# FREE-BREATHING–GATED DELIVERY CAN ACHIEVE HIGH-QUALITY PROTON TREATMENT FOR LUNG CANCER PATIENTS

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## HYPOTHESIS

- Free-Breathing Spirometer-Gated Proton Therapy can mitigate respiratory motion uncertainties without compromising patient comfort and dosimetric quality with existing cone-beam(CBCT) based image-guidance(IGRT).

## INTRODUCTION

- While 30% of lung cancer patients cannot tolerate breath-hold, free-breathing(FB) proton pencil-beam-scanning(PBS) deliveries compromise target coverage from the interplay effects of large motion.
- Currently spirometer-based motion monitoring is utilized in clinics for deep inspiration breathhold (DIBH) proton treatments
  - reproducible to within 5% of nominal plan
  - Reduced target volume
- We focused on establishing a safe treatment planning and delivery workflow utilizing existing CBCT imaging technology for spirometer gated free breathing (FB) treatments.

## METHODS

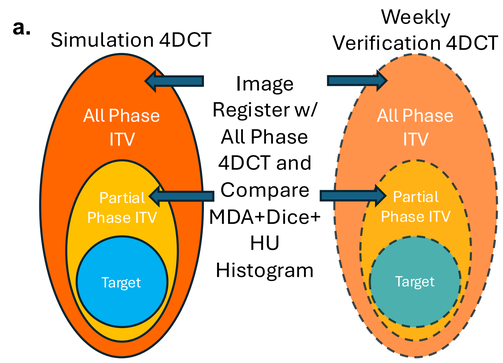
- Develop a motion-evaluation tool for variable gating phases that assessed motion and water-equivalent-thickness(WET) variation
- Target contours(iGTV), partial-phase CT, and treatment plan are created based on maintaining <6mm target motion.
- Verification (4D)CT scans were used as a surrogate for average CBCT to confirm reproducibility of IGRT with full-phase target while delivering over a partial-phase target, retrospectively. Image registration quality of partial-phase target and full-phase target was quantified comparing simulation 4DCT scan and verification scan(Vscan).
- End-to-end testing was performed with a 4D-motion phantom, including confirmation of delivery within the gating window.

## CONCLUSION

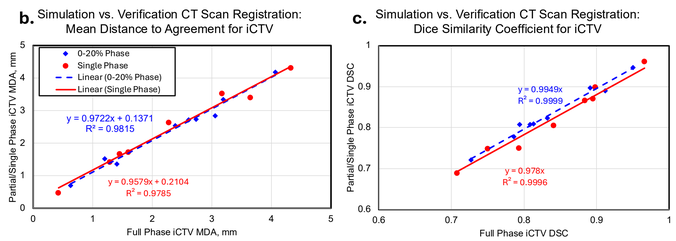
- Successfully performed E2E testing of Free-Breathing Spirometer-Gated Proton Therapy with 4D motion phantom
- **Beam-On only during gating window verified by SICA, even in irregular breathing patterns**
- **Average CBCT may be utilized for IGRT**, while delivering over a gated window. (Requires more validation with more clinical cases)
- **Future Work:** More validations considering **patient variability** (tumor position, size) with a **larger patient cohort.**
- Clinical decision on Gating Window is balancing:
  - Motion mitigation
  - ITV volume
  - Dose to OAR's
  - Delivery Time
  - Planning/Delivery Strategy (SFO vs MFO) – Dose Heterogeneity

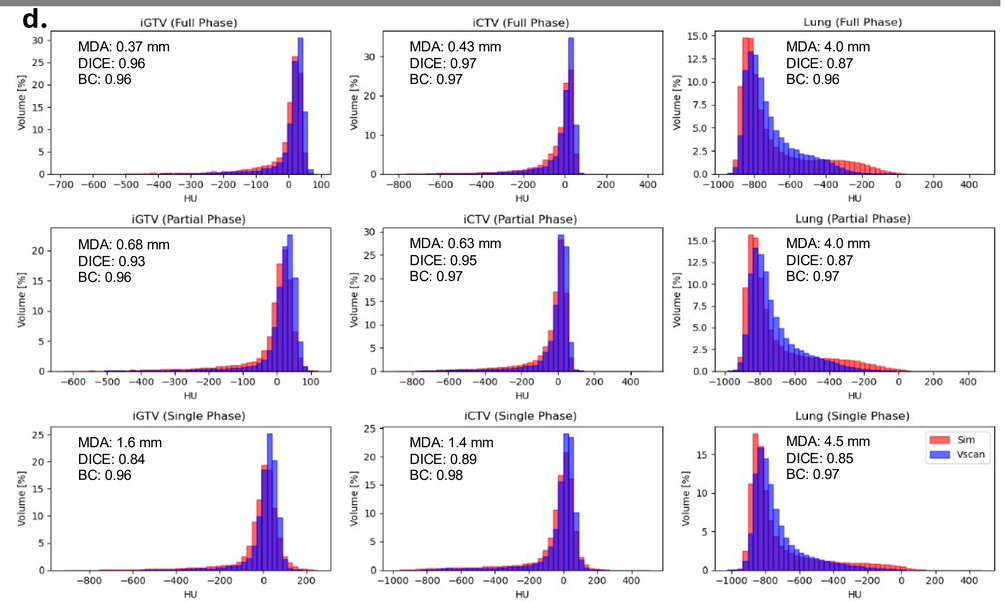
## FB-GATED DELIVERY USING CBCT FOR IGRT WAS DEMONSTRATED VIA PLANNING ON EXAMPLE PATIENT AND END-TO-END TESTING WITH A 4D-MOTION PHANTOM.

## ALL-PHASE CBCT IGRT MAY ENSURE REPRODUCIBILITY FOR PARTIAL-PHASE DELIVERY




~1-to-1 Relation Between Full-Phase vs. Partial Phase Fusion MDA/DICE



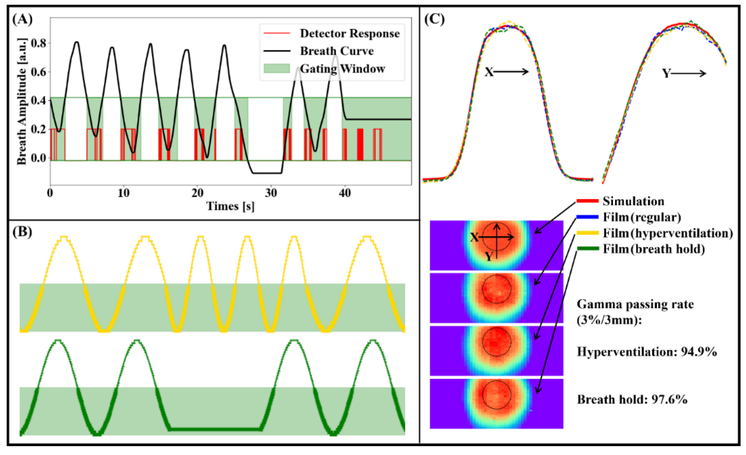

✓Mean Distance to Agreement<2mm
✓0.8<DICE Similarity Coeff.<1
✓0.9<Battacharrya Coeff. (HU Overlap)<1

*May Require tighter agreement for SBRT/SRS treatment

**Figure 1.** Verifying the feasibility and reproducibility of CBCT-based IGRT while planning and delivering within a gated window for a patient from figure 3. 4DCT verification scan (Vscan) was used as a surrogate for CBCT to compare the registration accuracy of a full-phase target for partial (80-10%) phase or single-phase delivery. **a.** Illustration of the comparison **b.** Mean-distance-to-agreement (MDA) and **c.** Dice-similarity-coefficient (DSC) to correlate registration accuracy of full phase to partial/single phase target, comparing CT sim scan to Vscan **d.** MDA, Dice, and HU histogram overlap (Battacharrya coefficient, BC) using full phase iCTV for image registration. Ideally, MDA<2mm, 0.8<DICE<1, 0.9<BC<1.

## PATIENT UNCERTAINTIES

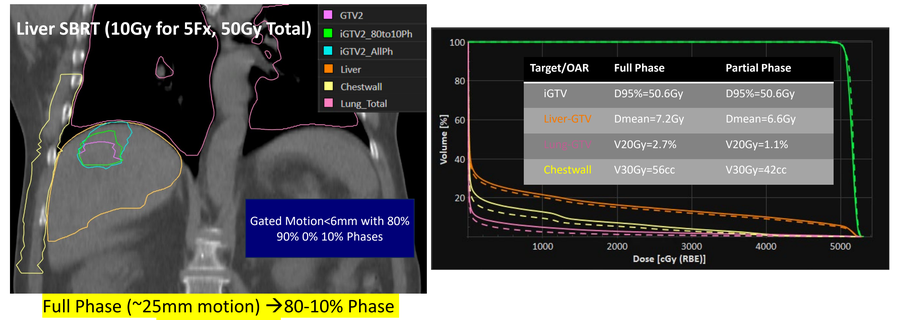
**Beam ON only During Gating Window even for Irregular Breathing**




**20kHz strip ion chamber array detector confirmed proton delivery only within gating window**

**Figure 2.** Results for gating accuracy and irregular breathing tests with the 4D motion phantom. a. physiological breathing trace (black line) measured by SDX (spirometer) with a gating window (GW) selected around the exhale. The beam-on signals detected by the 2D ion chamber array (red line) exist only within the GW, confirming the great correspondence between the gating signal and the actual beam delivery. b. Irregular breathing patterns of motion phantom, including hyperventilation (yellow line) and breath hold (green line), as measured by SDX, with the thicker parts showing where SDX sent the beam-on signal to the beam delivery system. c. comparison of 2D dose distribution and line profiles from simulation and film measurements under regular breathing, hyperventilation, and breath-hold patterns shown in (B), all compared to the simulation dose.

**Choosing Gating Window to keep Target Motion <6mm**




Full Phase (~25mm motion) →80-10% Phase (~6mm motion)
iGTV Volume: 86cc → 45cc

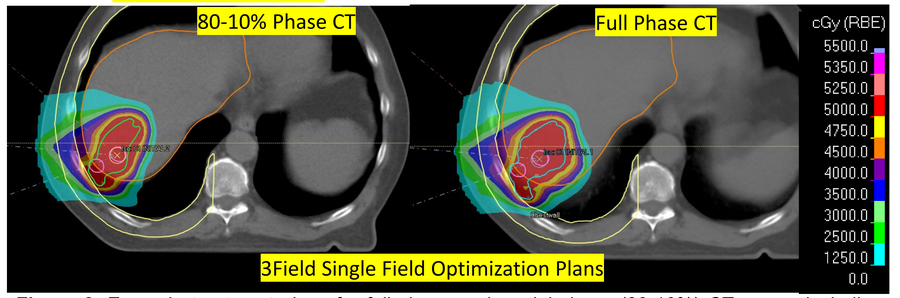



**Figure 3.** Example treatment plans for full-phase and partial-phase (80-10%) CT scans, including dose distribution, dose-volume histogram, and volume changes in the target and lung. 80-10% phase was chosen for the gated plan to reduce motion from 12mm to <6mm. Equivalent beam angles were used for the two plans. Note: iGTV=GTV+internal intrafraction target motion