# CYBERKNIFE (AND A BIT ABOUT RADIXACT) FOR PROSTATE SBRT

Matthew Witten, PhD, DABR
Chief Physicist, Department of Radiation Oncology
Director, Division of CyberKnife Radiosurgery
Clinical Associate Professor, NYU Grossman Long Island
School of Medicine

**Radiation Oncology**

# Disclosures

- None

# Things I Do Not Recommend

- PowerPoint
- Post-It Notes
- Social Media
- Outsourcing all cognition to AI

# Things I Recommend

- The novels of Alan Hollinghurst, particularly *The Line of Beauty*, and his new one *Our Evenings*
- London
- High-Intensity Interval Training

# SBRT Machine Requirements

# What are necessary characteristics of a treatment platform for SBRT treatment delivery according to AAPM?

- TG-142
  - Daily
    - Laser localization 1 mm
    - Distance indicator ODI @ iso 2 mm
    - Collimator size indicator 1 mm
  - Monthly
    - Typical dose rate output constancy 2% @ stereo dose rate, MU
    - Treatment couch position indicators 1 mm/0.5°
    - Localizing lasers ±1 mm
  - Annual
    - SRS arc rotation mode Monitor units set vs delivered 1.0 MU or 2% whichever is greater, Gantry arc set vs delivered 1.0° or 2% whichever is greater
    - X-ray monitor unit linearity ±5% (2–4 MU), ±2% 5 MU
    - Coincidence of radiation and mechanical isocenter ±1 mm from baseline

# Do any of these QA tests really matter today?

- In the era of image-guidance and SGRT, do the therapists use the lasers, ODI, digital collimator, couch, or gantry indicators to set up the patient?
  - Probably not.
  - Why are we performing all these QA tests?
    - Unclear, but the pace of change in AAPM QA recommendations is glacial.
- These tests simply do not provide sufficient inputs to determine if the machine is delivering SBRT treatments with expected accuracy.

NYU Langone
Health

# SBRT Delivery

- Small margins -> high geometric accuracy of treatment delivery.
  - Total measurable clinical geometric accuracy (not simply mechanical accuracy or vendor specifications) of ~ 1 mm or less.
- Dosimetric accuracy is of course always important, but in the context of SBRT, it could be argued that geometric accuracy is paramount.
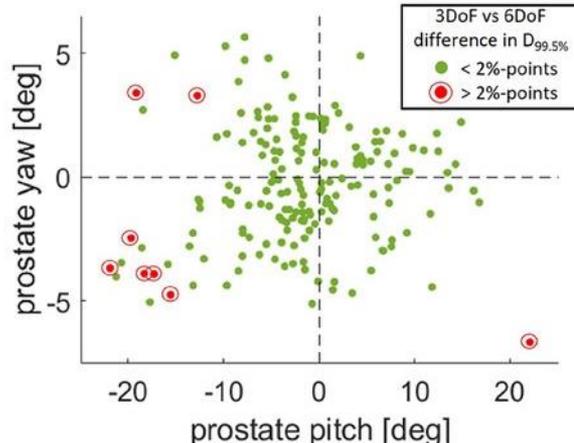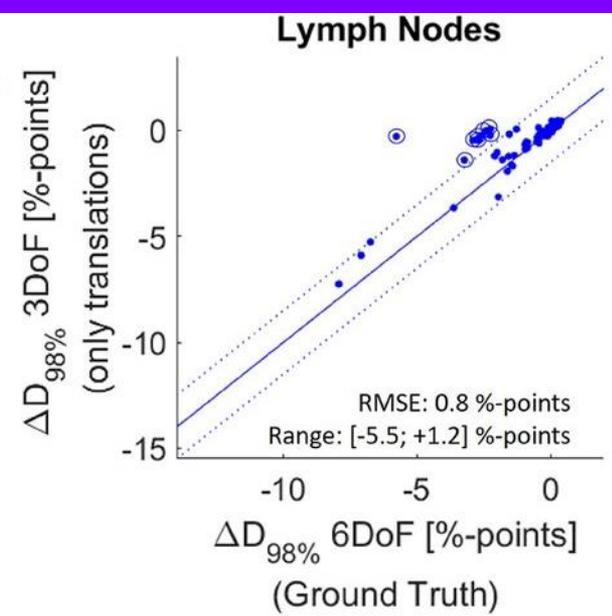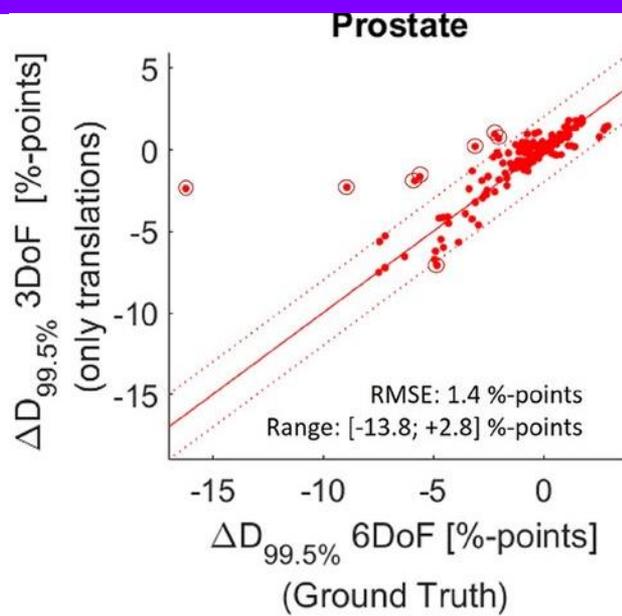
# Intrafraction Prostate Motion is a Challenge

Source: Klucznik KA, Ravkilde T, Skouboe S, et al. Quantifying dose perturbations in high-risk prostate radiotherapy due to translational and rotational motion of prostate and pelvic lymph nodes. Med Phys. 2024; 1-11. https://doi.org/10.1002/mp.17366
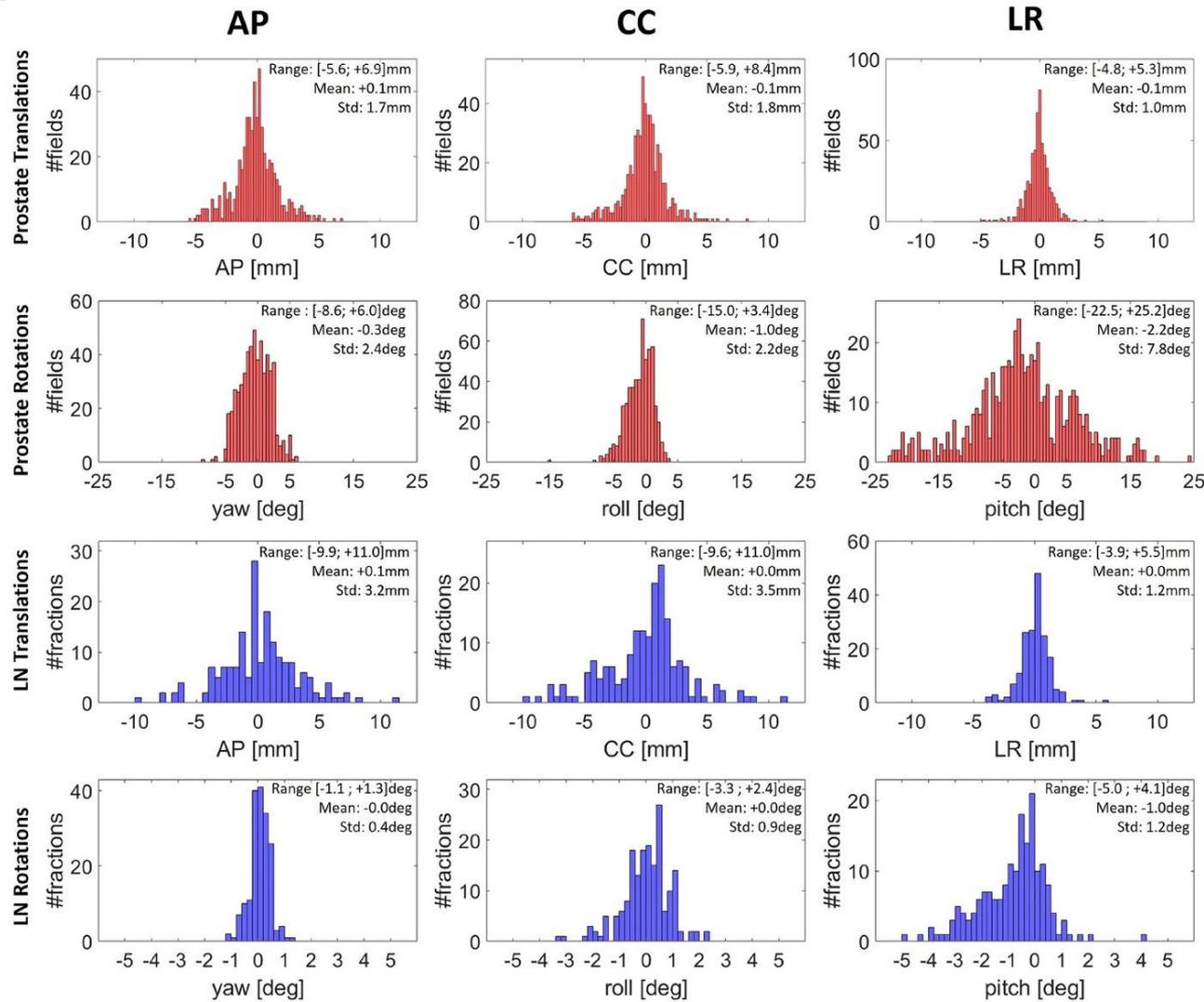
# Dose Perturbations

Source: Klucznik KA, Ravkilde T, Skouboe S, et al. Quantifying dose perturbations in high-risk prostate radiotherapy due to translational and rotational motion of prostate and pelvic lymph nodes. Med Phys. 2024; 1-11. https://doi.org/10.1002/mp.17366



NYU Langone Health
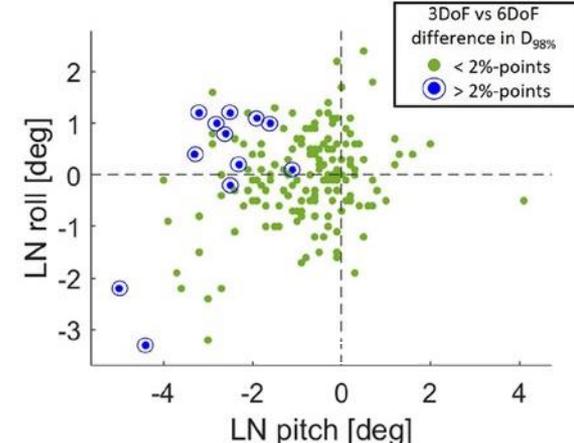
# D$_{99.5\%}$ to CTV

- The prostate CTV ΔD99.5% was [-16.2; +2.5]% for single fractions and [-3.0; +1.7]% when averaged over all imaged fractions.
- 18 pts received 39 x 2 Gy fx to prostate.
- Since the LN rotations were small, almost all motion-induced underdosed fractions could be identified using 3DoF motion, whereas, **for the prostate, only 38/45 (80%) of underdosed fractions were found, showing that 6DoF motion should be included for accurate motion-including dose reconstruction.**
- Source: Source: Klucznik KA, Ravkilde T, Skouboe S, et al. Quantifying dose perturbations in high-risk prostate radiotherapy due to translational and rotational motion of prostate and pelvic lymph nodes. Med Phys. 2024; 1-11. https://doi.org/10.1002/mp.17366

# SBRT is Different

- Klucznik KA, Ravkilde T, Skouboe S, et al. conclude that: "Using the developed framework for dose perturbation monitoring, we found that the differential 6DoF target motion caused substantial dose perturbation for individual fractions, which largely averaged out…"
- Don't have the luxury of averaging the dosimetric errors over many fxs, since pt receives at most five fxs.
- Prostate motion could severely perturb the planned dose distribution.

# What Do We Do About This?

- Authors suggest: "clinical implementation of real-time motion-including prostate and LN dose reconstruction during patient treatment."
- We can do better though, by compensating in real-time for this intrafraction prostate motion.

# Compensate for Prostate Motion

- Imaging strategy: either image almost in real-time or set imaging frequency based on gradient of motion of the prostate.
- Track the prostate and compensate by displacing the dose distribution in real-time.

NYU Langone Health

# Radixact and CyberKnife Allow For Real-Time Intrafractional Motion Compensation: Track/Detect/Correct

# PACE-B

Alison C Tree, Peter Ostler, Hans van der Voet, William Chu, Andrew Loblaw, Daniel Ford, Shaun Tolan, Suneil Jain, Alexander Martin, John Staffurth, John Armstrong, Philip Camilleri, Kiran Kancherla, John Frew, Andrew Chan, Ian S Dayes, Aileen Duffton, Douglas H Brand, Daniel Henderson, Kirsty Morrison, Stephanie Brown, Julia Pugh, Stephanie Burnett, Muneeb Mahmud, Victoria Hinder, Olivia Naismith, Emma Hall, Nicholas van As, E Lartigau, S Patton, A Thompson, M Winkler, P Wells, T Lymberiou, D Saunders, M Vilarino-Varela, P Vavassis, T Tsakiridis, R Carlson, G Rodrigues, J Tanguay, S Iqbal, M Winkler, S Morgan, A Mihai, A Li, O Din, M Panades, R Wade, Y Rimmer, M Panades, N Oommen,

Intensity-modulated radiotherapy versus stereotactic body radiotherapy for prostate cancer (PACE-B): 2-year toxicity results from an open-label, randomised, phase 3, non-inferiority trial, The Lancet Oncology, Volume 23, Issue 10, 2022, Pages 1308-1320, ISSN 1470-2045,

https://doi.org/10.1016/S1470-2045(22)00517-4.

(https://www.sciencedirect.com/science/article/pii/S1470204522005174)

NYU Langone Health

Radiation Oncology

# PACE-B Study Toxicity



Figure 19: CTCAE GU toxicity by treatment platform for SBRT delivery
SBRT-CK = SBRT delivered by CyberKnife; SBRT-CL = SBRT delivered on conventional linac
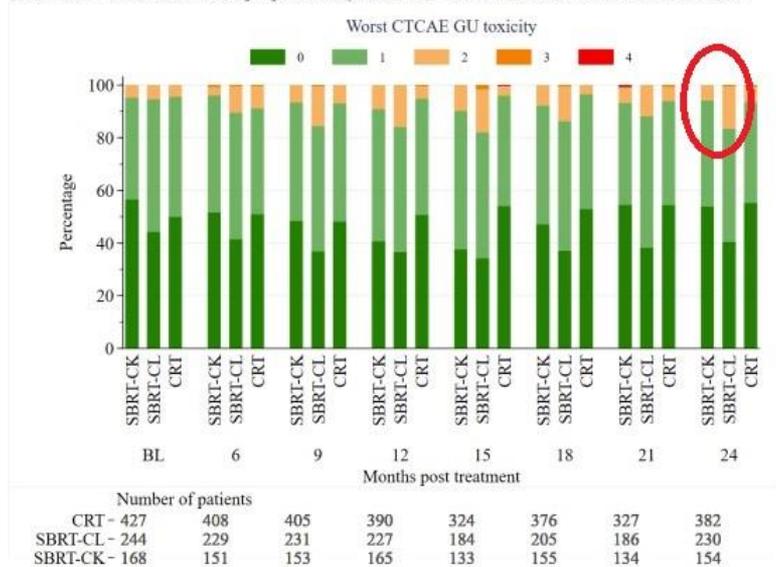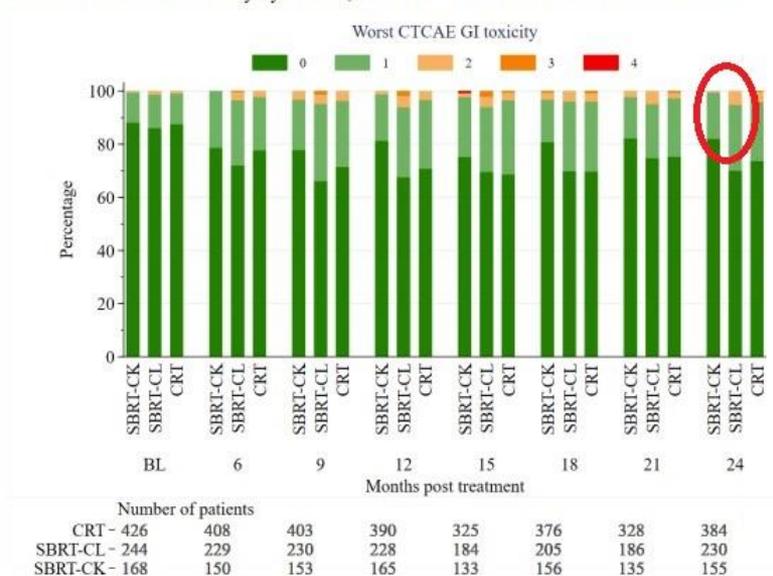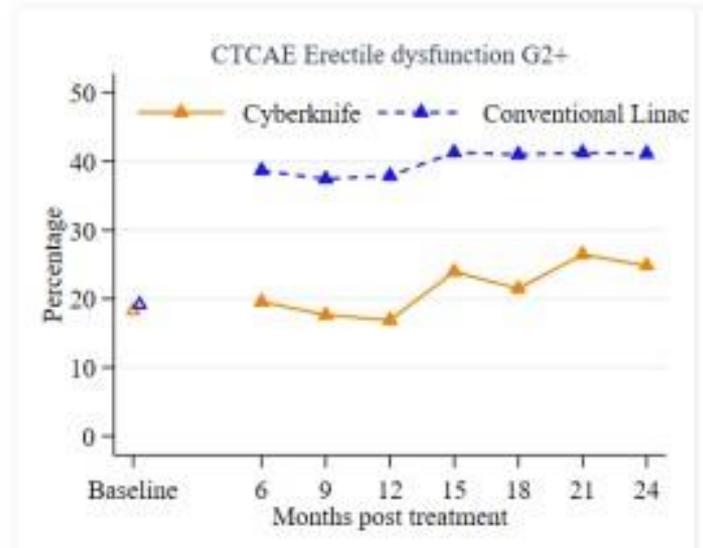
Figure 20: CTCAE GI toxicity by treatment platform for SBRT delivery;
SBRT-CK = SBRT delivered by CyberKnife; SBRT-CL = SBRT delivered on conventional linac

# Erectile Dysfunction – CyberKnife SBRT vs Conventional Linac SBRT



CTCAE Erectile dysfunction G2+

# Dosimetric Comparison of CyberKnife and Conventional Linac Prostate Stereotactic Body Radiation Therapy Plans: Analysis of the PACE-B Study

# Dosimetric Comparison of CyberKnife and Conventional Linac Prostate Stereotactic Body Radiation Therapy Plans: Analysis of the PACE-B Study

- Surprisingly, despite the lower urinary toxicity, CK-SBRT had generally higher planned doses to the urethra, bladder, and BT. This is likely due to more heterogeneous dose planning with CK-SBRT, with doses prescribed to the 65% to 85% isodose line.
- CK-SBRT plans had lower rectal D2% and smaller posterior margins, possibly explaining the trend toward lower gastrointestinal (GI)toxicity.
- Differences between planned and delivered doses are likely, especially in the CL-SBRT cohort, where intrafraction tracking is absent.
- In contrast, CK-SBRT allows for intrafraction prostate motion tracking, ensuring more precise delivery of planned doses, which may explain the differing toxicity outcomes.
  - There are, however, other confounding factors due to the nonrandomized nature of the comparison that could also explain the differing toxicity outcomes.
    - CK centers are often large academic institutions with extensive SBRT experience.
    - Nonstatistically significant trend toward more low-risk disease patients (without seminal vesicle involvement in the CTV) and fewer patients on baseline alpha-blockers in the CK-SBRT cohort.

# CyberKnife

# CyberKnife System

# CyberKnife System Components

- Linac
  - X-band – 9.3 GHz.
  - High shunt impedance and electric field strength.
- Robot
  - KUKA 6-axis robotic manipulator.
- Imaging System
  - Two ceiling-mounted kV x-ray sources.
  - Two in-floor amorphous Si with CsI scintillator, 40 x 40 cm$^2$ detectors.
- MLC
  - 26 leaf-pairs, 3.85 mm width @ 800 mm SAD.
- Fixed and Iris collimators
- Ceiling-mounted Synchrony camera
  - LEDs for respiratory tracking
- Couch
- Collimator exchange table

# Node Sets



M6 Workspace Patient Plane
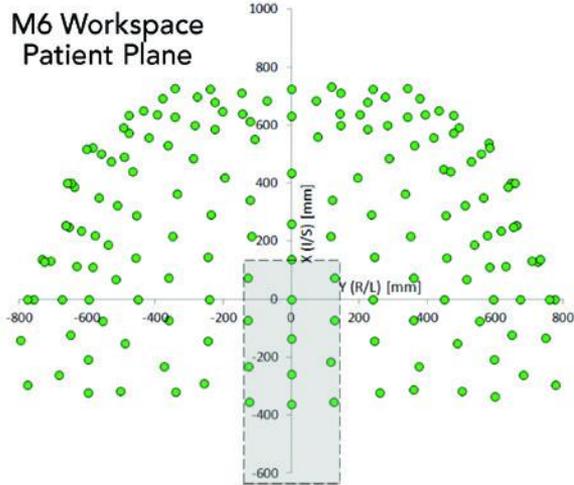
Right:Left = 50% : 50%
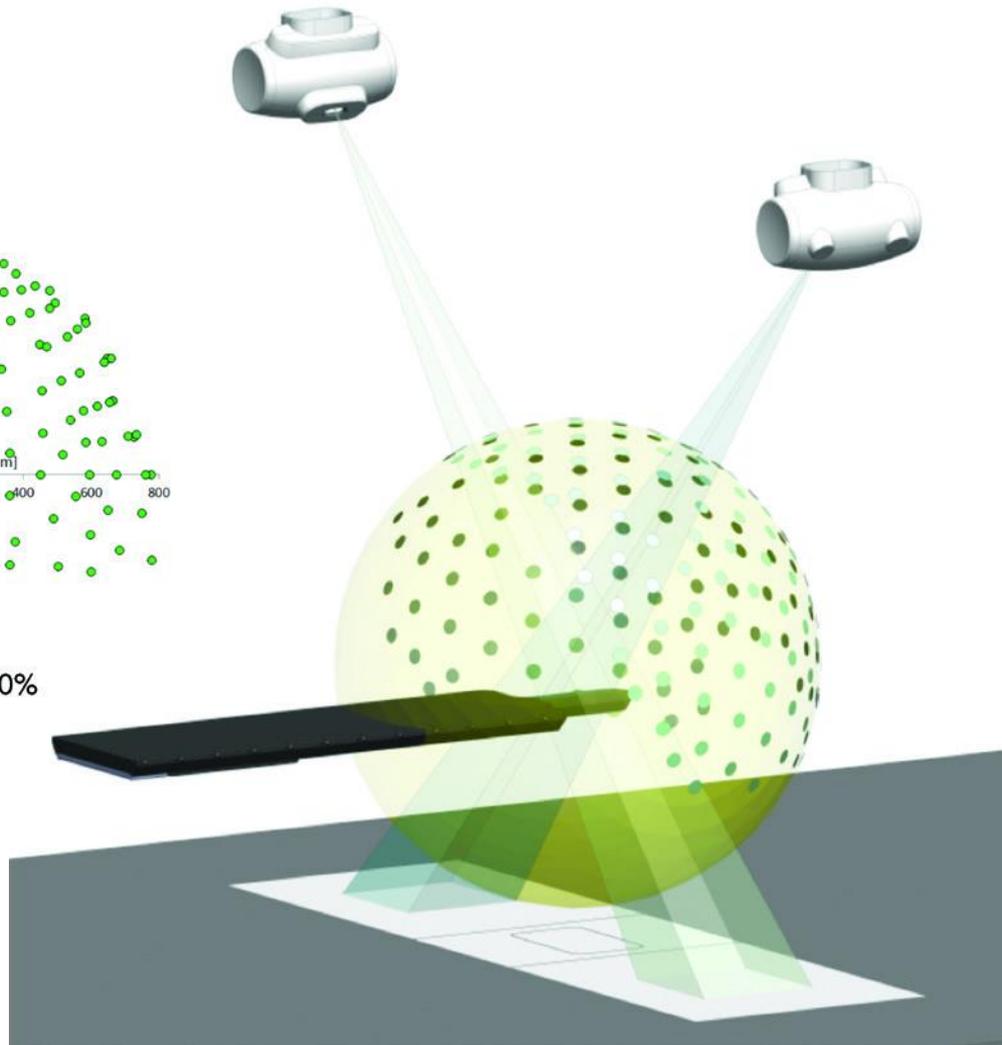
# Fiducials

- Surrogate for the prostate.
- Tracking in six dof.
  - If used for tracking, fiducial configuration (spacing) is important. Without proper placement, tracking rotations may not be possible, which has implications for PTV margins.

# Radixact

NYU Langone
Health

# System Components

- X-band linac
- MV detector array
  - Parallel plate ionization chambers (pressurized Xe-filled cavities separated by stainless steel septa) housed in an Al case.
  - 640 channels.
- kV imaging system
  - Ring-mounted kV source.
  - Flat-panel kV CsI:Tl detector, 43.2 x 43.2 cm$^2$ active area.
- Ceiling-mounted optical camera
  - LEDs for respiratory tracking.
- Couch

# Radixact System



Linac, jaws & MLC

kV source

kV detector

MVCT detector

NYU Langone Health

Radiation Oncology
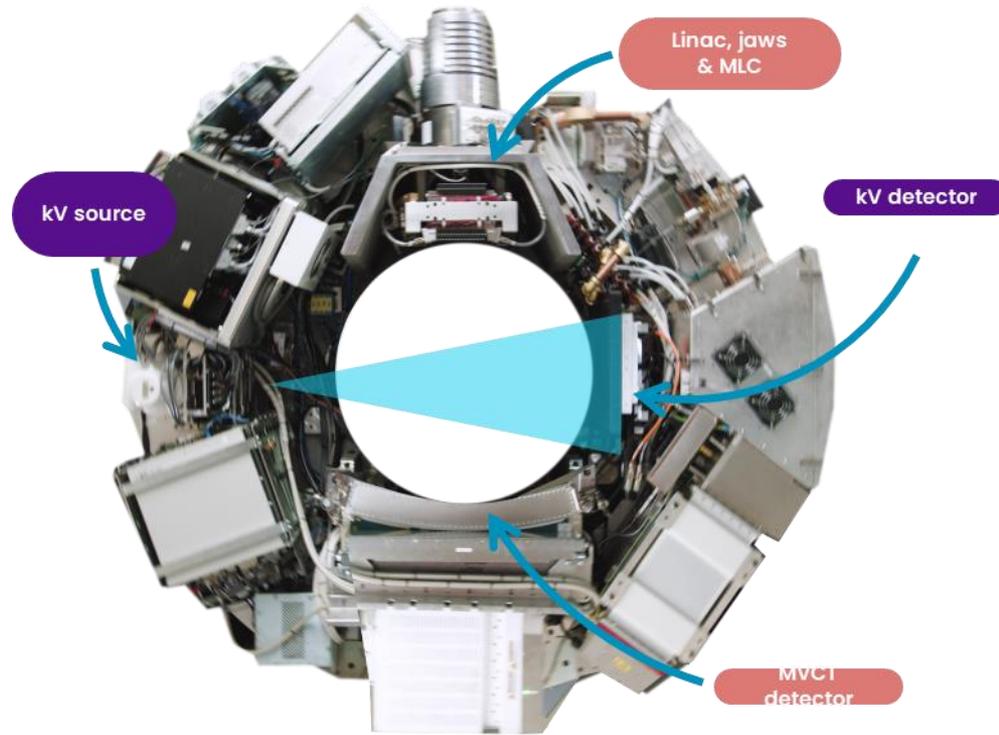
# End-To-End QA For Motion Tracking

# Same Test For Both CyberKnife And Radixact

- Test the entire workflow for overall clinical targeting accuracy
  - CT -> Image Import -> Contouring -> Planning -> Treatment Delivery.
- Targeting Error Tolerances
  - CyberKnife 0.95 mm radial error.
    - 5 dof motion compensation achieved via robotic arm.
    - Yaw is manually adjusted in case of traditional couch or adjusted using Robocouch.
  - Radixact 1.5 mm RMS error.
    - IEC Y motion compensation achieved via jaws.
    - IEC X and IEC Z motion compensation achieved via MLC and is discretized.
      - Shift one leaf if target displacement in IEC X/Z is a little more than ½-leaf width.
      - Thereafter, shift one leaf for each additional target displacement of one leaf width.
      - Shift based on centroid of prescription target.

# Ball Cube



Ball-cube

"S"

"L"

NYU Langone
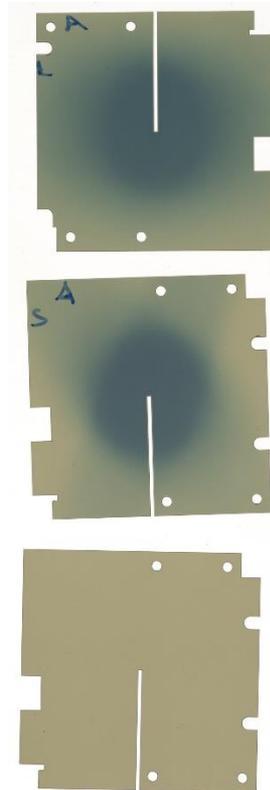Health
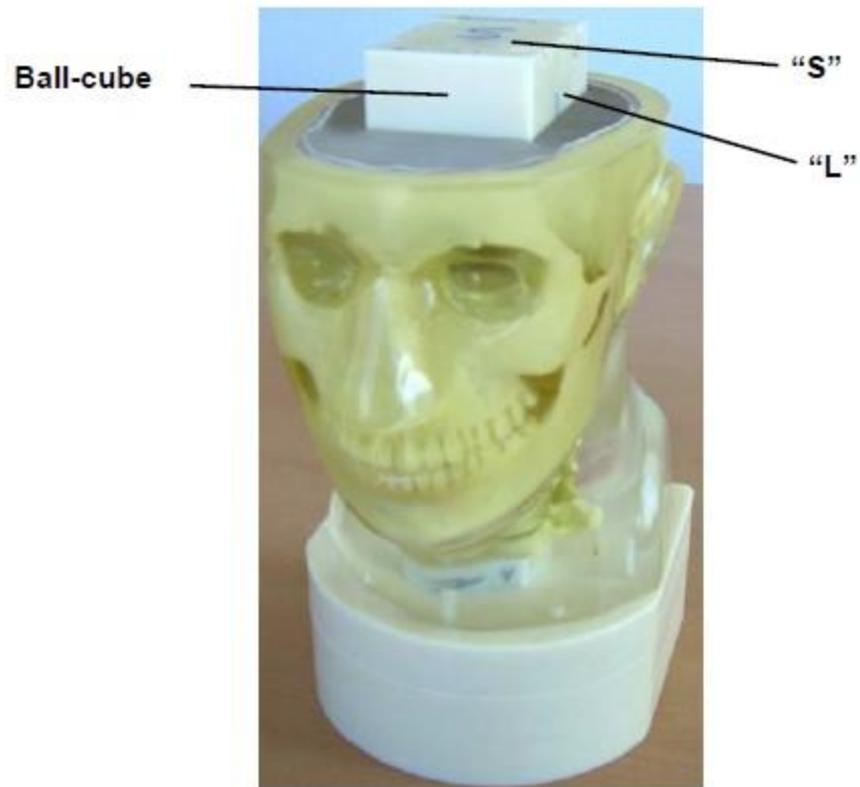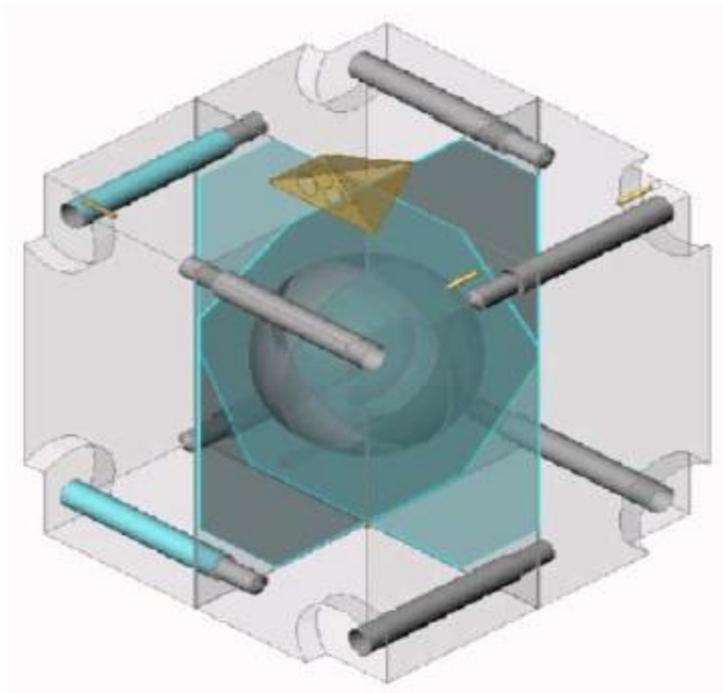
# E2E Film Analysis

### Radixact
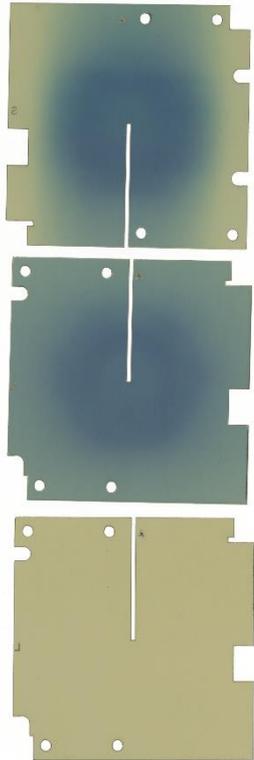


Error information:
Left error (mm): -0.02
Anterior error from A/L image (mm): 0.09
Superior error (mm): -0.29
Anterior error from A/S image (mm): 0.48
Average Anterior error (mm): 0.28
Total targeting error (mm): 0.41 (radial)
Total targeting error (mm): 0.23 (RMS)

10 mm SUP misregistration introduced @ delivery

### CyberKnife



Error information:
Left error (mm): 0.03
Anterior error from A/L image (mm): 0.69
Superior error (mm): -0.21
Anterior error from A/S image (mm): 0.58
Average Anterior error (mm): 0.64
Total targeting error (mm): 0.67

# Conclusion

- Hit the target accurately.

# Thank you

Radiation Oncology

NYU Langone Health