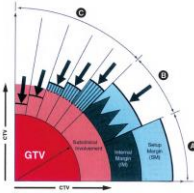


# End of ITV: Gating is the Best ITV Killer



Daniel A. Low, Ph.D.  
UCLA

---

---

---

---

---

---

---

---

## Disclosures

- Varian Grant
- Siemens Grant
- Accuray Grant

---

---

---

---

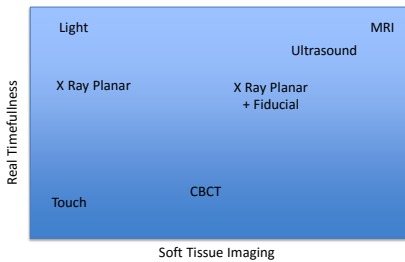
---

---

---

---

## What Is So Hard?



---

---

---

---

---

---

---

---

### \*Respiratory Motion\*

- Lung
- Liver
- Pancreas, etc.
- Liver motion typically greater than lung, penumbra also sharper, so consequence of missing is worse

---

---

---

---

---

---

---

---

### MR+RT

- 3 companies formed, one academic investigational device
  - ViewRay
  - Elekta/Philips
  - University of Alberta – MagnetTx (6/21/16)
  - Australian Program

---

---

---

---

---

---

---

---

### Can MR+RT Eliminate ITV?

- Excellent soft tissue contrast
- Systems have or will have at least rapid ( $\geq$  4fps) planar imaging
- Can this be used to eliminated ITV?

---

---

---

---

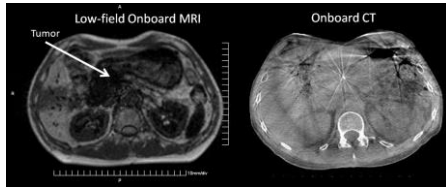
---

---

---

---

### Liver



---

---

---

---

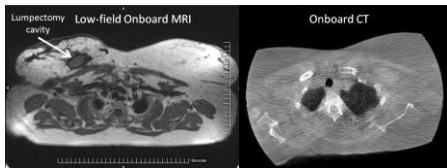
---

---

---

---

### Breast



---

---

---

---

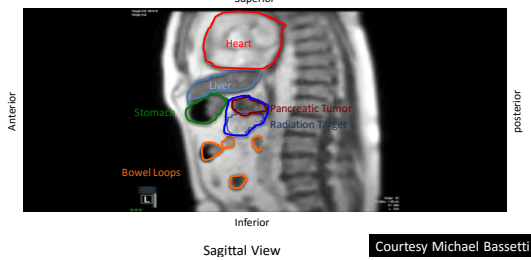
---

---

---

---

### Pancreas IMRT with breath hold gating



---

---

---

---

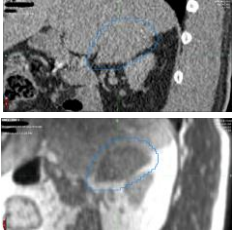
---

---

---

---

### Recent ViewRay Patient



- Treating HCC metastasis to adrenal.
- Poor definition vs. liver on non-contrast CT
- Easily visible on 0.35T MR w/ Eovist contrast injected prior to every Tx.
- > 1 cm motion during normal breathing.
- SBRT 8 Gy x 5 fx, gated treatment.

---

---

---

---

---

---

---

---

### \*Free Breathing\*

- Typically exhale phase longer than other phases
- More efficient to gate at exhalation
  - If gating at 50% of time, most efficient at exhale
  - Decreases motion by more than half

---

---

---

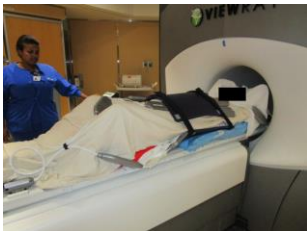
---

---

---

---

---



---

---

---

---

---

---

---

---

### ViewRay Gating Accuracy - Methods

Target rod film insert (MRI w/dose)

Target rod film insert (jpeg)

CIRIS Gating Phantom

Courtesy Jim Lamb

Actual tumor trajectories from MRI-guided treatments.

---

---

---

---

---

---

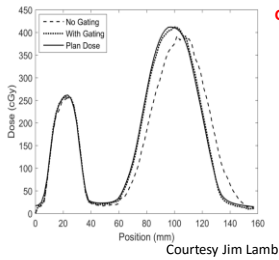
---

---

---

---

### ViewRay Gating Accuracy - Results



Gamma pass rate vs. static plan - 3%/3mm

Trajectory	Ungated	Gated-3 mm margin, 5% ROI
Breath hold	49.9%	95.2%
Free breathing 1	25.0%	91.7%
Free breathing 2	32.9%	98.6%

32 combinations of trajectory and gating parameter were evaluated, this is a representative subset.

---

---

---

---

---

---

---

---

---

---

### What About The Rest Of Us?

- Most of us don't have MR+RT machines
- Can we eliminate ITV?
- Examine ITV from breathing motion

---

---

---

---

---

---

---

---

---

---

## Breathing Motion Management

- Typical Workflow
  - 1) Get 4DCT to determine motion
  - 2) Motion? Plan ITV for gating or non-gating
  - 3) (non marker) Get CBCT at Linac
  - 4) Position tumor and treat/gate

---

---

---

---

---

---

---

---

## What's Wrong With That?

- 4DCT provides inferior images with respect to noise and sorting artifacts
- 4DCT provides no quantitative information regarding its own quality/accuracy
- Treatment planning with 4DCT does not provide guidance as to tradeoffs between motion mitigation strategies

---

---

---

---

---

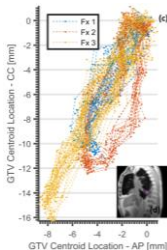
---

---

---

## What's Wrong With That?

- Breathing patterns & lung tumor positions change day to day
- At the machine, 4DCBCT provides similar artifact ridden information that has no quantitative assessment and sensitivity to irregular breathing patterns



---

---

---

---

---

---

---

---

## And During Treatment?

- How to translate mediocre 4DCT data to real time?

---

---

---

---

---

---

---

---

## Solution: Model-Based CT

- Breathing is irregular in TIME
- Develop a biologically-guided motion model
- Breathing motion is *not* irregular in AMPLITUDE
  - Hysteresis can be a function of breathing RATE
- Our model takes amplitude and rate and converts to position in time

---

---

---

---

---

---

---

---

## Our Model (“5D”)

- Mathematically:

$$\vec{X} = \vec{X}_0 + \underset{\text{amplitude}}{\vec{\alpha}v} + \underset{\text{rate}}{\vec{\beta}f}$$

---

---

---

---

---

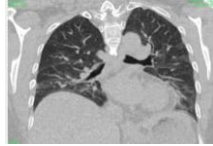
---

---

---

## Model Data

- Useless unless we can measure tumor position (and other lung structures) during free breathing and correlate against amplitude and rate
- Fast Helical Free Breathing CT (FHFBC T)
  - All modern CT scanners can do this!
  - Monitor breathing during scan acquisition
  - Take scans back and forth until required number reached (10-ish)



---

---

---

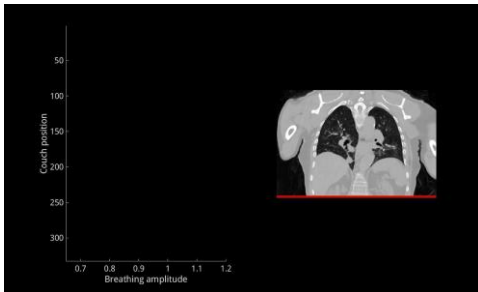
---

---

---

---

---



---

---

---

---

---

---

---

---

## Steps

- Fast helical CT scans have no sorting artifacts
  - Relatively few and small motion artifacts
- Deformably map fast helical CT scans to single "reference" scan
- Assign breathing phase to each slice
- Use deformation maps to fit model

---

---

---

---

---

---

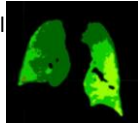
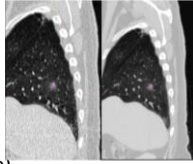
---

---



## Output

- Unlike 4DCT:
  - No sorting artifacts
  - Use most or all of dose (low noise)
  - Can create image at any breathing phase
  - Verification of accuracy (rebuild original helical CT scans and compare)



Courtesy Dylan O'Connell

---

---

---

---

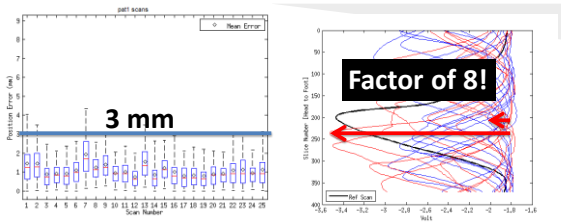
---

---

---

---

## Error Distribution by the Scans




---

---

---

---

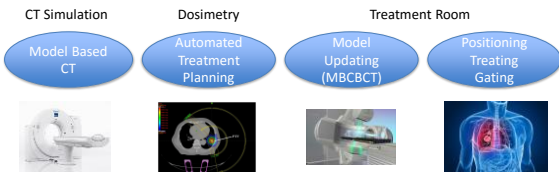
---

---

---

---

## Plan




---

---

---

---

---

---

---

---

## Conclusions

- For those of us that MR+RT
  - ITV is dead
- For those of us that don't have MR+RT
  - ITV may be dying for breathing motion
  - Will require further development and commercialization

---

---

---

---

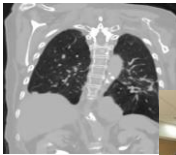
---

---

---

## Thank You!

- Daniel A. Low, Ph.D.
- John Lewis, Ph.D.
- Tai Dou, Ph.D.
- Dylan O'Connell
- Lisa Yang
- James Lamb, Ph.D.
- Dan Ruan, Ph.D.
- David Thomas, Ph.D.
- Anand Santhanam, Ph.D.
- Hao Gao, Ph.D.
- Jiulong Li
- Minsong Cao
- Yingyi Yang
- Percy Lee, M.D.



---

---

---

---

---

---

---