Multi-Phase Interplay and Gradient Dose Effects on Moving Tumors Calculated Using IGOR

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Purpose & Background

- The interplay effect (between MLC and tumor motion), and the gradient effect (from tumor motion across the PTV dose gradient) cause dose perturbations in moving tumors during RT.
- Some authors have reported that interplay and gradient (I&G) effects during SBRT treatments *are* a clinical concern [1], while others have reported that they are *not* [2].
- I&G effects are *highly* patient specific and depend on: MLC leaf trajectories, dose rate, size of tumor, motion amplitude, and the patient's breathing pattern and breathing rate (BPM). In addition, I&G effects also depend on the tumor's phase of motion at the start of treatment (ie, tumor start phase).

  → I&G effects should be determined for each patient plan where large tumor motion is expected.
- However, measuring I&G effects is difficult and time-consuming and start phases are not considered.

  → I&G effects are often not measured or fully characterized.
- **GOAL: Develop a GUI-driven I&G simulator which incorporates patient-specific parameters *and* multiple start phases for multi-arc VMAT treatments:**

IGOR: Interplay and Gradient Observations in Radiotherapy

Methods & Materials

- Matlab-based (Mathworks Inc., Natick, MA) 3D homogeneous VMAT dose engine [3].
  - Dose for each arc is calculated over 200 control points while applying 3D tumor motion.
  - For each arc, 10 different 3D doses are calculated, each at different start phases spaced 36° apart.
  - All multi-arc start-phase combinations are calculated (Fig 1).

    → 100 3D dose combinations for plans with two VMAT arcs.
- During simulation dose is accumulated in the moving target volume (MTV; GTV+PTV margin) and selected moving OARs.
  - Interplay effects are quantified by comparing simulated MTV DVHs with those obtained by motion-sampling the static dose distribution using the MTV.
  - Gradient affects are quantified by comparing MTV DVHs obtained by motion-sampling the static TPS dose distribution with the PTV DVH obtained from the TPS dose.
- Simulated cosine/triangle motion matched to RGSC traces.
- 1 cm, 2 cm, 3 cm sup-inf motion using CIRS lung phantom008A.
- EBT3 Gafchromic film (Bridgewater, USA); EPSON 10000XL scanner (Suwa, Japan).

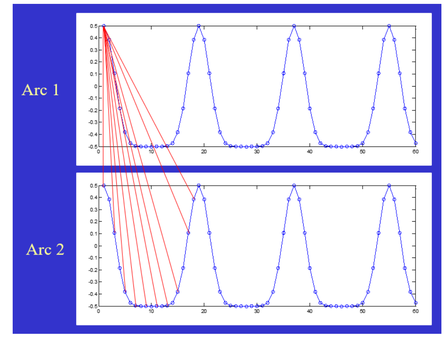

Figure 1. First 10 start phase combinations for a plan with two VMAT arcs.

Results

- IGOR's GUI inputs (Fig 2) facilitate I&G simulations; confidence interval (CI) entry defines upper and lower DVH bounds in output.
- Relative moving-minus-static 2D dose difference maps for 1-3 cm motion agree well between film and IGOR (2 cm motion in Fig 3); moving GTV and MTV mean and SD doses agree to within 1%.
- I&G effects vary greatly between patients and over the different start phase arc combinations (Fig 4a,b):
  - Patient 1: 3 cm of motion, total effects vary from -9.2%–1.4%.
  - Patient 2: 2 cm of motion, total effects vary from 0.9%–4.6%.
- Increasing dose rate (DR) from 800–2400 MU/min for Patient 2 *decreased* I&G effects (3.6% to 2.8%) and *increased* I&G variation (0.3% to 0.8%) over the phase combinations (Fig 4c).
- I&G effects can be clinically significant for hypo-fractionated SBRT treatments even for medium (~ 2 cm) tumor motion.
- In general, interplay effects (Fig 5a) generate dose heterogeneities in the MTV; the DVH's mean is value mostly unchanged. Gradient effects (Fig 5b) manifest as a shift (usually decrease) in dose.
- IGOR I&G simulations complete in < 10 minutes on a standard PC for a 2-arc VMAT lung plan.

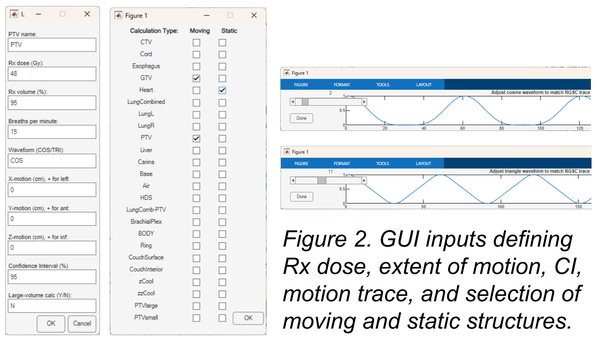

Figure 2. GUI inputs defining Rx dose, extent of motion, CI, motion trace, and selection of moving and static structures.

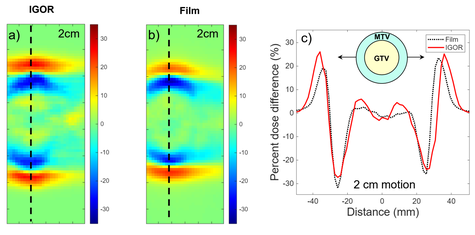

Figure 3. Moving-minus-static percent dose difference maps for IGOR (a) and film (b) for 2 cm motion in a CIRS lung phantom for a 2-arc delivery; corresponding difference profiles in (c).

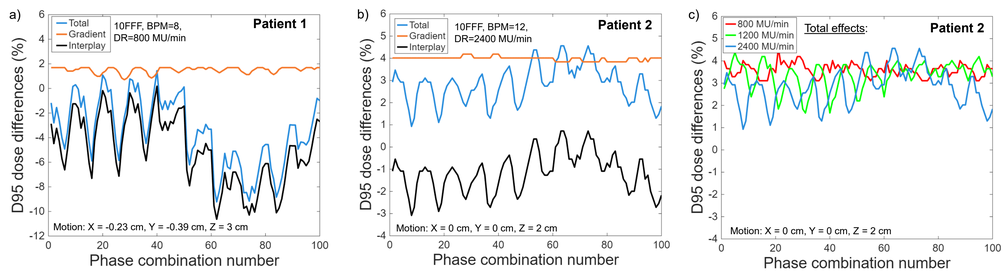

Figure 4. Interplay, gradient, and total I&G effects as a percent of the TPS PTV D95 over all phase combinations from a 2-arc treatment are shown for two patients (a,b). Total I&G effects for Patient 2 are shown (c) for dose rates of 800, 1200, and 2400 MU/min.

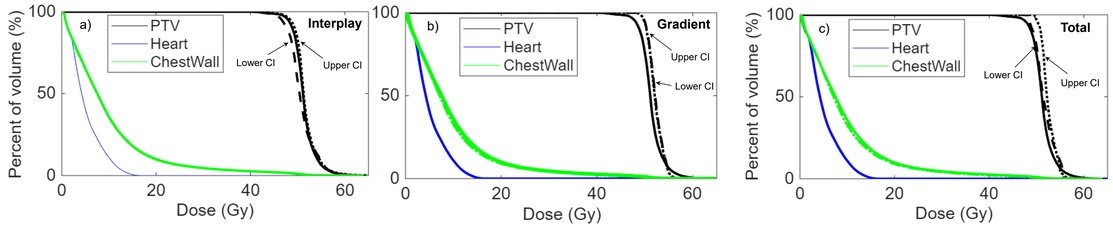

Figure 5. DVH results from IGOR showing interplay (a), gradient (b) and total I&G effects (c) for the moving PTV and chest wall structures (heart is a static structure). TPS DVHs are shown as solid lines, the lower (dashed line) and upper (dotted line) confidence interval DVHs are shown.

Conclusions

- A multi-phase analysis is needed to fully characterize I&G effects on moving tumors during hypo-fractionated SBRT treatments.
- I&G effects are patient specific and should be evaluated per-patient for patient plans where large tumor motion is expected.

References

[1] **Gauer et al.** Under-reported dosimetry errors due to interplay effects during VMAT dose delivery in extreme hypofractionated stereotactic radiotherapy. *Strahlenther Onkol.* 2018;194:570–579.

[2] **Stambaugh et al.** Experimentally studied dynamic dose interplay does not meaningfully affect target dose in VMAT SBRT lung treatments. Med Phys. 2013;40:091701.

[3] **Steciw S.** A convolution-superposition fluence model for the Siemens HD120 multi leaf collimator with application to a 3D VMAT dose engine. *Biomed Phys Eng Express.* 2023;9:065004.

Acknowledgements

The author would like to thank Dr. Bryson Dietz for conducting the film measurements presented in this work.