Part 2: Motion management for pancreatic radiotherapy

Monitoring, mitigation, and impact of intrafraction tumor motion

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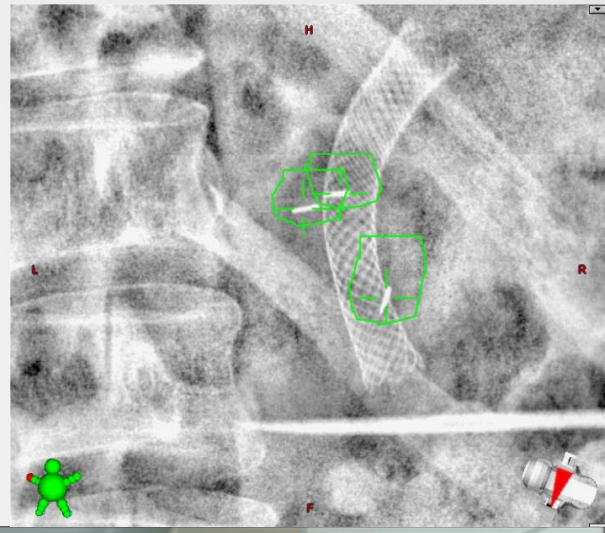
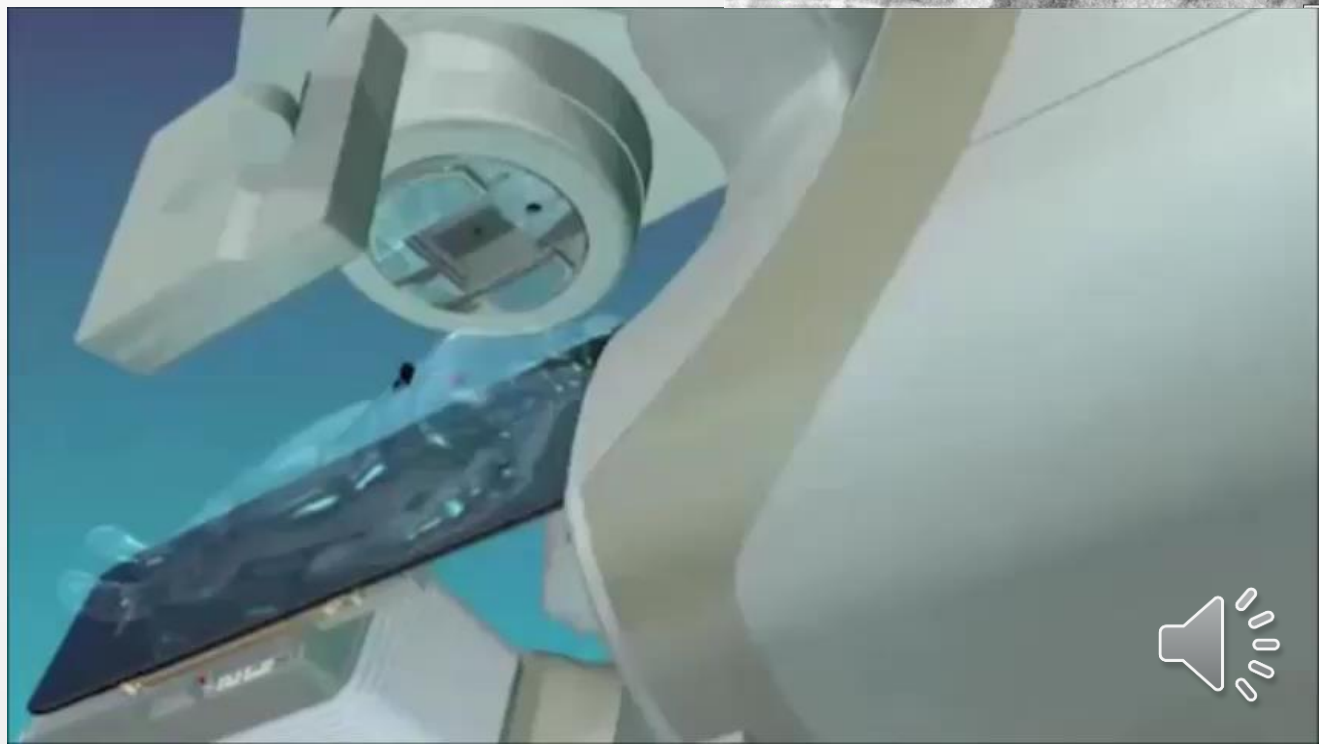
- Conflicts of Interest
  - Automated Tracking of Fiducial Marker Clusters in X-Ray Images: *US Provisional Patent Application 62/368,870* - July 2016

kV monitoring during pancreatic SBRT



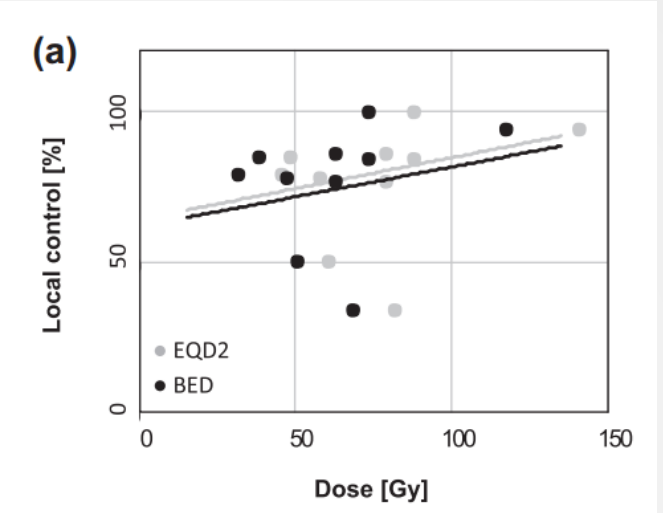
- Periodic monitoring of tumor position
- Using the on-board kV imager
  - Tumor or surrogate must be visible on kV
- Goal: understand how to establish a kV monitoring program
  - Requires careful coordination between simulation, planning, pre-treatment setup, and monitoring!

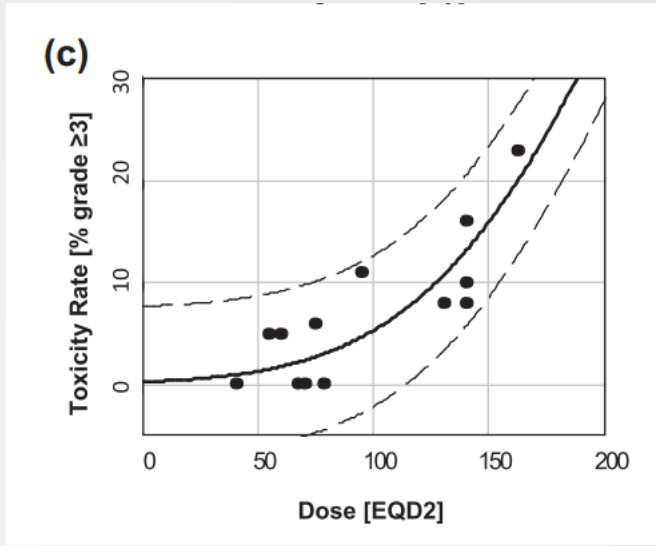


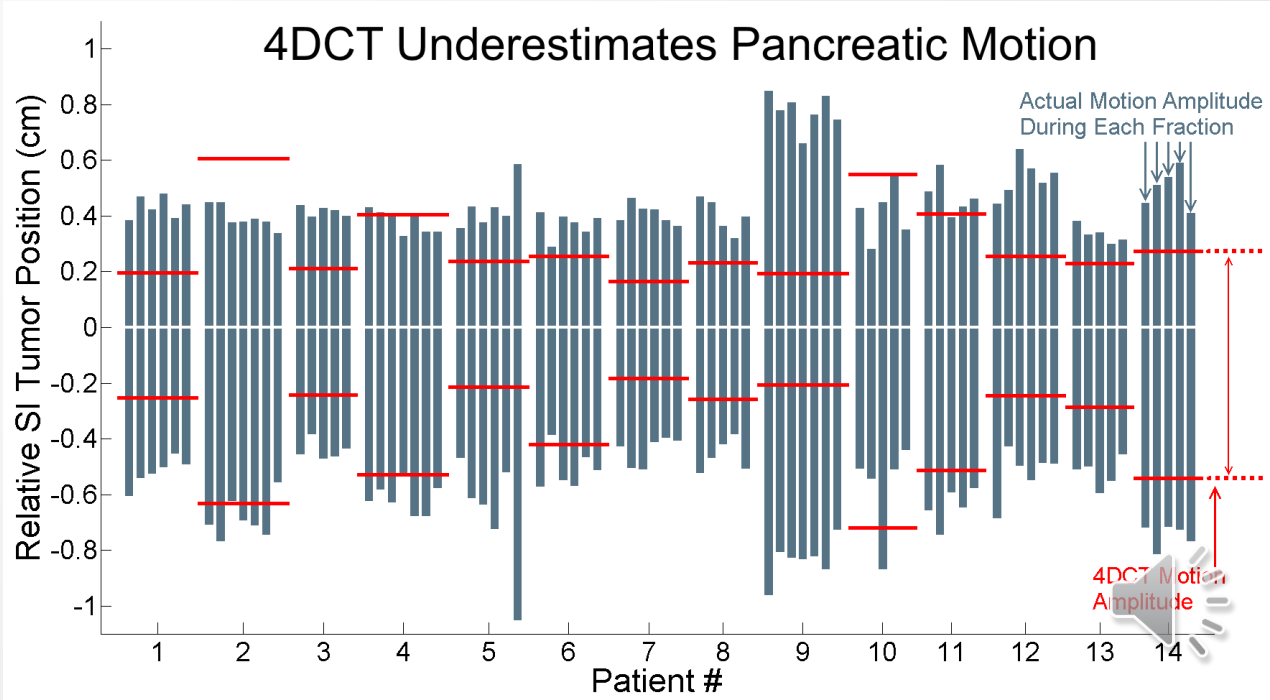
Pancreatic SBRT

- Clinical rationale for dose escalation
  - More dose improves local control but increases toxicity
- Motion inhibits escalation
  - Difficult to mitigate
  - 4DCT underestimates pancreatic tumor motion
  - Increased dose to bowel

Brunner *et al*, Green Journal 2015

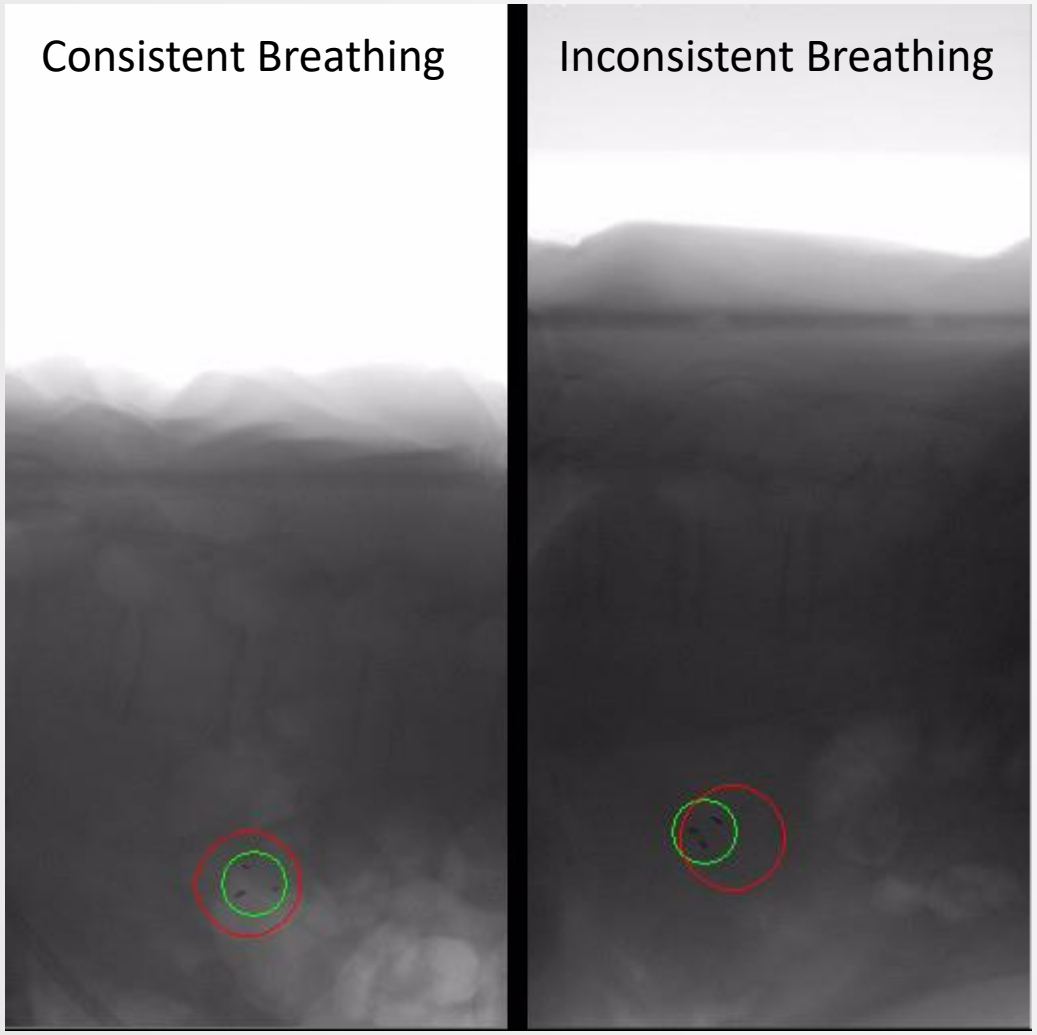






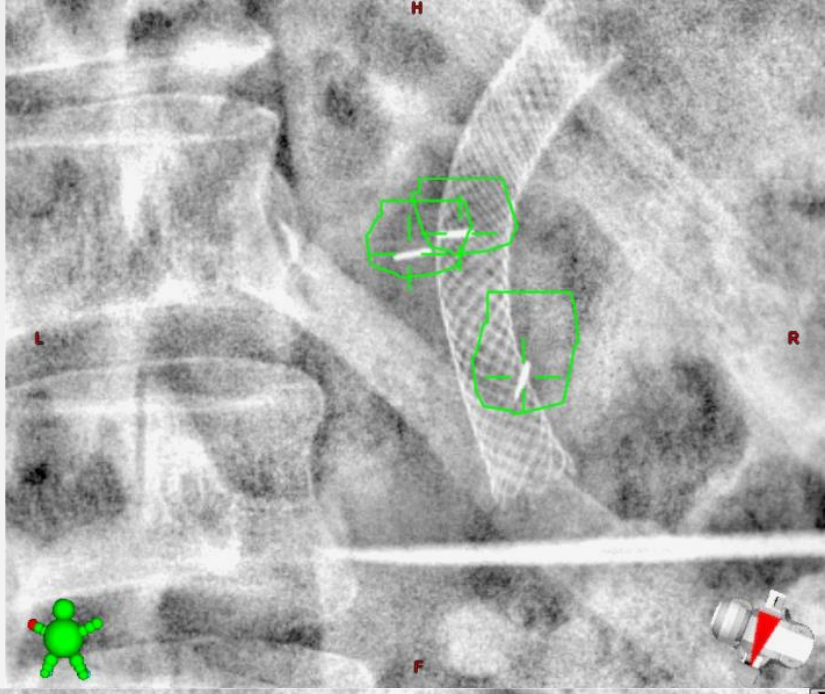
Jones *et al*, Green Journal 2014

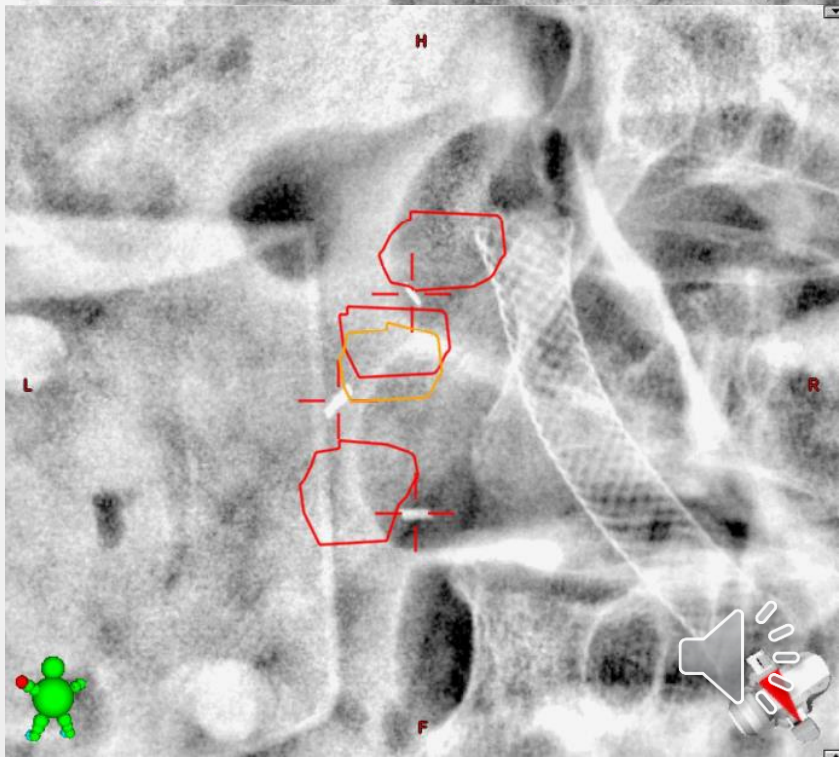
Treatment and Motion



- CBCT projection images from two patients
  - Some patients show consistent breathing
- Patients with inconsistent breathing are much harder to treat
- Respiratory gating reduces motion
  - 5 mm average motion range
  - Still high

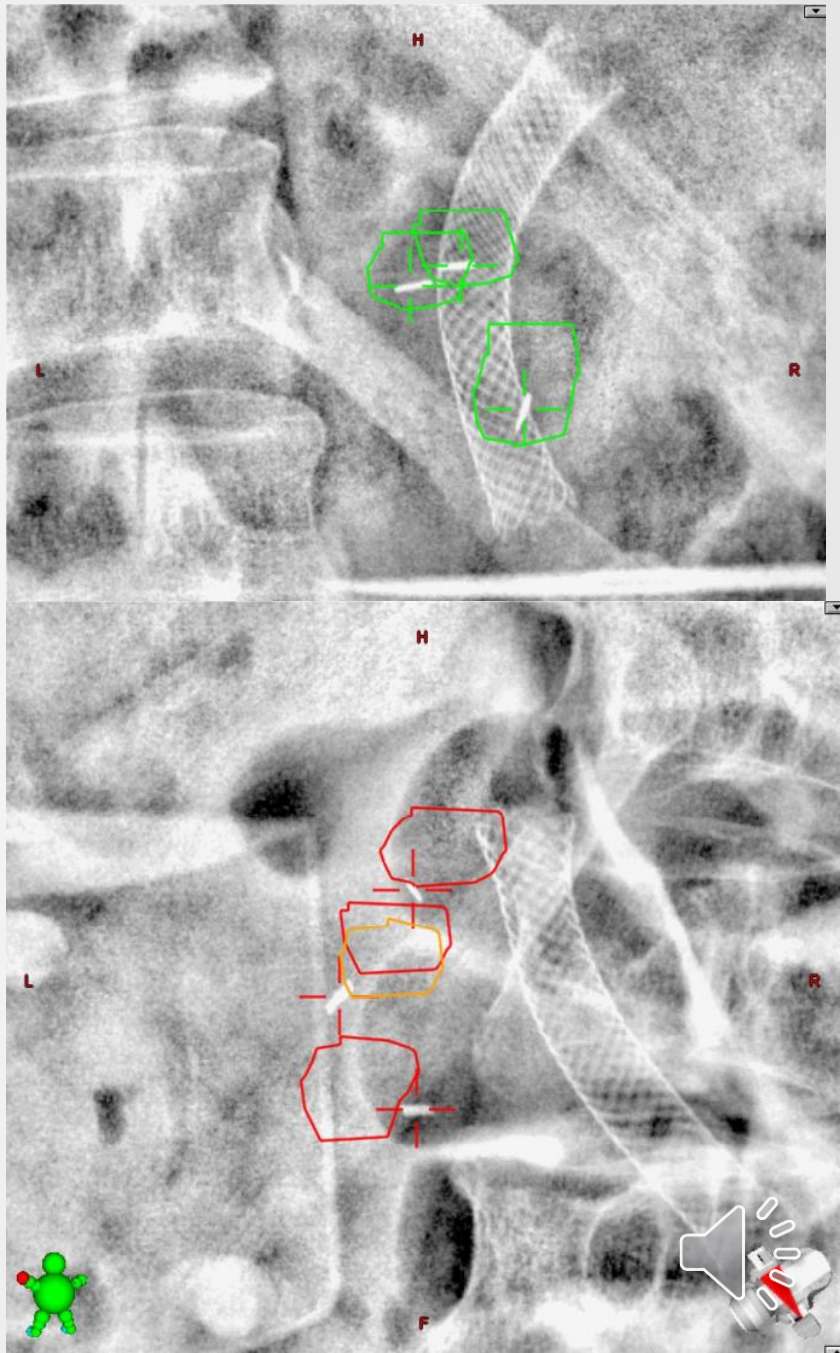

kV_89_1a - 2/5/2019 3:13 PM - 89°
Motion
Amplitude Gating
Auto Scale
Verification
Scale [cm]
5.0
Total kV Dose [mGy]
29.50
Timer [min]
0.1
Reset
HU%:
Anode
10
Housing
15





Triggered imaging and Panc SBRT

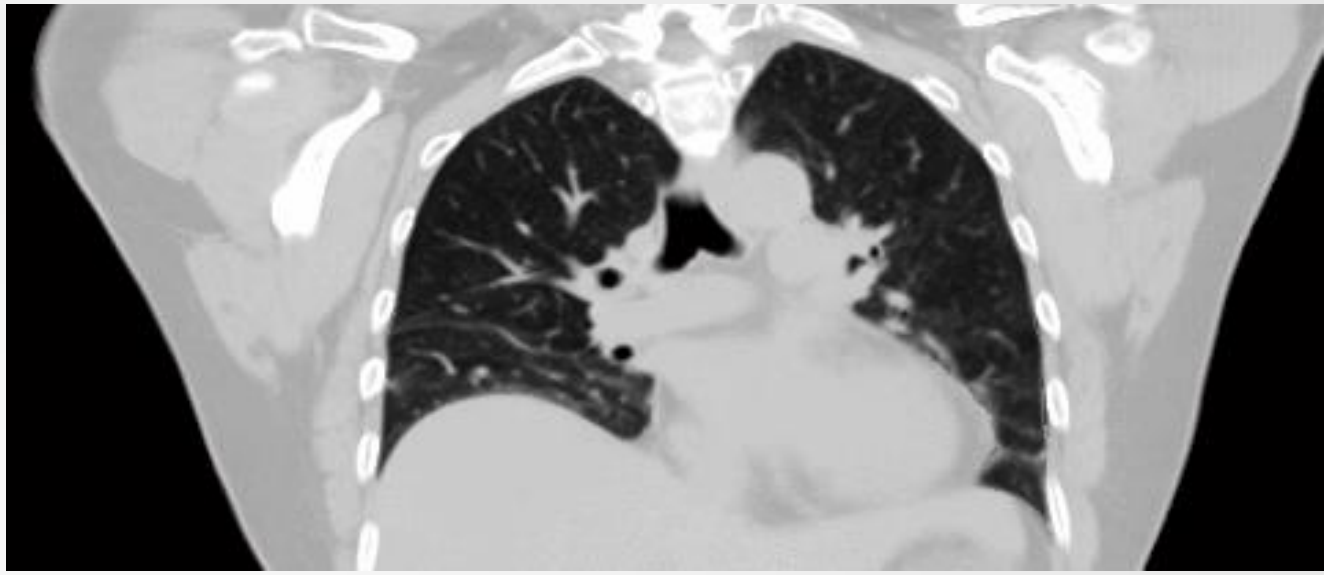
- Images taken with on-board kV imager
  - It's OK that imaging axis and treatment axis are different
  - Majority of motion is in the head-toe direction (fully sampled)
  - Arc delivery – any shifts will be detected a max of 90º later
- Soft-tissue contrast not required
  - Quickly localize the fiducials

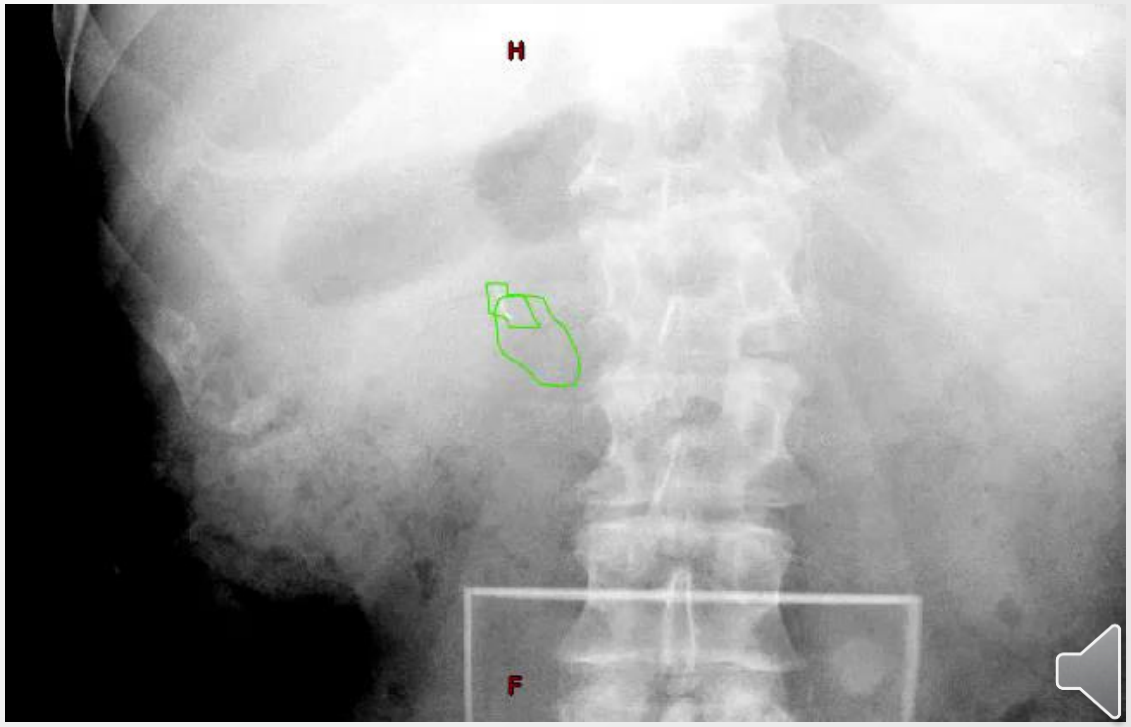


Implementing a kV monitoring program: Major considerations

Choosing a surrogate

- Must be visible on kV imaging
  - High-contrast – quickly visible
  - Not soft-tissue based
- Gold fiducial markers
  - 3+ markers implanted 1-2 weeks prior to simulation
    - Impact of migration small
- Surrogates for other tumor sites
  - Lung tumor
    - Not visible from all angles
  - Diaphragm
    - Useful for liver or inferior lung tumors



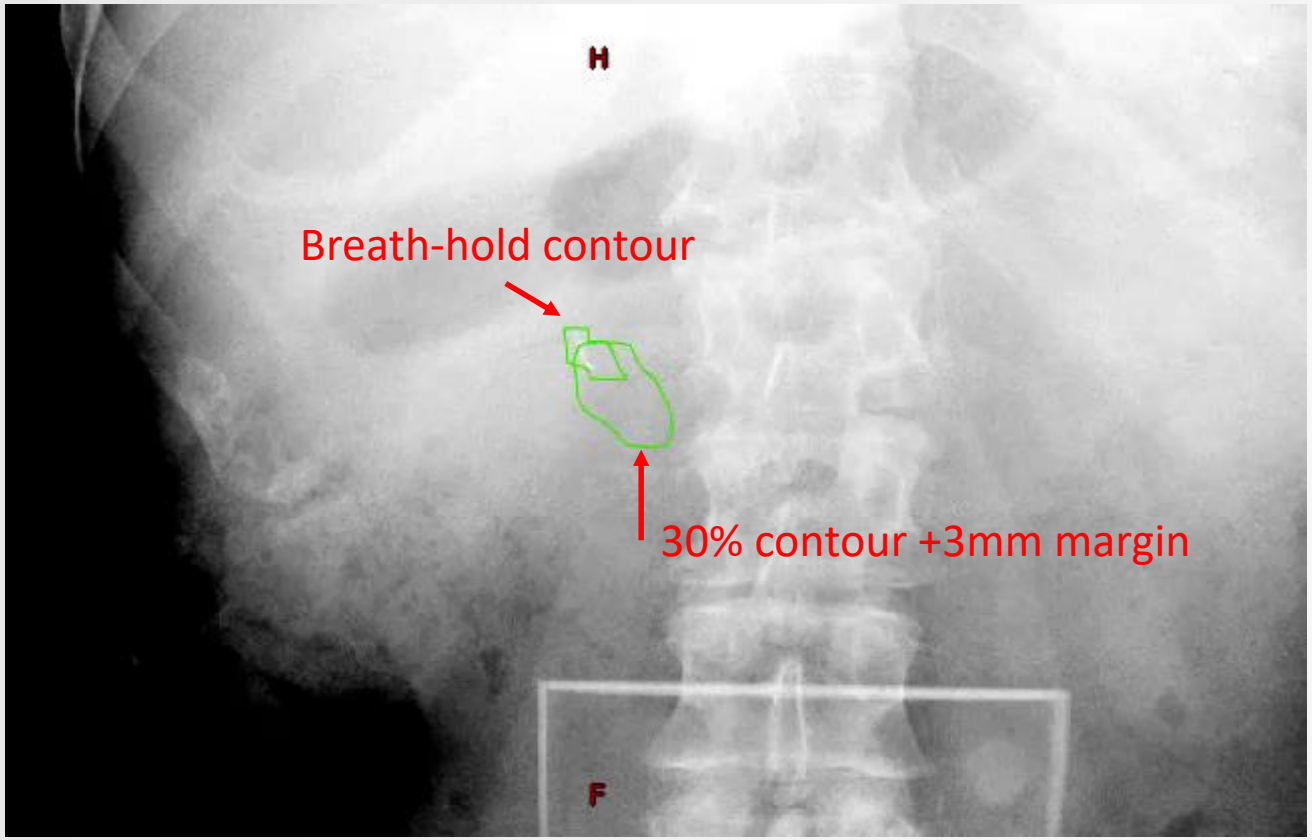


CT Simulation

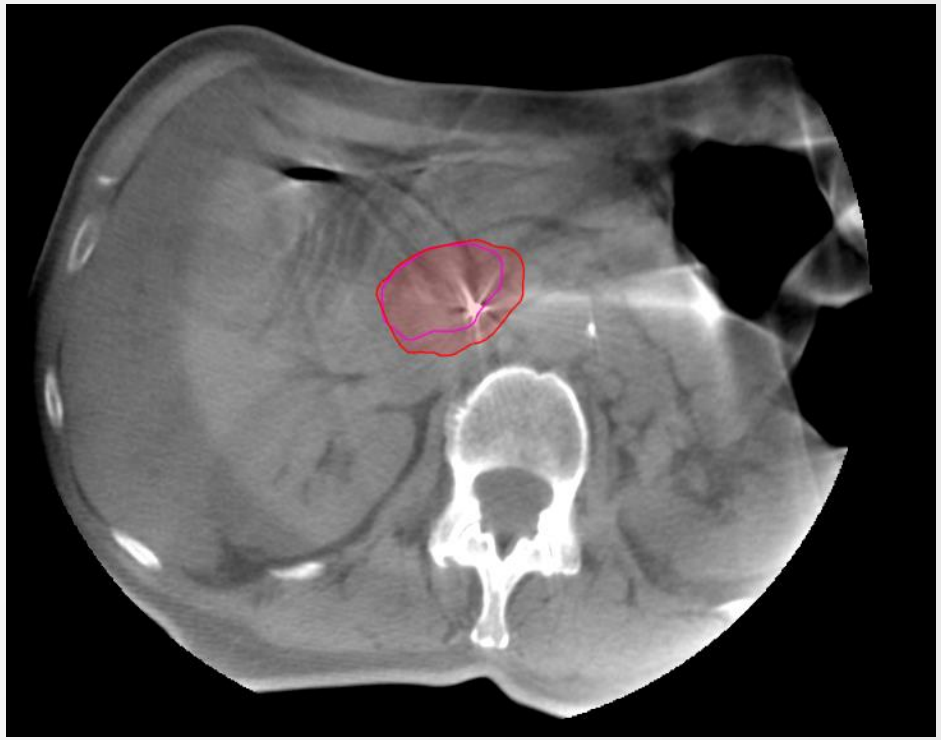
- Establish a reference position
  - What is the timing of kV monitoring?
  - Capture the surrogate position at a time point corresponding to kV monitoring
- Other motion management concerns
  - If gating, match plan CT to treatment position

- Our workflow
  - End-exhale breath hold planning CT
    - High-quality image for contouring
    - Pre-treatment setup using breath hold CBCT
    - Treatment with end-exhale gating
  - 4DCT
    - Determine respiratory gating thresholds
    - Contour fiducial markers at 30% phase (when kV imaging occurs)
      - Reference location for kV monitoring

Initial patient setup

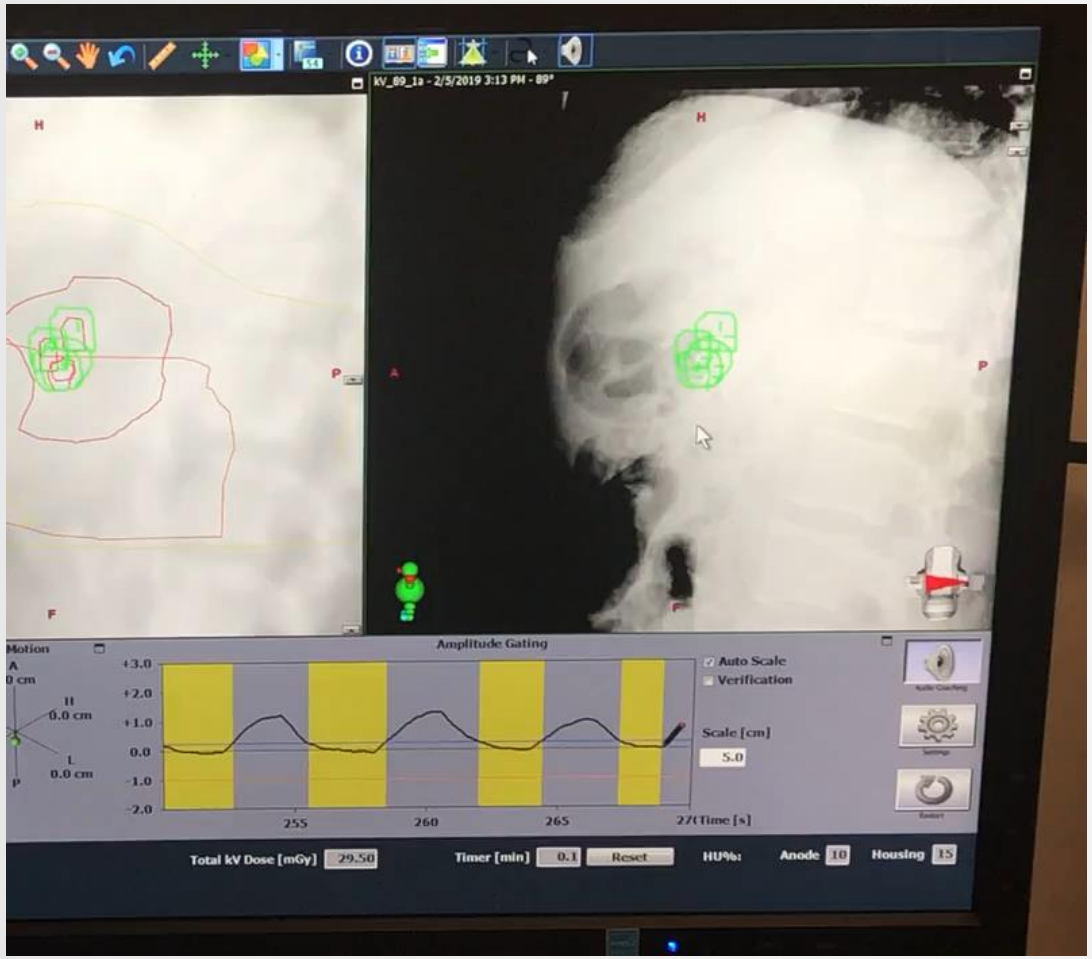


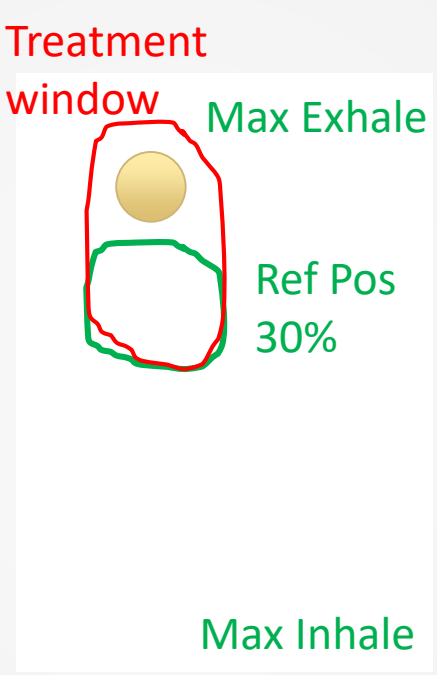
- AP Fluoro
  - See entire motion range
  - Set longitudinal shift accurately
    - Allows for detection of bad breath hold

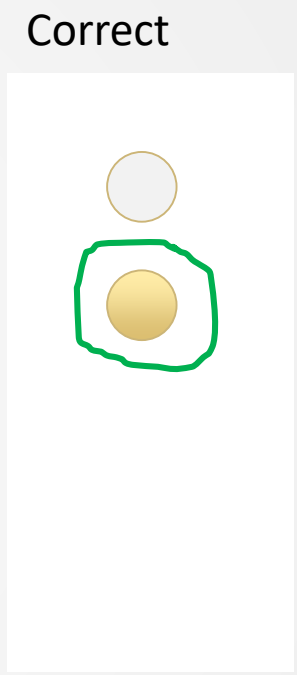


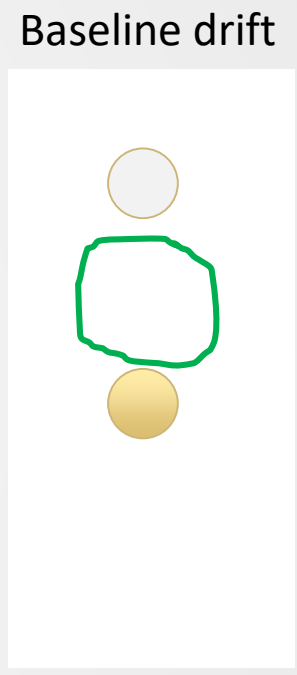
- Exhale breath-hold CBCT
  - Coached and controlled by therapists
  - Excellent image quality, soft tissue contrast
  - Align to fiducials

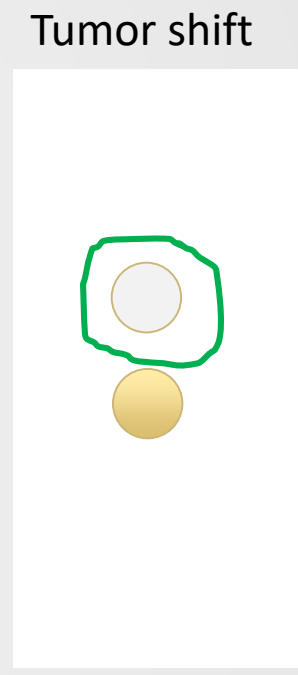
kV Monitoring - Workflow









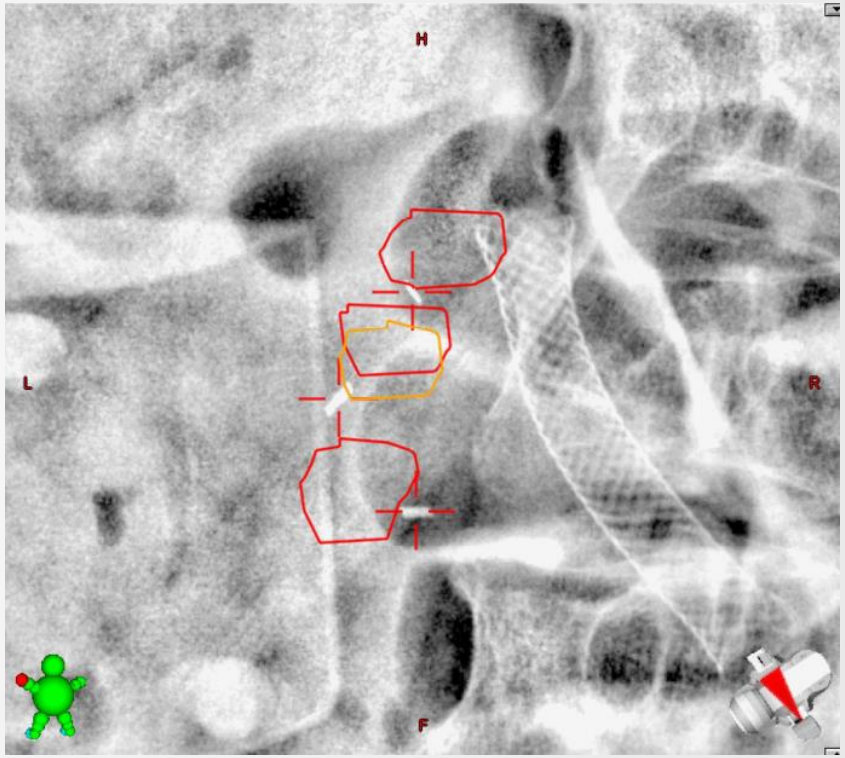


- Baseline drift – images are taken too early (or too late)
  - Pause - Adjust amplitude gating thresholds
- Tumor shift – target moves from tx location
  - Shift - Re-localize target

Causes of error

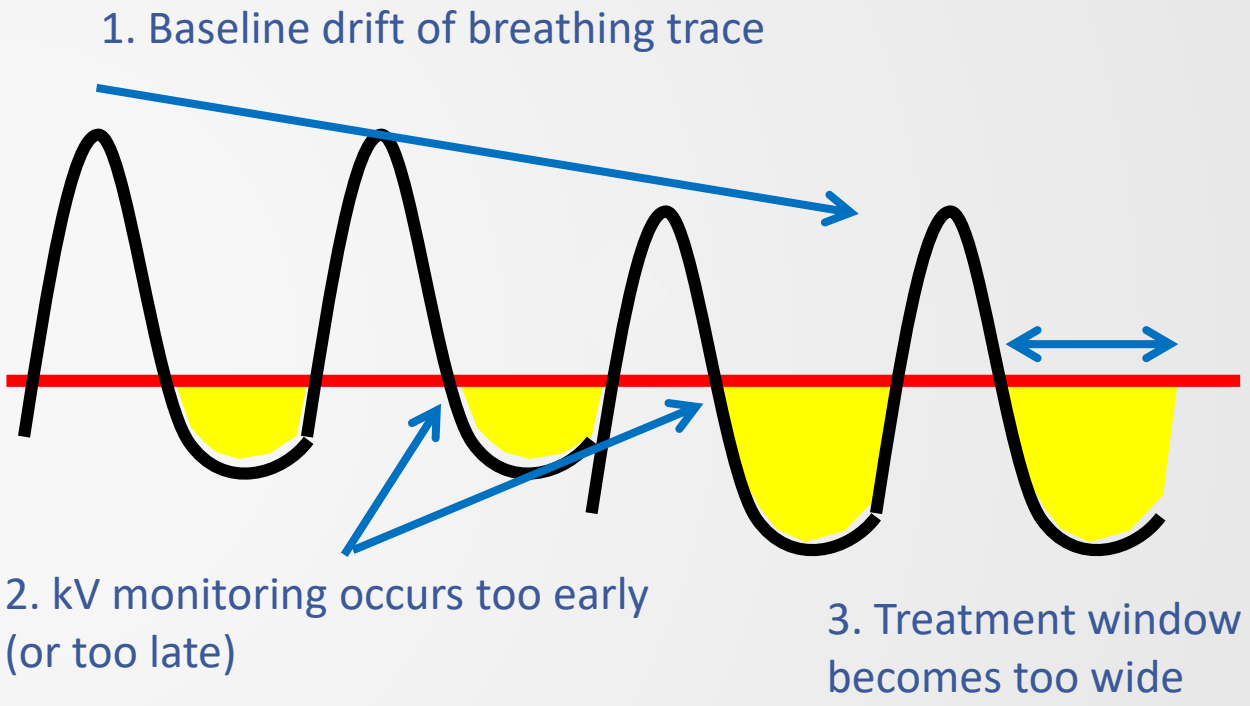
- What to do when fiducial markers are observed outside the expected location?

- Cause #1: Image was taken at the wrong time
- Cause #2: Tumor has shifted



Cause #1: Image taken at the wrong time

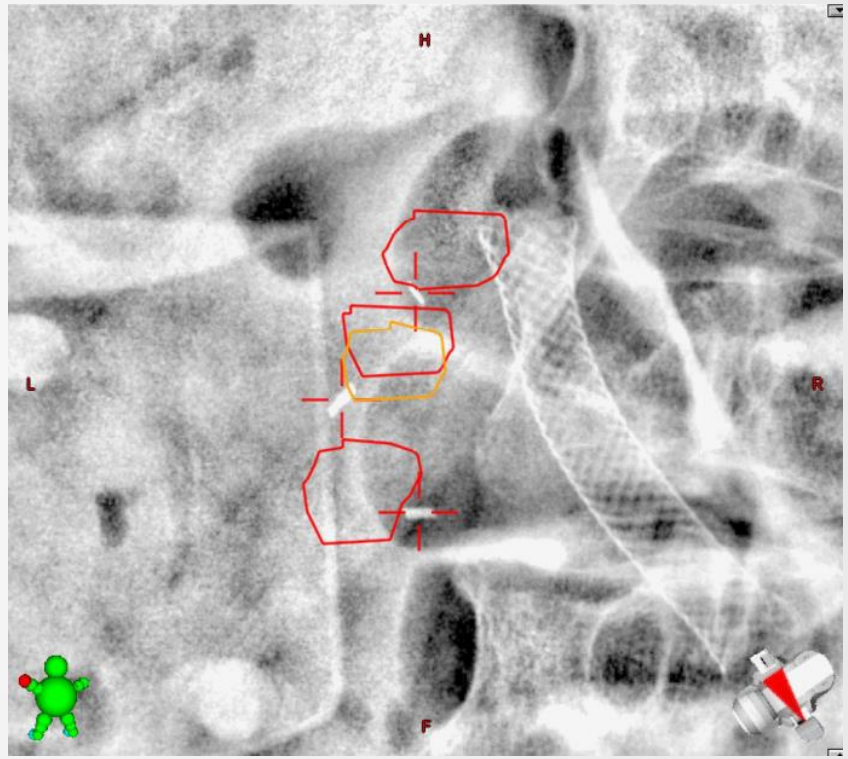
- Respiratory baseline drift
- Changes to the breathing trace can change the timing of imaging
- Can be caused by physical changes or an artifact of the breathing monitoring system
- To fix: pause treatment, reset breathing monitoring system, or adjust gating thresholds



Ruan, D., et al. "Real-time profiling of respiratory motion: baseline drift, frequency variation and fundamental pattern change." *Physics in Medicine & Biology* 54.15 (2009): 4777.

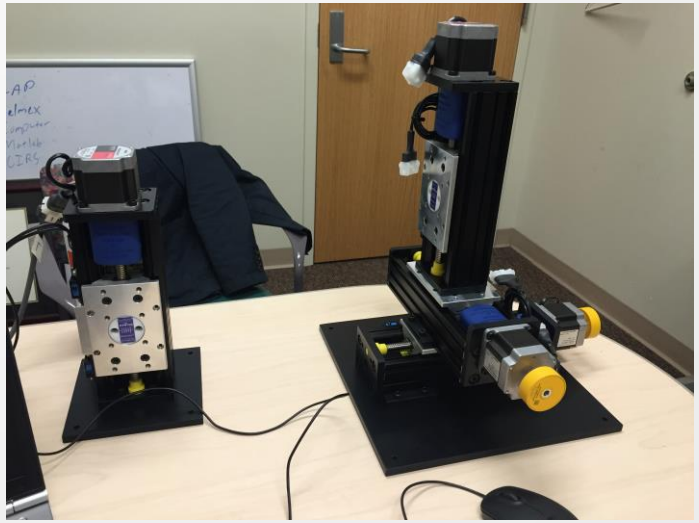
Cause #2: Tumor has shifted

- Can be due to
  - Gross patient shifts
  - Changes in respiratory pattern
  - Internal motion
    - Small bowel changes
    - ~1 cm interfraction shifts are common
- To fix:
  - 2D->3D shifts using kV monitoring image
  - re-do initial setup imaging
    - Fluoro, CBCT



QA of kV monitoring

- Not a recommendation, just my experience
- Commissioning
  - End-to-end test with a moving phantom
    - We used a 3D programmable motion platform, phantom with OSLD inserts
    - Also possible – phantom with repetitive motion and imaging features on kV
- Periodic QA
  - kV imaging accuracy
    - Covered by daily imaging QA
  - Gating system
    - Covered by monthly QA of gating system



What is the benefit?

Pilot study

- What is the impact of kV monitoring on
  - Clinical workflow?
  - Treatment accuracy?
  - Tumor dose?

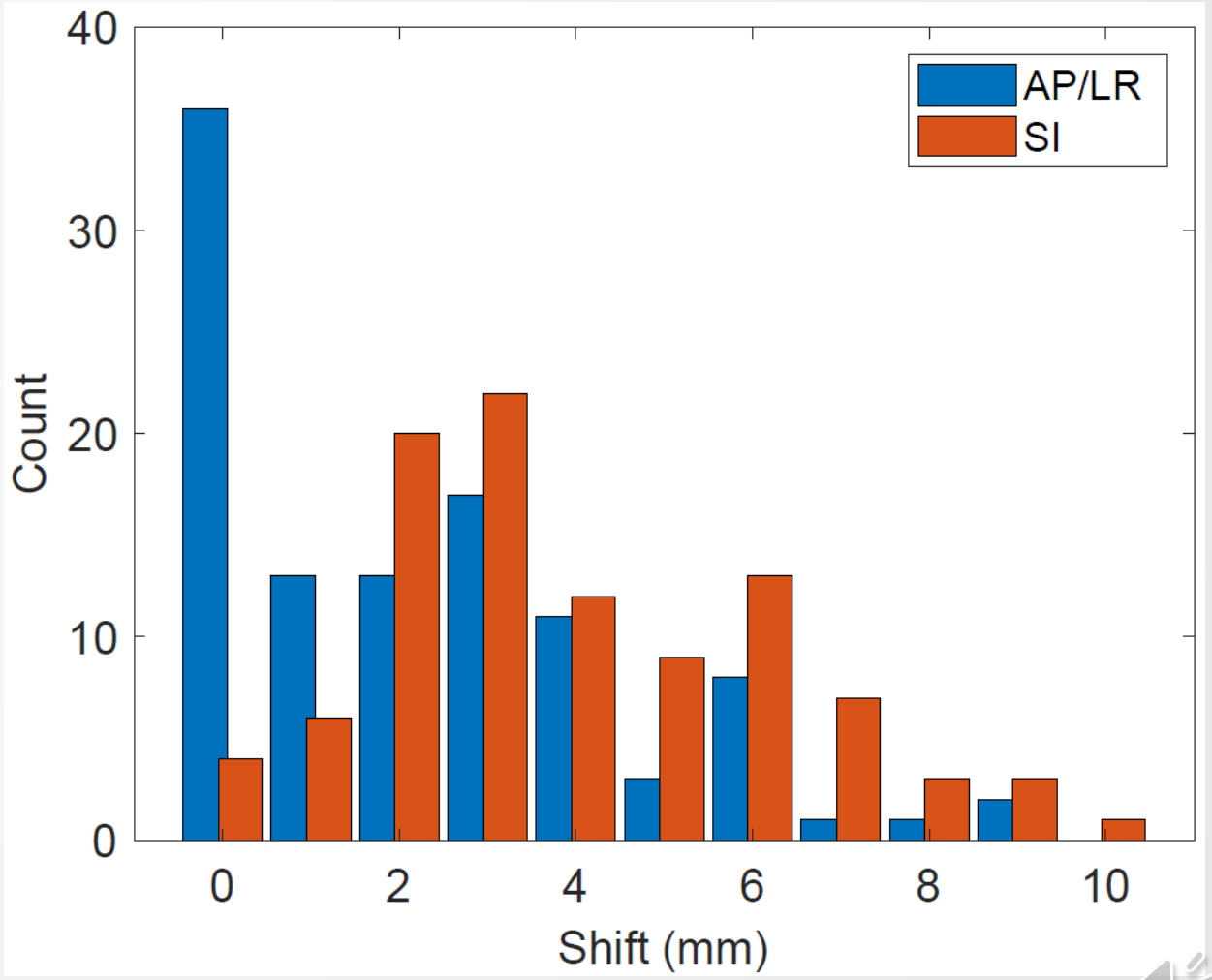
- 68 pancreatic SBRT patients
- Chart review of all in-treatment imaging actions
  - Pauses to adjust for breathing
  - Shifts to adjust for motion

Cohort	Number	
All Patients	68	
Gating	53 (78%)	
Compression	15 (22%)	
	Median	Range
Dose per Fraction	660 cGy	500 – 900 cGy
Number of Fractions	5	3 – 5
Number of Fiducials	3	1 – 7
Treatment Time	485 s	137 – 1331 s
PTV Volume	41 cm^3	16 – 349 cm^3
BMI	23	17 – 40

Results

- Average “pause rate” of 0.81/fx
  - Roughly 4 pauses total during a 5 fraction treatment
  - Pause time: 1.9 ± 1.8 minutes
- Average “shift rate” of 0.32/fx
  - 1-2 shifts per patient over 5 fractions
  - Median shift of 5.2 mm
    - Mostly in the SI direction
  - Shifts larger in longer treatments
    - 5.3 v 4.7 mm average

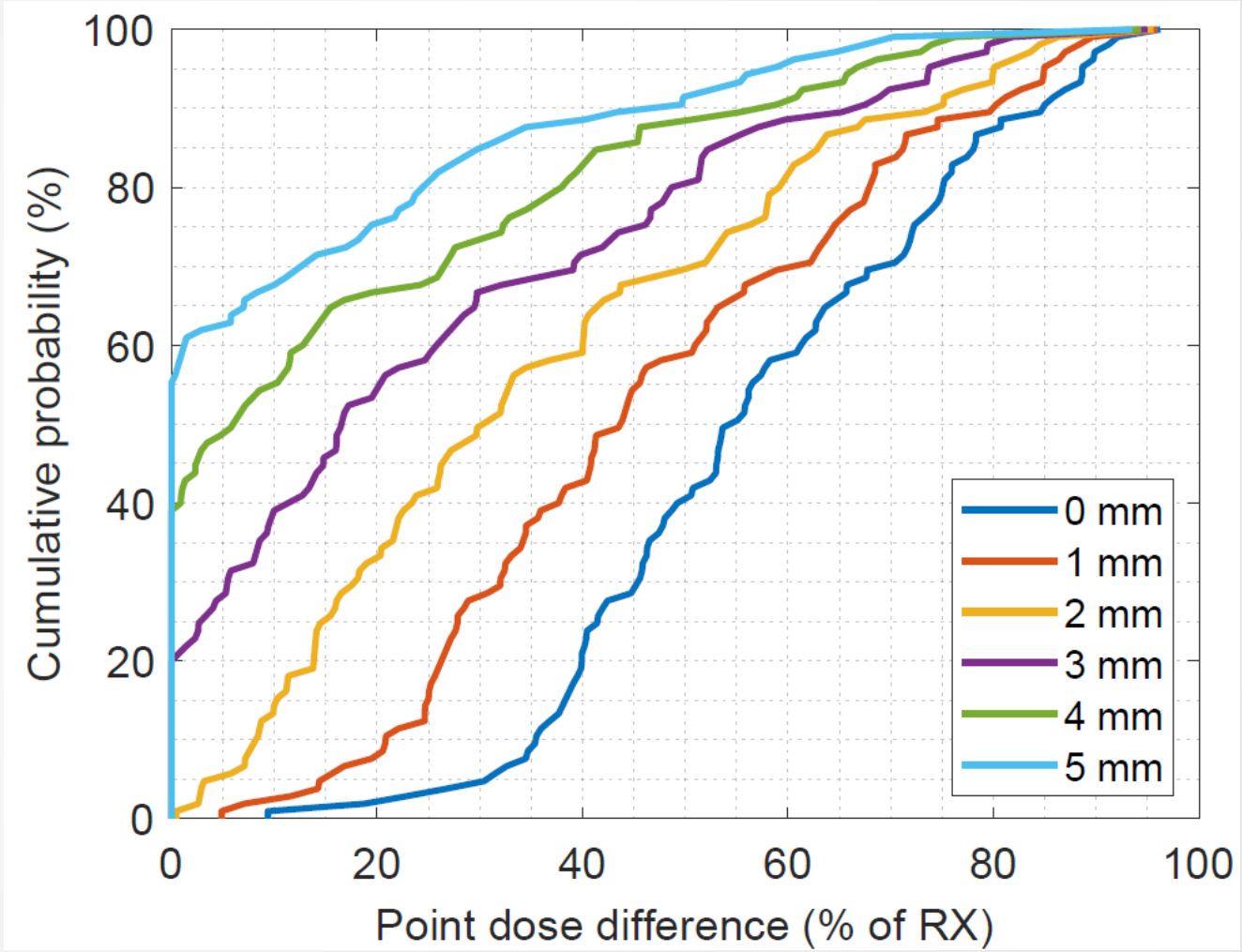
Histogram of couch shifts applied



Dosimetric effect

- 45% of shifts resulted in dosimetric differences
  - Of these, average was 23% of rx
- Identified a potential for margin reduction
- Results tied to the fiducial contour margin
  - Shift threshold
  - 3 mm

Cumulative histogram of dose defects



Vinogradskiy *et al*, "The clinical and dosimetric impact of real-time target tracking in pancreatic SBRT," Red Journal 2019

Conclusions

- kV monitoring is feasible for pancreatic SBRT
  - Significant benefits to treatment accuracy
  - Potential dosimetric benefits
- Moderate changes in workflow
  - Small but not insignificant
  - Introduce 2-5 minute pauses
- Key workflow points
  - Identify a suitable surrogate
  - Understand timing of kV monitoring
  - Measure surrogate position during simulation
  - Not every error means tumor shift
    - Understand the impact of respiratory baseline drift

Thanks!

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