Memorial Sloan Kettering Cancer Center

Clinical approaches, experiences and lessons learned from a large SBRT program

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About me

- No conflict of interest

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About MSKCC

- Eight locations/sites across New York and New Jersey
- Total number of linacs = 29+
  - 22 TrueBeams
    - 1 HD MLC
  - 7 C-series
  - 1 MR linac (Elekta Unity)
- 1 ExacTrac
- 2 Calypso
- 18 AlignRT
- All TBs have 6DOF couch except 2 machines with Calypso

Overview of SBRT at MSKCC

- Wide range of disease sites
  - Brain, lung, GI, prostate, paraspinal

- Intrafractional motion management strategies
  - Treatment techniques
    - Respiratory gating
      - Limited
    - Compression
    - Deep inspiration breath-hold (DIBH, most frequently used)
      - Can be reliable if patient can tolerate
  - Monitoring techniques
    - 2D kV imaging
    - ExacTrac
    - Calypso
    - Intrafractional motion review (IMR)
    - Simultaneous MV/kV imaging (in-house)

Intrafractional motion monitoring for SBRT

	Motion monitoring method	Matching structure
SBRT paraspinal/bone	ExacTrac IMR	Hardware (if available) Anterior of vertebral body
SBRT prostate	MV/kV IMR 2D kV	Fiducials
SBRT lung	Calypso 2D kV	Beacons/fiducials
Ablative/SBRT GI	IMR 2D kV	Fiducials/stent

2D kV imaging

- Only on non-TrueBeams
- kV pairs during treatment
  - Every other partial or full arc for VMAT
  - Every other gantry angle for IMRT
- Manually match on structure by therapists
  - Shift if needed
- Not very efficient

ExacTrac

- A pair of kV imaging units (sources “on” the floor and imagers mounted on the ceiling)
- kV images auto-matched to images created from planning CT
- Provides 6DOF shift
- At MSK
  - Manually trigger of kV imaging
    - No fixed number of triggers, approximately 1-2 times per arc/between gantry angles at therapists’ discretion
  - Relative monitoring only (not used for setup)
  - No automatic beam-hold

ExacTrac and paraspinal

- N = 1019 treatment sessions
  - 194 patients
- Rx
  - 24 Gy × 1
  - 9-10 Gy × 3
  - 6 Gy × 5
- All sim'ed with myelogram unless contraindicated
  - MRI can be used instead of myelogram
- Immobilization: CDR
- Initial setup: CBCT
- Intrafractional motion monitoring: ExacTrac
  - ~3-5 image pairs triggered per tx session
  - Stop tx when x/y/z > 2 mm or rotation >1.5º
  - CBCT re-acquired and couch shifted
- > 2 mm shift occurred in 6 out of 1019 treatment sessions (~0.6%)
  - All shifts occurred in second half of the treatment sessions
- While >2 mm shift occurrence appears to be low, it does happen and does not seem to be predictable

Table 1 Time from beginning of setup imaging to end of treatment (treatment time) and to time of intrafractional correction

Patient	Treatment time (min)	Time to correction (min)
# 1: Single fraction	38.9	30.7
# 2: Fraction 2 of 5	26.5	22.7
# 2: Fraction 5 of 5	12.3	9.9
# 3: Fraction 3 of 5	31.9	23.8
# 4: Single fraction	38.1	25.4
# 5: Fraction 3 of 5	23.4	12.6

Frequency of large intrafractional target motions during spine stereotactic body radiation therapy. Wu et al. Practical radiation oncology 2020 (10) e45-49

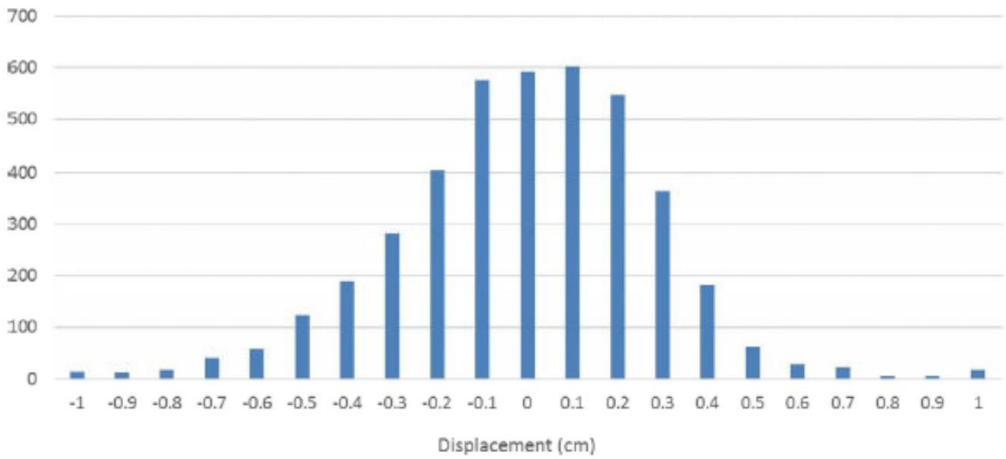
Intrafractional motion review (IMR)

- Varian TrueBeams (v2.7 MR3)
- 2D kV imaging
- Imaging trigger can be based on time, MU, gantry angle or RPM gating (start or end of gate)
- Matching based on fiducials or bony structures
  - Typically with a 2 mm margin
  - No matching done on soft tissue
- Therapist monitors matching and interrupt treatment if
  - Matching is significantly off on a single image
  - Matching is about 1-2 mm off on a few successive images

IMR trigger settings for SBRT tx	
VMAT	Every 20-40 degrees
IMRT	Non-FFF: every 200 MU 6FFF: every 300-500 MU

IMR and GI

- N = 8 patients
- VMAT with DIBH using RPM (gating window: 3 mm)
- Fiducials (i.e. marker, clips, stents)
- IMR triggered every 20º- 40º
- Based on over 5000 IMR images, relative from initial CBCT setup, fiducial displacement (sup-inf)
  - < 3 mm, 78.5% of the time
  - < 5 mm, 90.1% of the time
  - > 1 cm, 0.6% of the time
  - Average 0.6 mm, Std 2.9 mm
- Demonstrates residual motion within gating window
  - Random
  - Internal motion ≠ external motion



Histogram of the tumor displacements relative to the initial position determined at the beginning of each fraction for all patients.

Intrafraction tumor motion during deep inspiration breath hold pancreatic cancer treatment. Zeng et al. JACMP 2019 20(5) pp37-43

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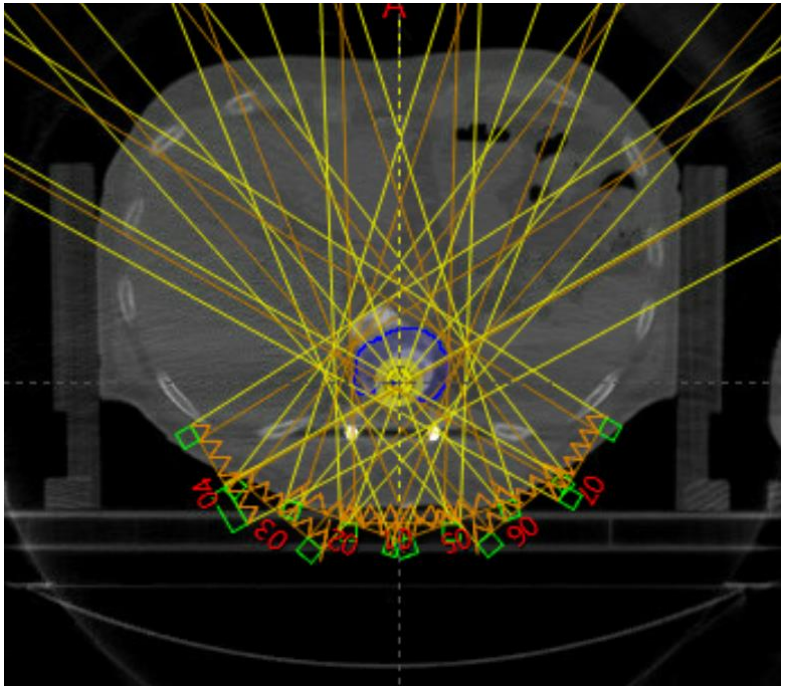
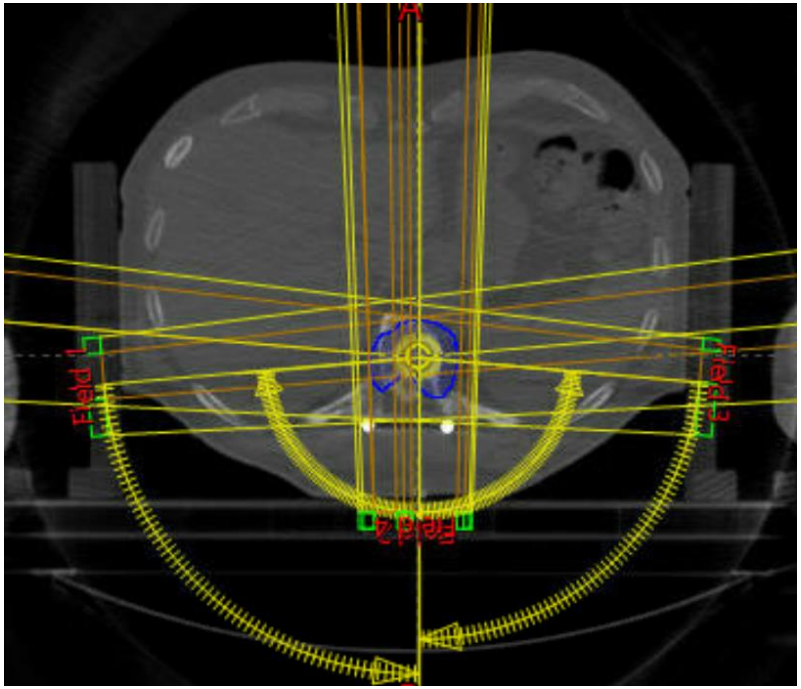
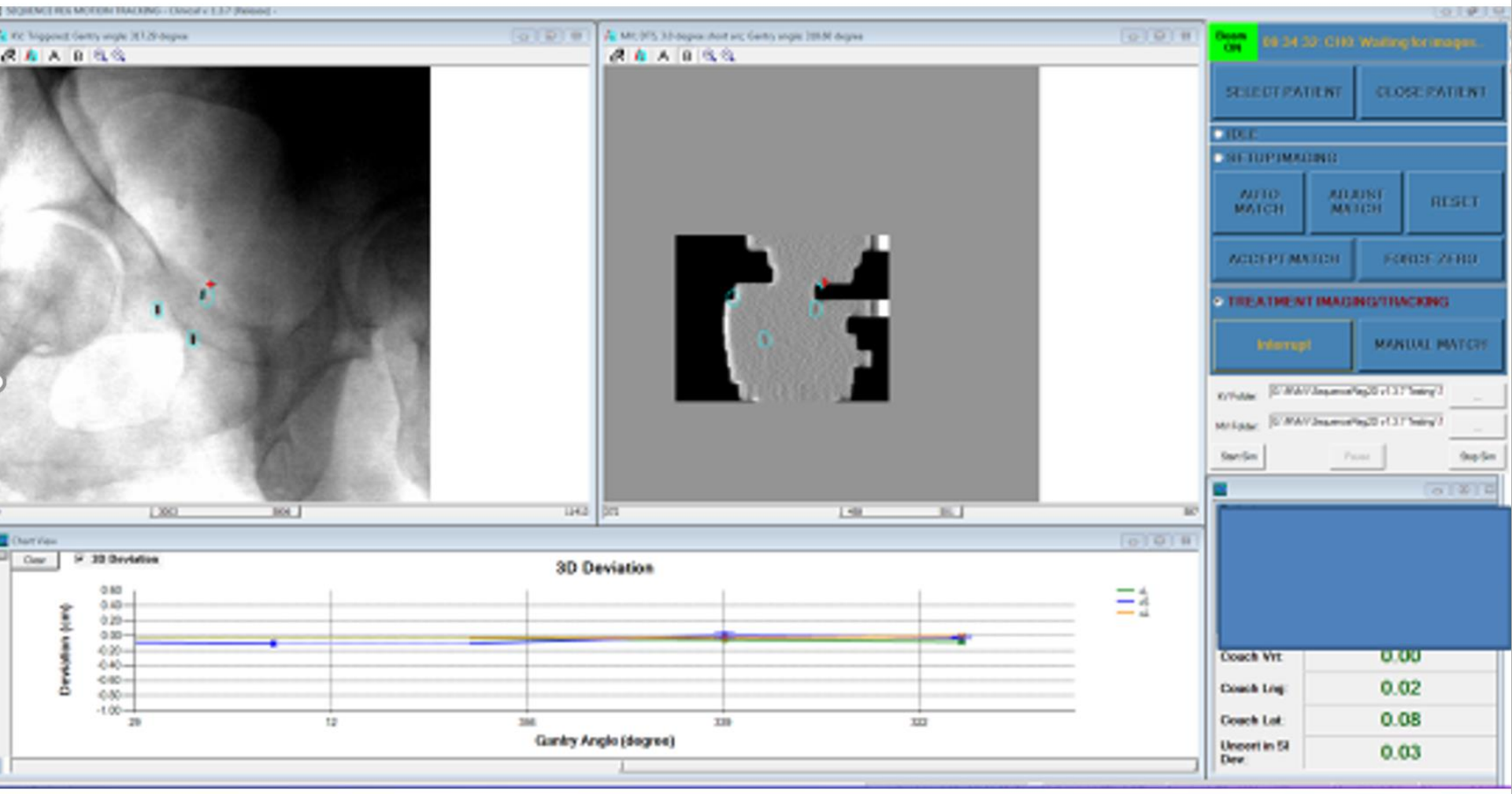
IMR and paraspinal

- No preferential motion axis
- IMRT/VMAT
  - ➢ Usually all posterior beams/arcs
- IMR may miss motion in certain axes, e.g. ant-post





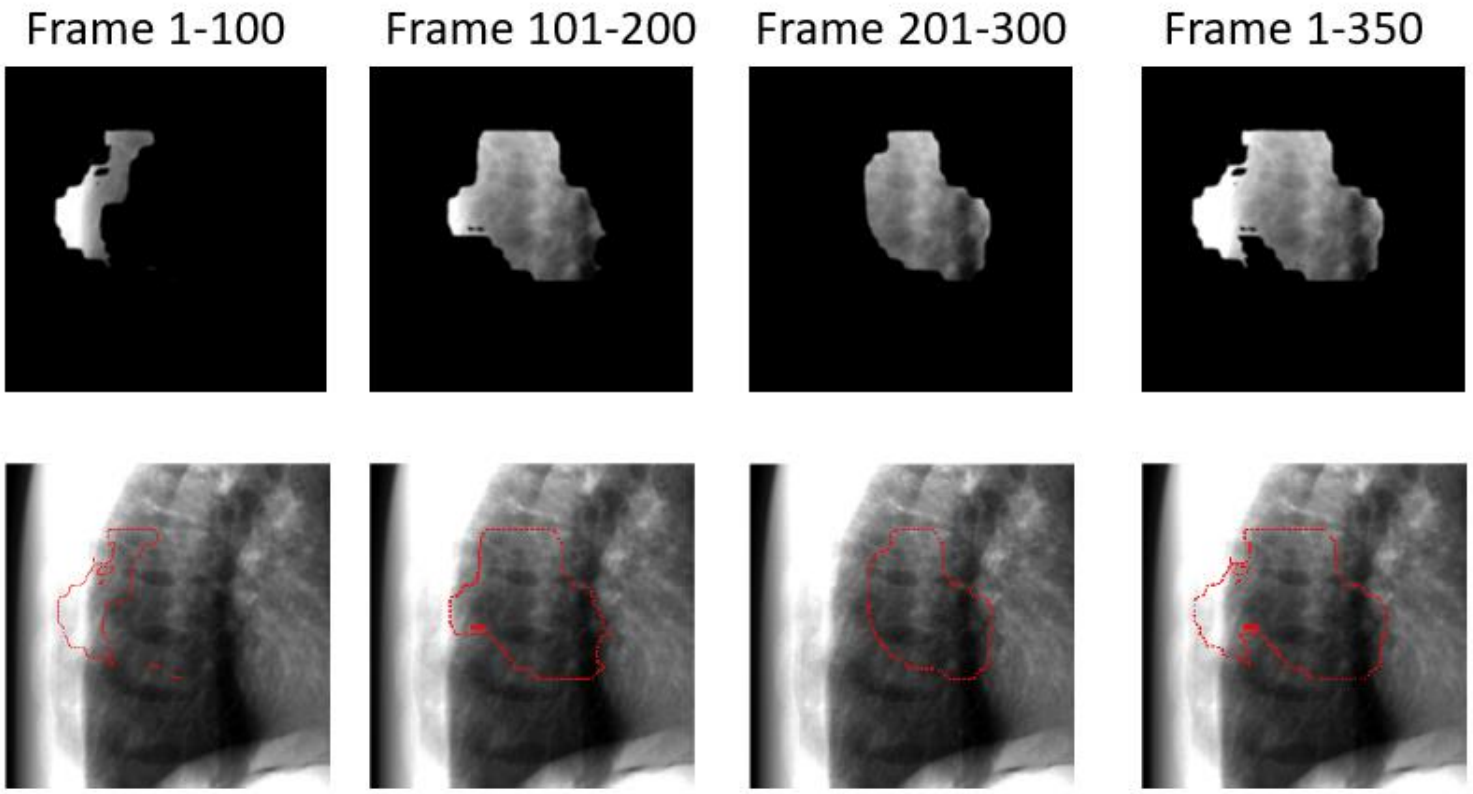

SELECT PATIENT
CLOSE PATIENT
SETUP IMAGING
AUTO MATCH
RESET
ACCEPT MATCH
TREATMENT IMAGING/TRACKING
Interrupt
MANUAL MATCH
3D Deviation
Deviation (cm)
Gantry Angle (degrees)
Couch Vrt
0.00
Couch Lng
0.02
Couch Lat
0.08
0.03

Simultaneous MV/kV imaging and prostate

- Alarm triggered when >1.5 mm shift is recorded for two consecutive control points
- Occurs ~1.2 times per patient on average
- MV/kV pair acquired to confirm
  - Similar shift observed unless patient drastically changes breathing pattern
  - Shift patients based on MV/kV pair

In development: markerless MV/kV

- Varian MRA project (PIs: Tianfang Li, Xiang Li, Perry Zhang)
- Simultaneous MV and kV image acquisition during paraspinal treatment
- MV images are accumulated over the sliding window delivery until a bony structure is visible in the image



In development: markerless MV/kV

- kV images are taken at a frequency based on the MV image accumulation
- Acquired images are transferred to an in-house software for analysis via iTools Capture
- Preliminary phantom study shows matching accuracy of <0.5 mm
- To further improve robustness, machine learning-based algorithm is in investigation for image registration

AAPM 2020: ePoster
Markerless Motion Tracking with Treatment Beam Imaging in Spine SBRT Treatment: A Phantom Study.
Li *et al*

Calypso

- Non-ionizing radiation
- Automatic beam-hold
- Continuous target motion monitoring
- “Direct” tumor motion
- Implant with 2-3 beacons
- At MSK
  - Not used for GI/prostate
  - Two lung protocols
    - DIBH
      - Only eligible for patients capable of at least 5 breath-holds, with more than 20 seconds for each breath-hold
    - Free-breathing
      - Gate at end-expiration

MPPG 9a

Table 1 Minimum SRS-SBRT relevant equipment QA and tolerances for C-arm linac systems.

Frequency	Test	Tolerance
Daily	Laser localization — only if using SRS techniques relying on lasers for target localization (e.g., frame-based SRS without X-ray IGRT)	1 mm
	Collimator size indicator for clinically relevant aperture	2 mm total
	Radiation isocentricity test (limited gantry and couch positions) — maximum deviation in center of target object relative to each projection's beam central axis	1.0 mm SRS, 1.5 mm SBRT
	IGRT positioning/repositioning	1 mm SRS, 2 mm SBRT
	Imaging subsystem interlocks	Functional
	Stereotactic interlocks — cone size, backup jaws	Functional
	Accelerator output constancy	±3%
Monthly	Radiation isocentricity test — covering complete range of gantry, couch, collimator positions used clinically — *maximum deviation in center of target object relative to each projection's beam central axis* **Note: If both MLC and fixed conical collimators are used, both must be evaluated at least monthly*	1.0 mm SRS, 1.5 mm SBRT
	Treatment couch position indicators: relative over the maximum clinical range	1 mm/0.5°
	Output constancy at relevant dose rates	2%
Annually	SRS arc rotation mode (if used clinically)	1 MU, 1°
	MU linearity (≥5 MU to highest MU used clinically)	±2%
	Accelerator output	±1.5%
	Coincidence of radiation and mechanical isocenter	±1.0 mm maximum 3-D displacement from center of target object
	Verification of small-field beam data — relative output factors for cones and/or MLC	±2% from baseline for >1.0 cm apertures, ±5% from baseline for ≤1.0 cm apertures
	E2E localization assessment "hidden target test" using SRS frame and/or IGRT system	1.0 mm
	E2E dosimetric evaluation using SRS frame and/or IGRT system	±5% measured vs. calculated

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Thank you