Breathing Motion-Induced Dose Delivery Error Evaluations as Applied to Tomotherapy Dose Delivery

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Research work carried out at: Washington University in St. Louis
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Tomotherapy

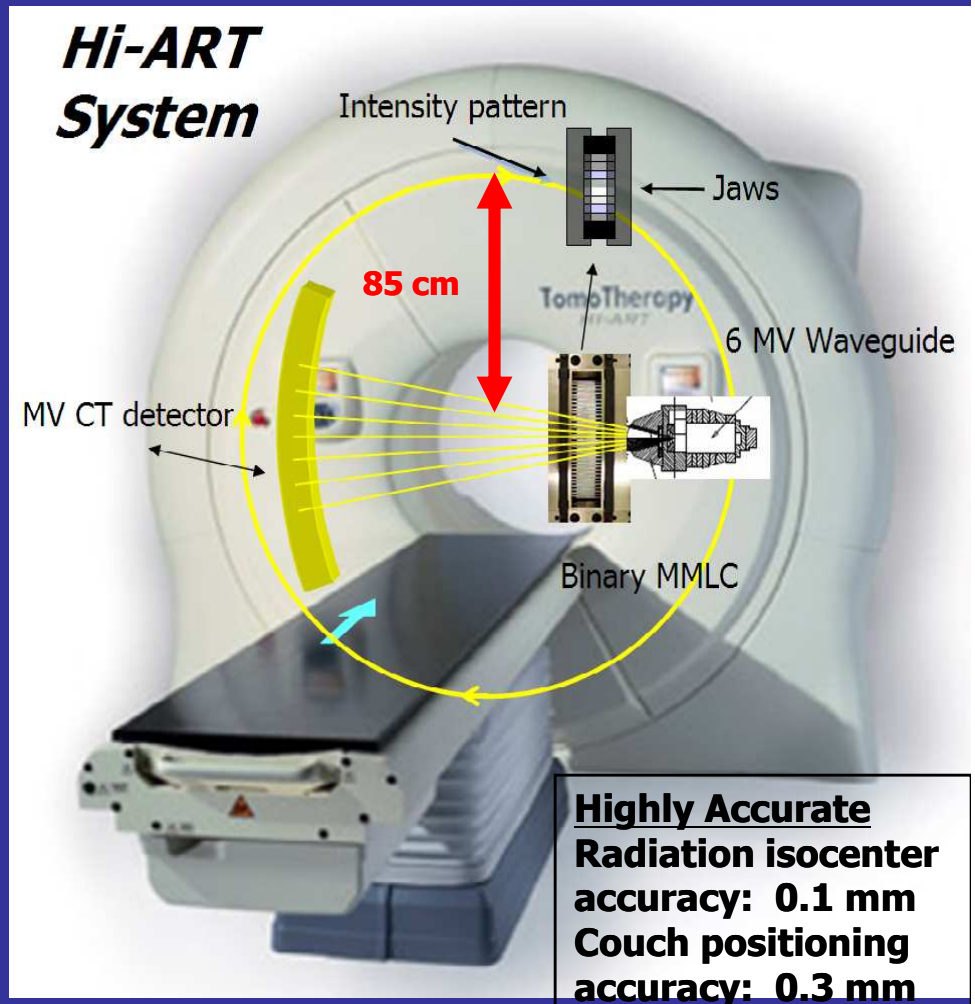
Major Components:

Tx Machine:

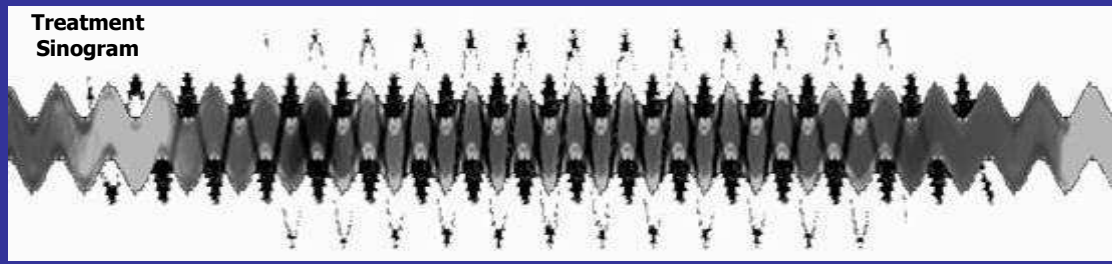
- Linear accelerator
- Binary multileaf collimator
- On board megavoltage - fan-beam CT scanner
- Computers - data acquisition and delivery
- Automated, computer controlled Tx couch

Outside Tx Room:

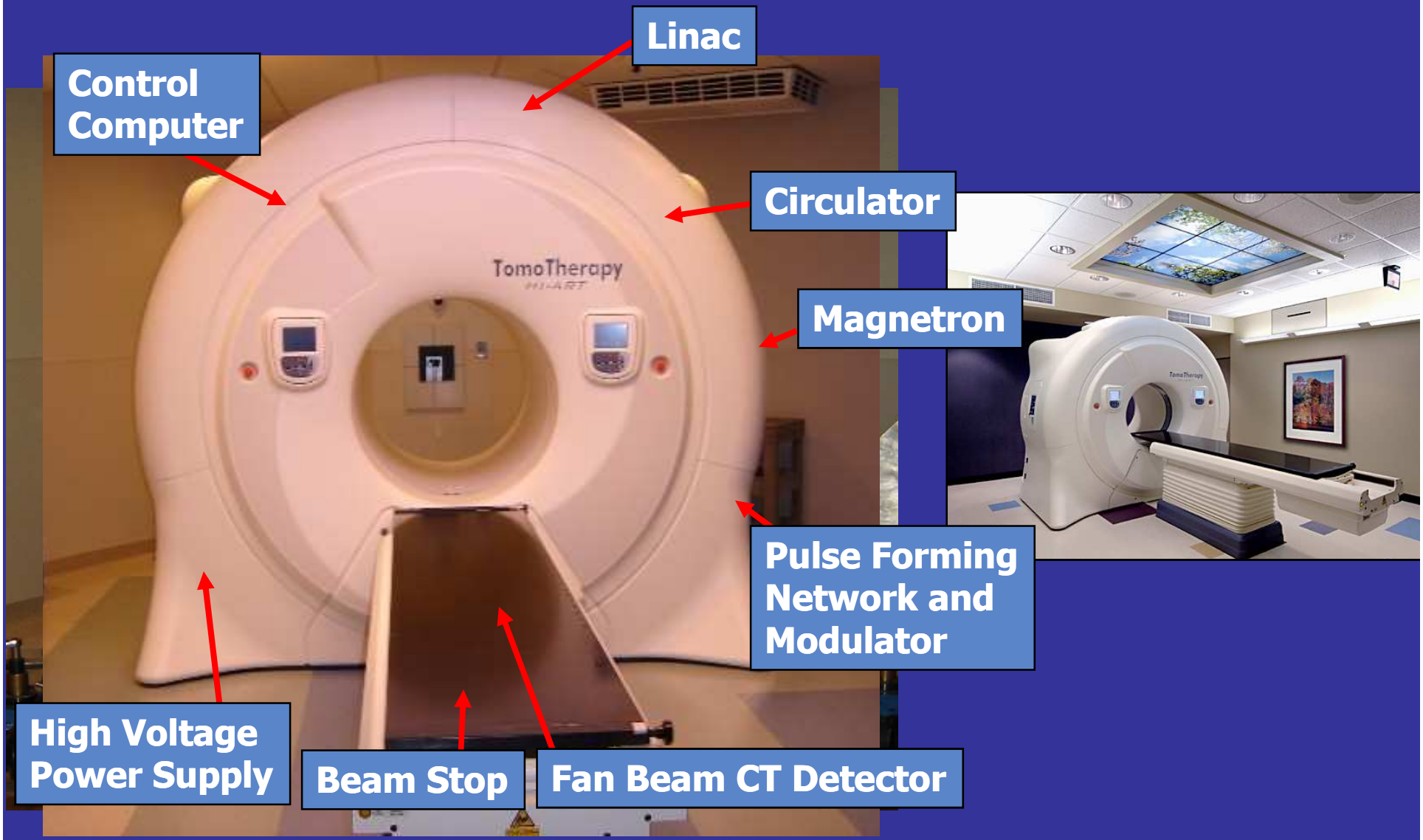
- Cluster rack– array of 32 CPUs
- 0.5 TB storage space
- Treatment planning and QA station



Highly Accurate
Radiation isocenter accuracy: 0.1 mm
Couch positioning accuracy: 0.3 mm



Hi-ART Components



Helical Tomotherapy

- Helical tomotherapy (literally “slice therapy”) is a fully integrated purpose designed Intensity Modulated Radiation Therapy (IMRT) or Image Guidance Therapy (IGT) delivery system
- An integrated system to use Megavoltage Computed Tomography (MVCT) for image guidance, which combines the benefits of tomotherapy and on-line volumetric imaging.
- Allows for integration of volumetric imaging and online validation for daily localization to achieve higher levels of conformality
- Dose conformality is affected by breathing motion.

Breathing Motion Modeling: Introduction and Previous Work

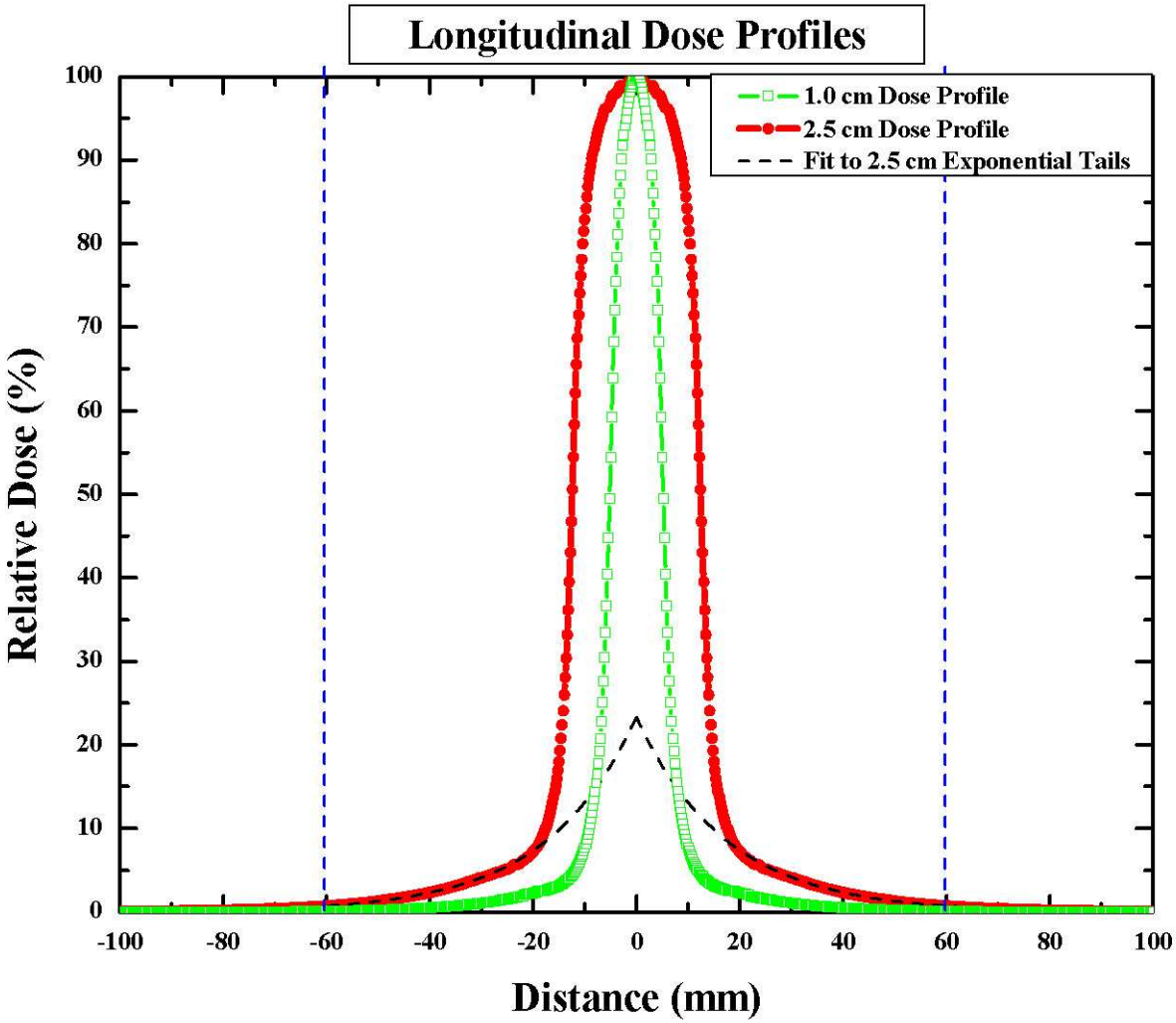
- Breathing Motion – Dose delivery errors in IMRT
- Previous works – Breathing frequency blurs errors
  (Yang et al, Med. Phys. 24, 425; Yu, et al. Phys. Med Biol. 43 91; Kissick, et al. Med. Phys. 32, 2346; Kanagaki et al Phys Med Biol. 52, 243)
  - Integrate dose from open-field sliding window
  - Typically use periodic breathing models
- Tomotherapy sliding motion slower than conventional MLC, but consistent narrow window

Breathing Motion Modeling: Our Study

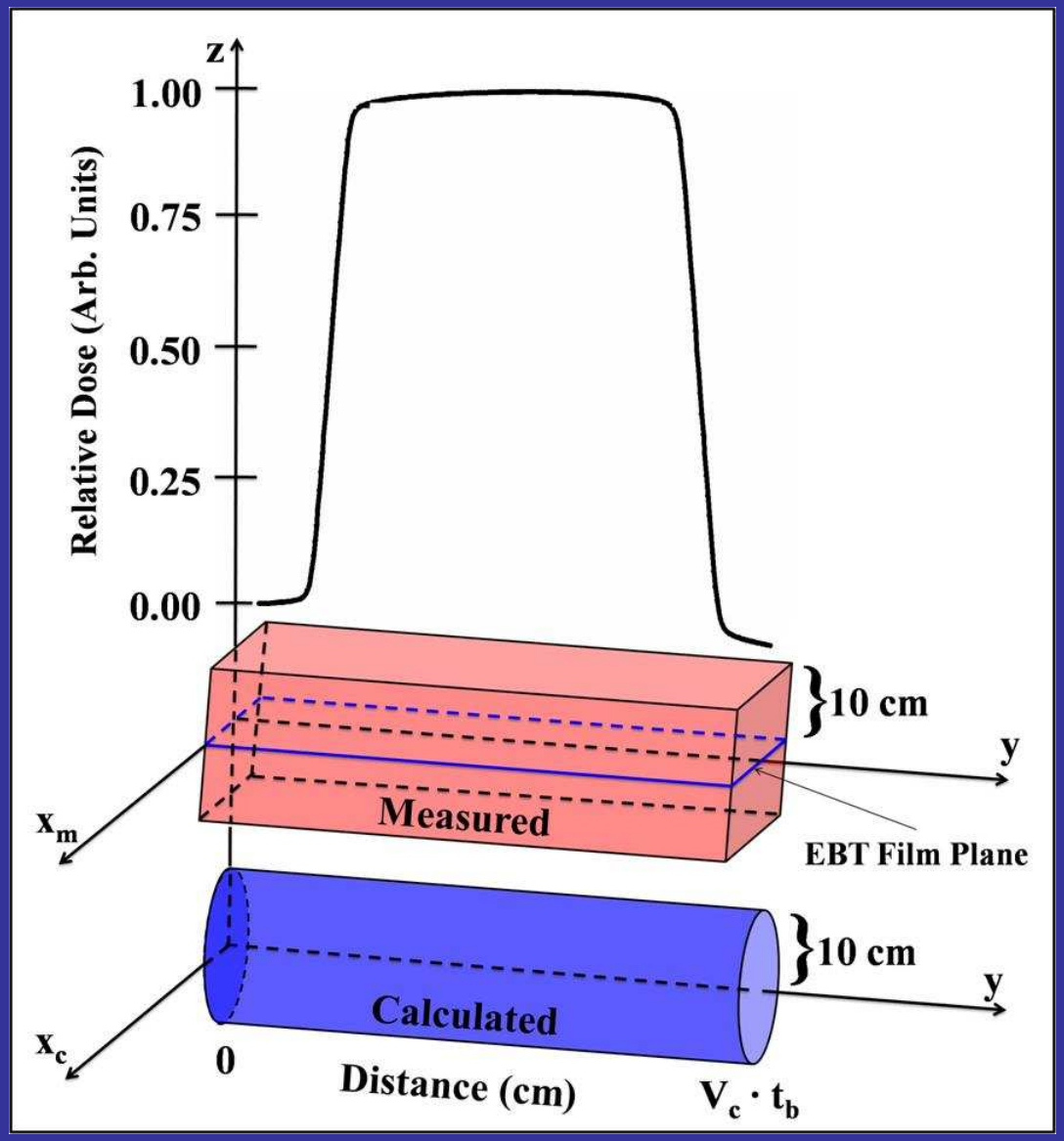
- Used *measured* dose profile (10 cm depth)
- Translate measured profile:
  - Couch velocity
  - Superimposed breathing motion of actual patient
- Breathing Motion = Scale factor × tidal volume
  - Allows multiple motion magnitudes to be studied
  - Scale factor of 0 = no breathing motion
- Convolve motion and profile = delivered dose profile
  - Convolution validated with measurement

Breathing Motion Modeling: Our Study

- **Investigated Parameters**
  - **Field width (1.0 cm, 2.5 cm)**
  - **Couch speed**
    - **Pitch**
    - **Modulation factor**
- **Used recorded patient breathing patterns**
- **Validate calculation algorithm with measurement**

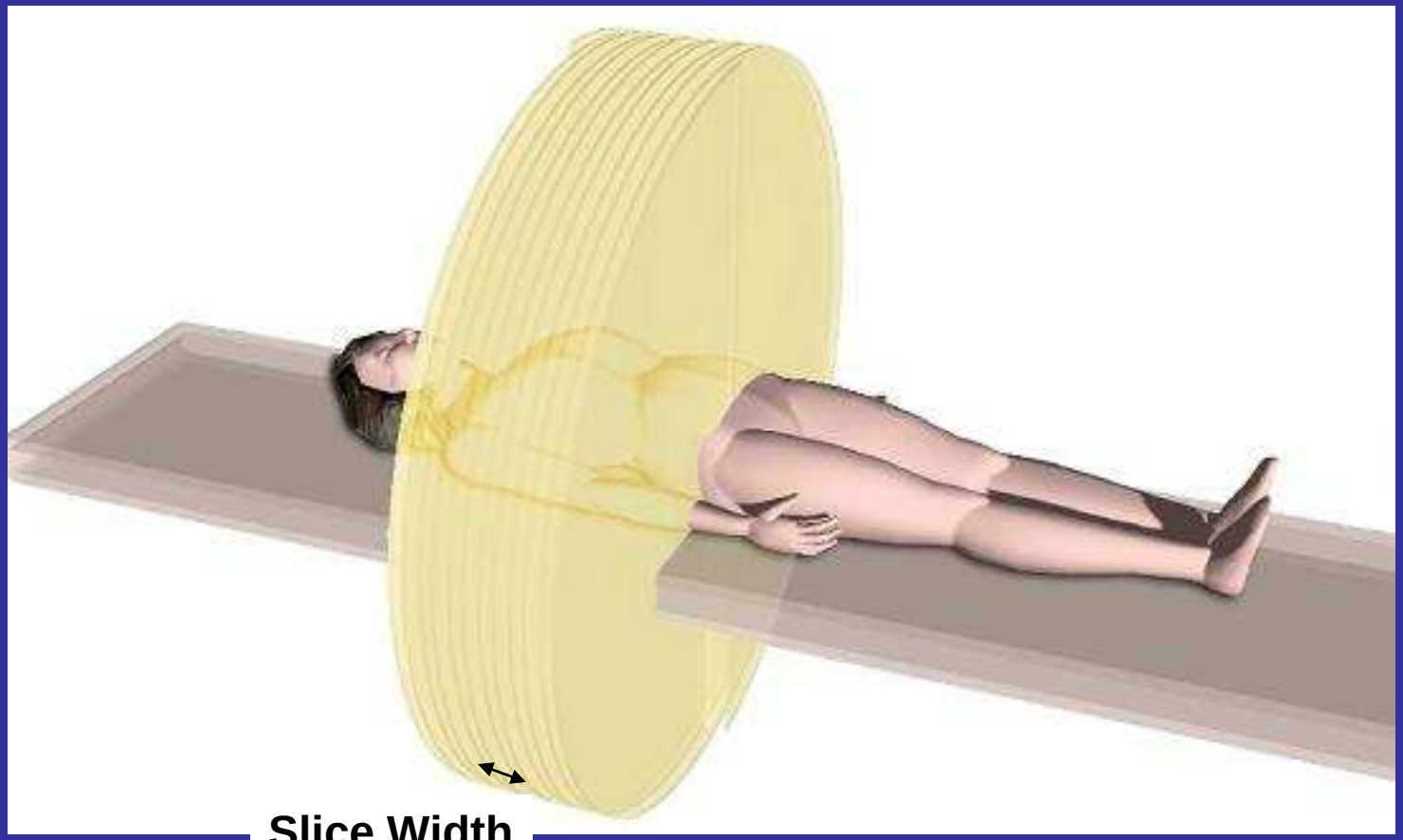


- Measured longitudinal dose profiles
- Setup was 10cm depth using rectangular slab geometry
- Profiles normalized to maximum measured dose
- Individual dose profiles combined for total measured and calculated dose profiles



- Measured and calculated Tomotherapy treatment delivery for a 2.5 cm field width
- Setup was 10cm depth using rectangular slab and cylindrical geometries
- Couch motion was directed along +y-axis.
- Individual dose profiles combined for total measured and calculated dose profiles
- Dose error ratio calculations were carried out at the isocenter

Helical Pitch



Slice Width

$$\text{Pitch} = \frac{\text{Distance Traveled Per Rotation}}{\text{Slice Width}}$$

Modulation Factor

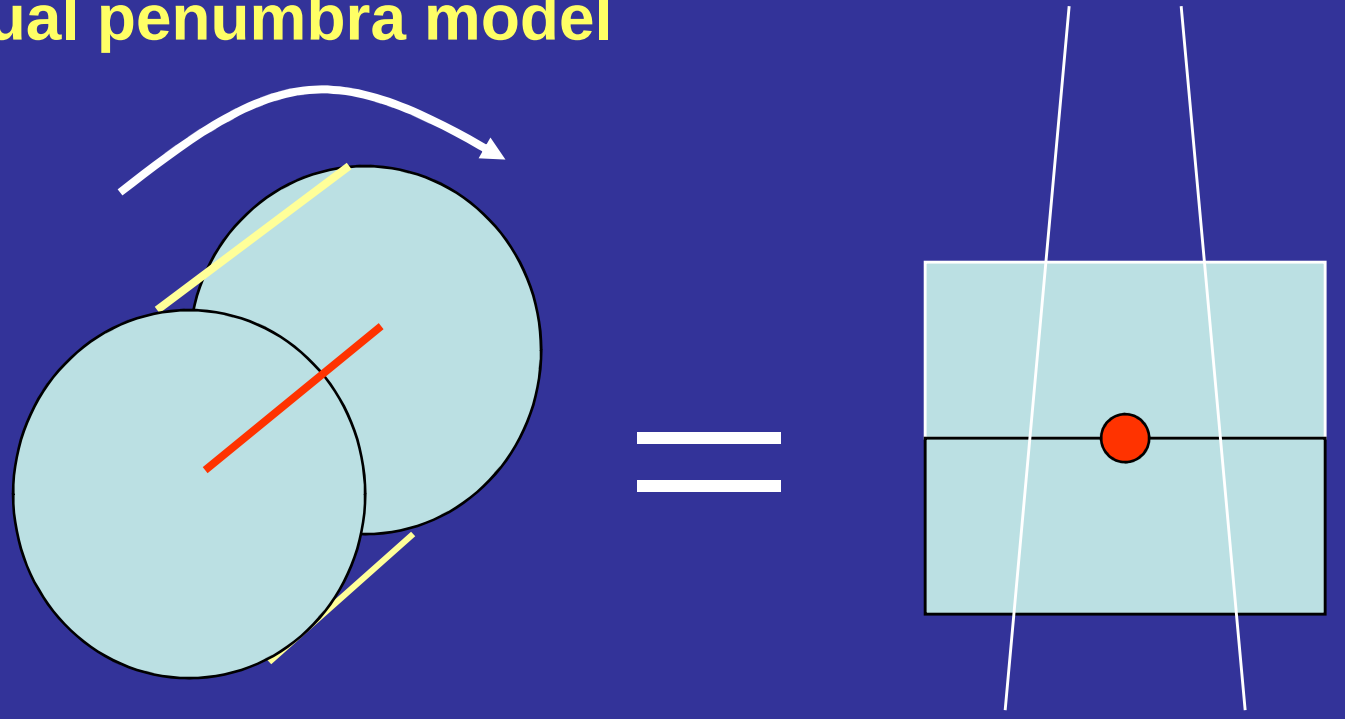
- Definition:
  - the ratio of the maximum to the average leaf open time for the projection (the averaging excluding leaves beyond the projection's field edge, which do not open)

    (a 'projection' corresponds to a gantry rotation of just over 7º, giving 51 projections per revolution)

J D Fenwick *et al.* PMB, Vol. 50, pp. 1505-1517, 2005

Breathing Motion Modeling: Our Study – Open Field

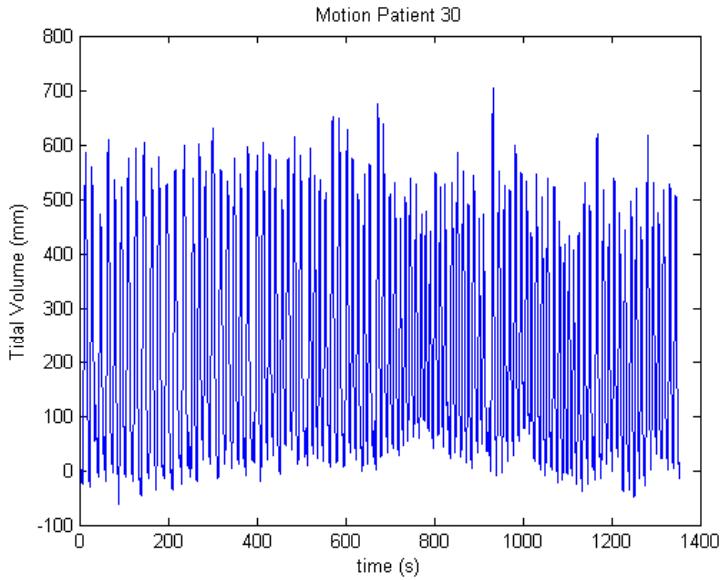
- **Study Tomotherapy model in simplified geometry**
  - **Central axis of cylindrical phantom, no modulation**
  - **Symmetry equivalent to parallel motion in flat phantom**
- **Used actual penumbra model**



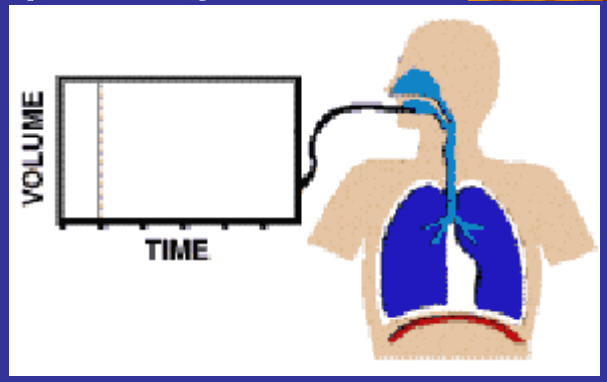
Assumption of Symmetry

Breathing Data

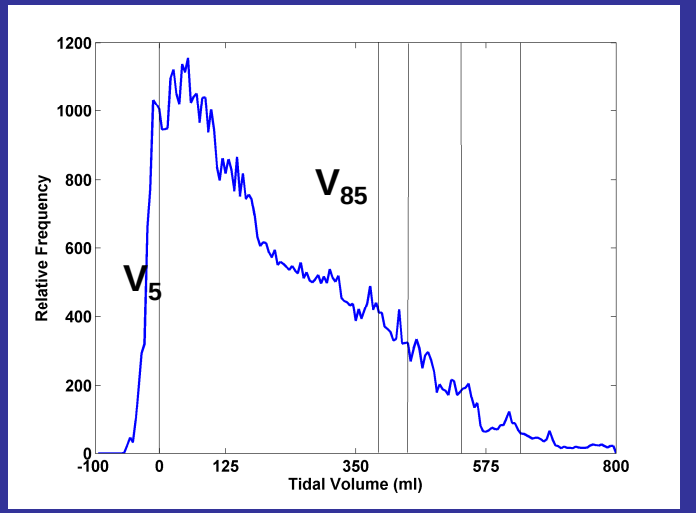
Regular Breather



Spirometry



Motion extent label is at 80th percentile tidal volume ($V_{85} - V_5$)



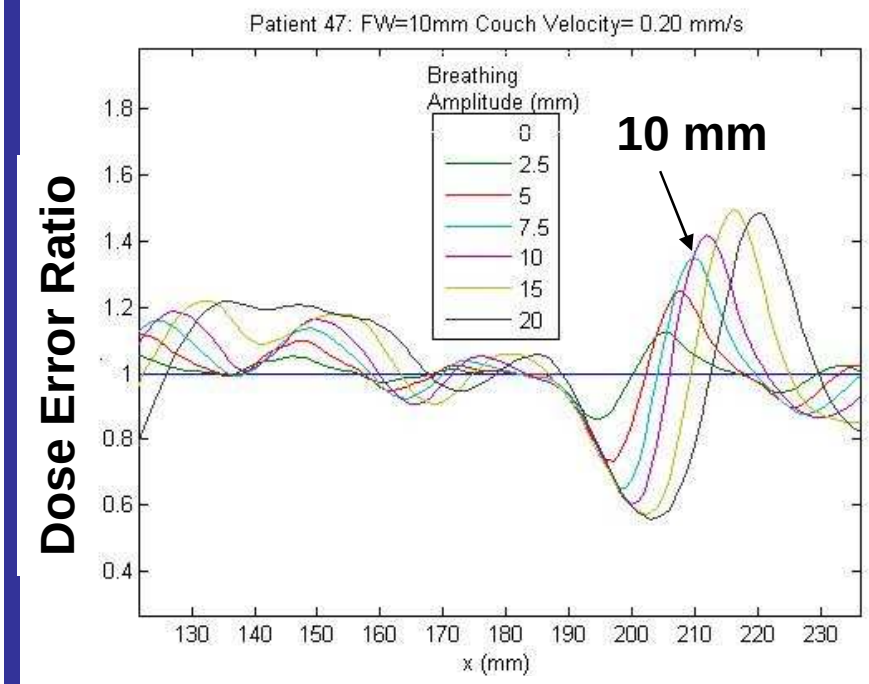
Simulation Parameters

52 Patients

Field Width (cm)	Couch Velocity (mm/s)	Breathing Amplitude (mm)
2.5	0.45 - 0.75	0 - 20
1.0	0.10 - 0.3	0 - 20

Simulation Results – Open field

0.2 mm/s



X (mm)

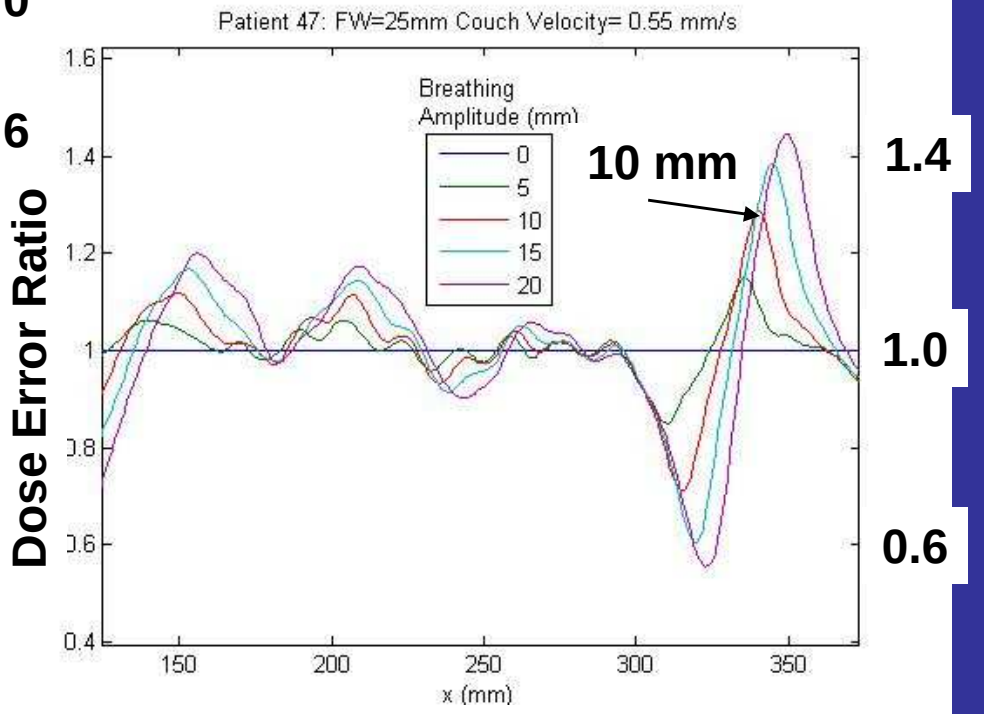
1.0 cm Field Size

1.4

1.0

0.6

2.5 cm Field Size



1.4

1.0

0.6

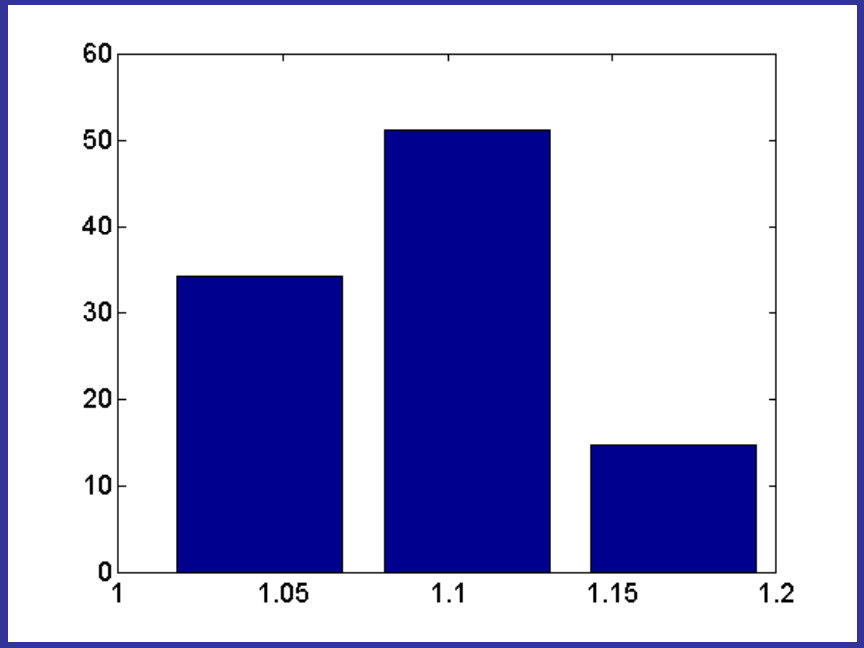
0.55 mm/s

X (mm)

Results: 52Patients – open field, 10 mm

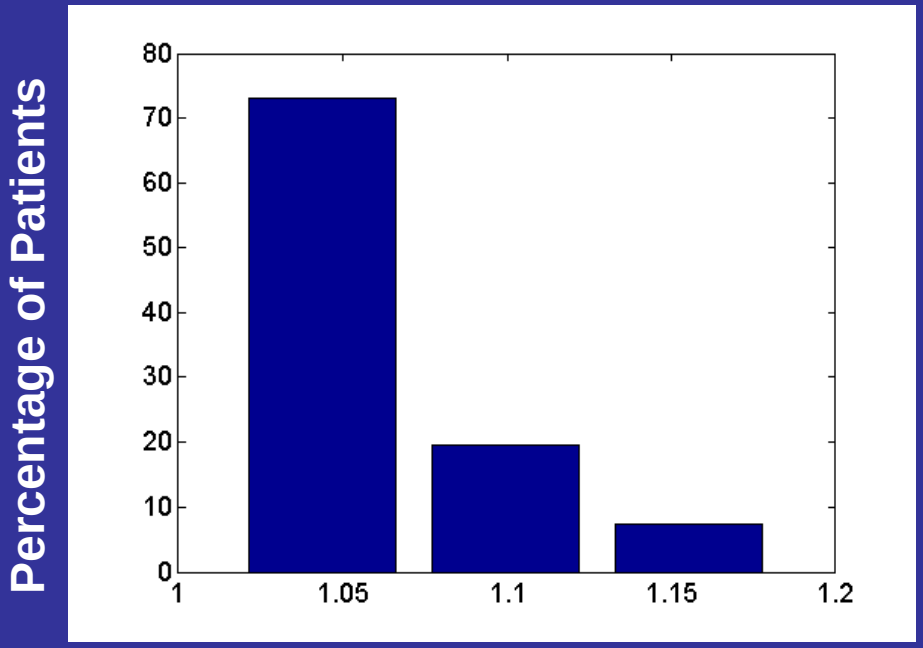
Field Width = 1.0 cm

Couch Velocity = 0.20mm/s



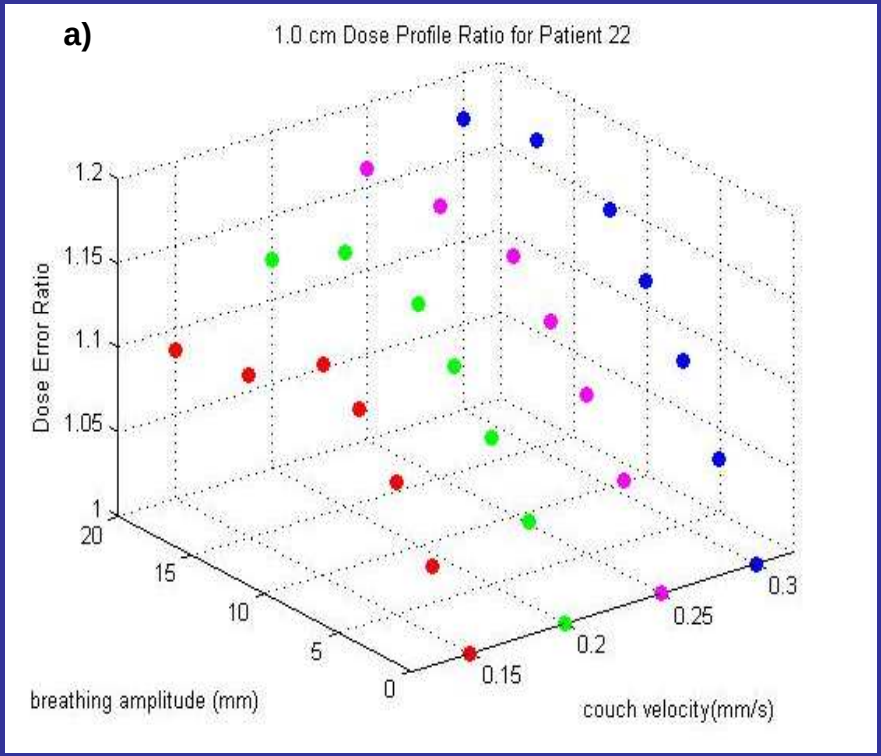
Field Width = 2.5 cm

Couch Velocity = 0.55mm/s

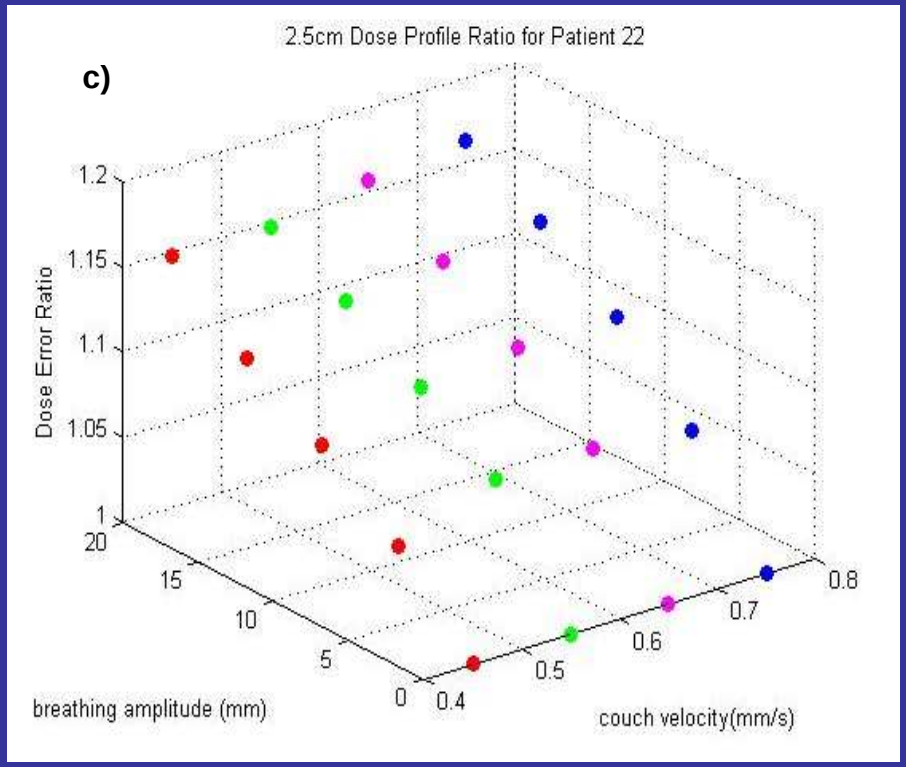


Results:
Patient 22 - open field

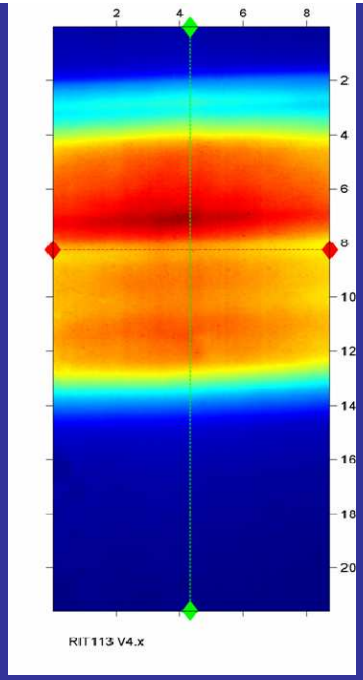
Field Width = 1.0 cm

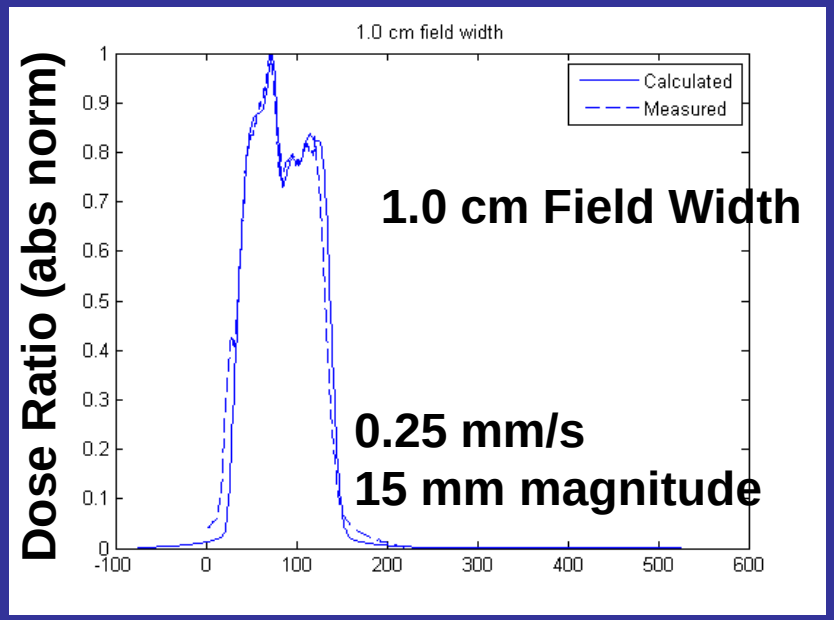


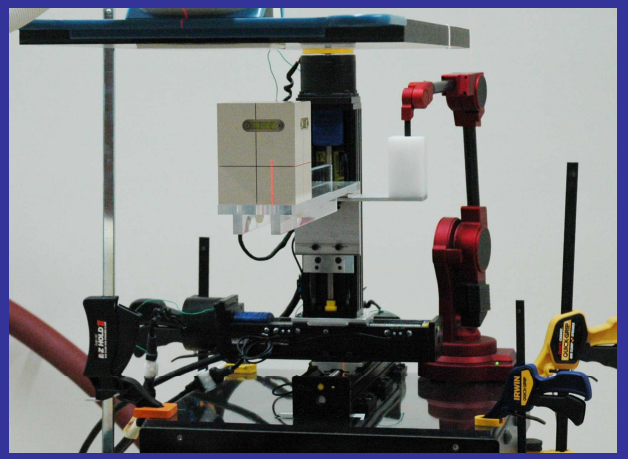
Field Width = 2.5 cm

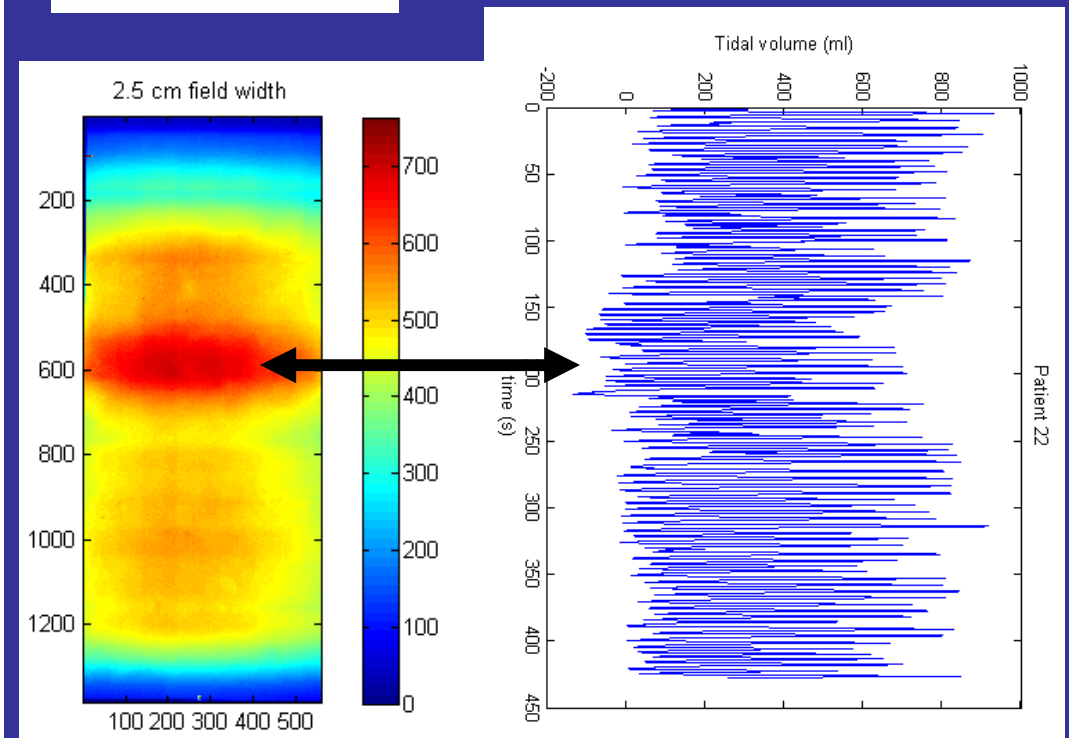


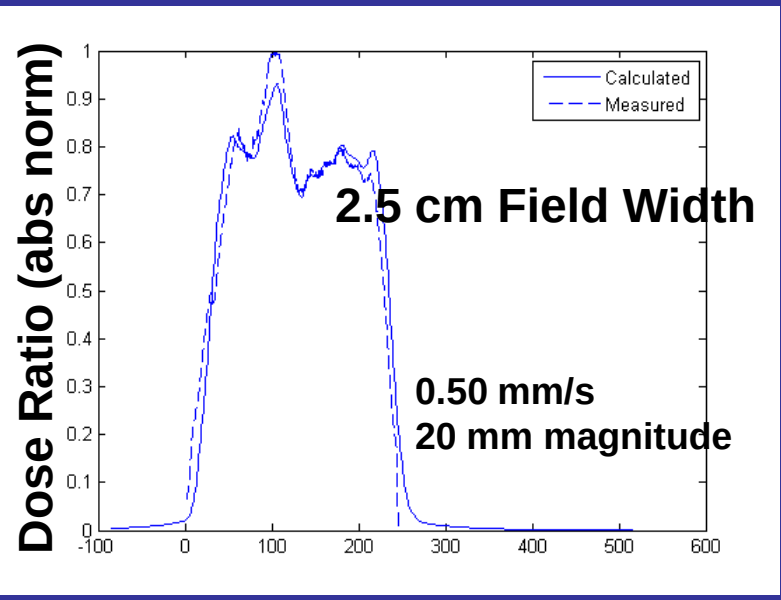
Validation


RIT113 V4.x


1.0 cm field width
Dose Ratio (abs norm)
Calculated
Measured
1.0 cm Field Width
0.25 mm/s
15 mm magnitude




2.5 cm field width
Tidal volume (ml)
time (s)
Patient 22


Dose Ratio (abs norm)
Calculated
Measured
2.5 cm Field Width
0.50 mm/s
20 mm magnitude

Conclusions

- Breathing motion does not “smear” out with Tomotherapy delivery
  - Drifts cause dose errors. Depending on the type of drift, the dose errors at a particular location will be either hot or cold
- Larger field width, slower couch velocity and smaller breathing amplitude result in lower errors
- In the presence of intensity modulation, dose errors can be observed
- Further work is necessary to determine the clinical impact of motion-induced errors
- Multiple fractions may average out these errors
- However, daily fraction dose will be affected. Biological consequence need to be determined
- Acceptable single-fraction dose error magnitude needs to be determined by rad onc community

Future Work

- Helical delivery
  - No modulation
    - Cylindrical phantom
  - Modulated
    - Phantom plan
- Improve patient-based 3D dose simulation
- Validate drifting
- Multiple fractions (multiple breathing patterns)

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THANK YOU!

Questions?