , and maximum dose, Dice, and HD95 can still disagree sharply within the organ when such spatial analysis is added.
- This tool bridges geometric validation and dosimetric accuracy verification, enabling physicists to identify error locations and guide clinical review of deformable dose accumulation.
- Studies and treatments relying on deformable dose should consider such spatial validation to ensure accurate assessment

References

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[2] Hardcastle N, et al. Multi-centre evaluation of variation in cumulative dose assessment in reirradiation scenarios. *Radiother Oncol.* 2024;194:110184.
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[4] de Sousa CFPM, et al. Modeling time-dependent recovery to improve esophagitis prediction in thoracic reirradiation. *Int J Radiat Oncol Biol Phys.* 2026.