



3D Dosimetry Applications and Innovations



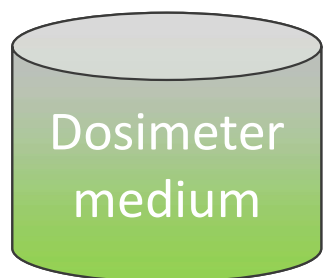
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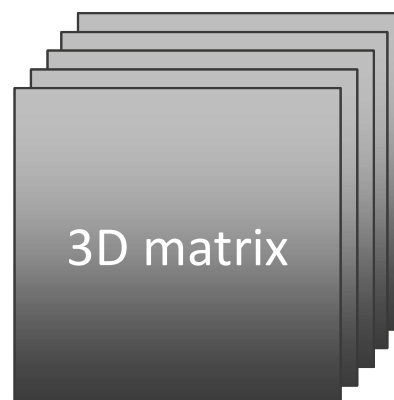
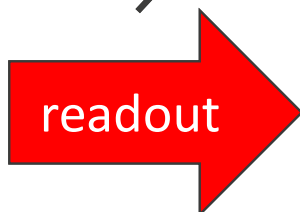
Conflict of Interest Statement

- Research funding from Radialogica LLC
- Ownership of ClearSight RT LLC
(unrelated to this topic)

3D Dosimetry Overview



- Optical CT
- MRI
- Ultrasound
- kV CT / CBCT



- Polymer gels / hydrogels
- Radiochromic plastic
- Stacks of 2D radiochromic film
- Polymeric/radiochromic materials in Micelle hydrogels
- Radiochromic Turnbull Blue gels
- Ferrous Xylenol orange gels

Common Advantages:

- Comprehensive!
- High Resolution

Common Challenges:

- Noise / Signal Drift
- Interbatch reproducibility
 - difficulty for absolute dose comparison
- Requires spatial registration
 - difficulty for absolute spatial comparison
- Lack of Widespread Analysis Tools
- Lack of Widespread Readout Technology

Jordan, Kevin. "Review of recent advances in radiochromic materials for 3D dosimetry." *Journal of Physics: Conference Series*. Vol. 250. No. 1. IOP Publishing, 2010.

NIPAM CT-based 3D dosimetry



Characteristics

- NIPAM: **N-Isopropyl acrylamide**:
- Used for traditional 3D dosimetry readout (MRI / optical CT)
- Customized formulation can also be used with CT-based readout (density change)
- kV-CT readout:
 - Dose causes a **change in density**
 - Low CNR is a challenge



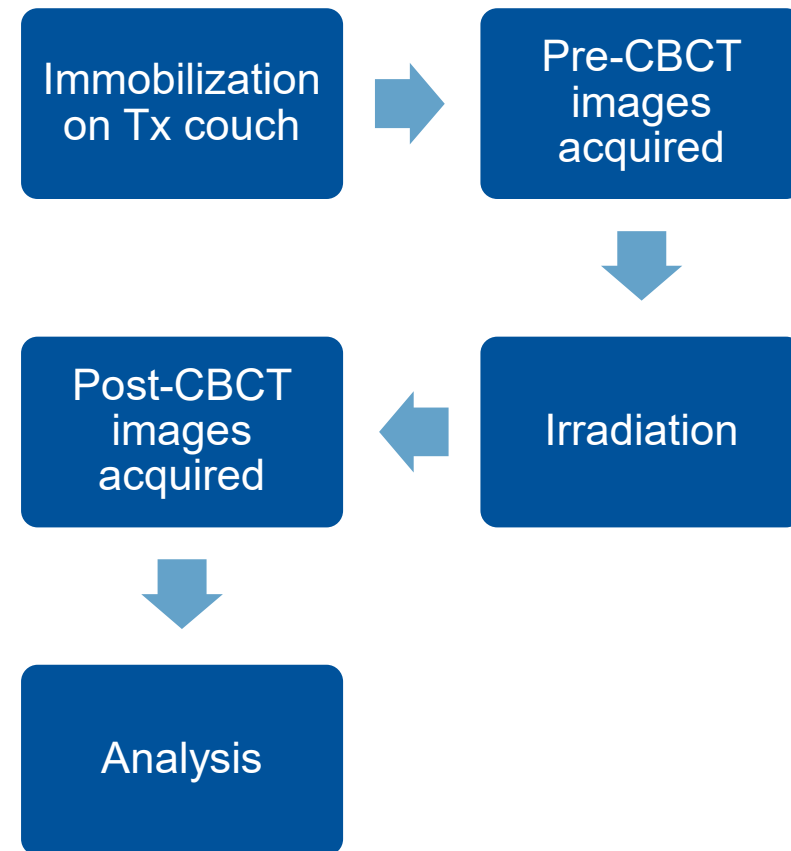
NIPAM CT-based 3D dosimetry



Our Focus: kV-CBCT Readout for NIPAM 3D Dosimetry

Why use CBCT?

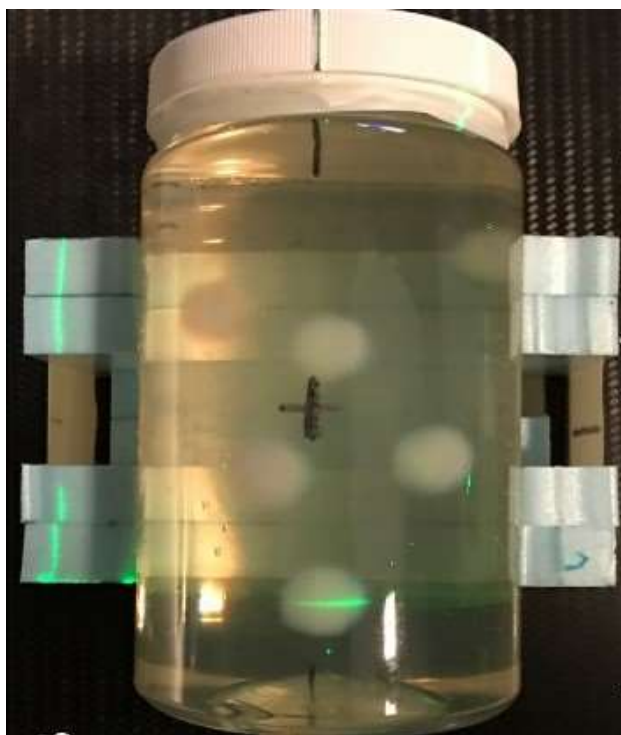
- Readout is in **same coordinate system** as patient alignment
 - **Eliminates registration step** between planned & measured dose
 - “**Linac-synchronized 3D dosimetry**”
- **Widespread applicability**
- Pre-imaging, irradiation, & post-imaging all carried out without moving dosimeter
 - Eliminates registration step between pre-irradiation image and post-irradiation image
 - Subtracting pre-image(s) from post image(s) helps **minimize reconstruction artifacts**



kV-CBCT NIPAM 3D Dosimetry

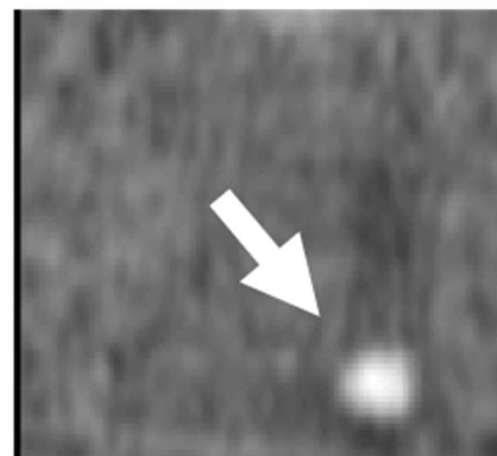
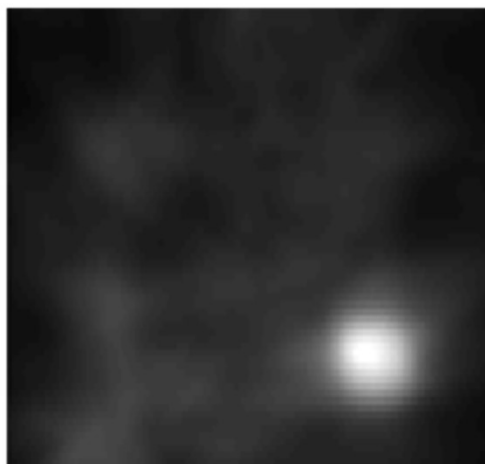


Proof of Concept

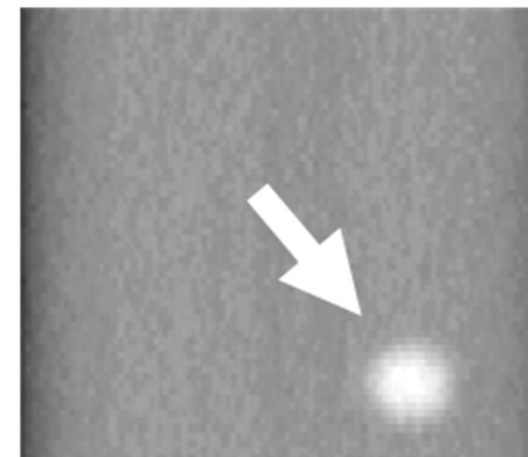


post-processed
av. CBCT
+ low pass filter

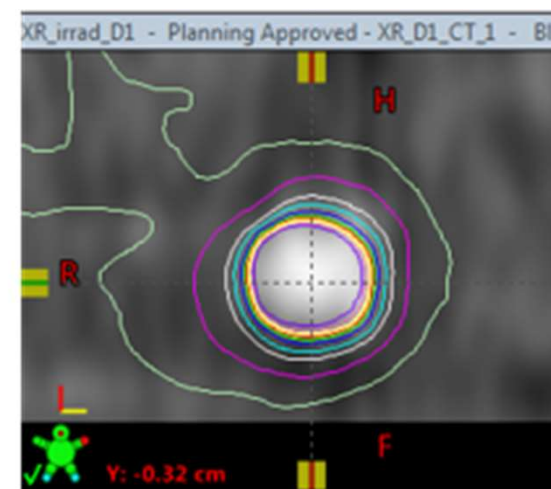
dose from TPS
(gray scale
0-30Gy)



average 5
diagnostic CTs



CBCT in TPS



Adamson, Justus, et al. "Delivered Dose Distribution Visualized Directly With Onboard kV-CBCT: Proof of Principle." *International Journal of Radiation Oncology* Biology* Physics* 103.5 (2019): 1271-1279.

Combined kV and MV isocenter uncertainty analysis for SRS

Unique couch and gantry angles used in the comprehensive isocenter verification test.

<i>Couch angle (°)</i>	<i>Gantry angle (°)</i>
0	45
0	135
0	180
0	270
45	45
90	45
270	45
315	45



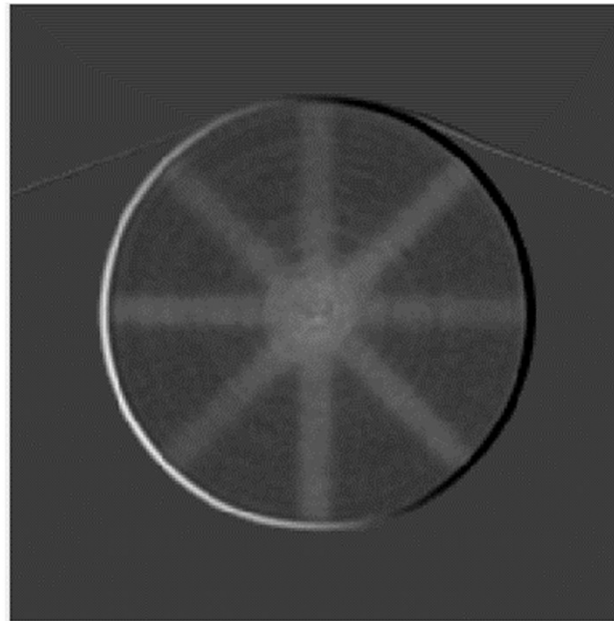
Isodose volume for isocenter verification plan.

Materials and Methods: CBCT Technique

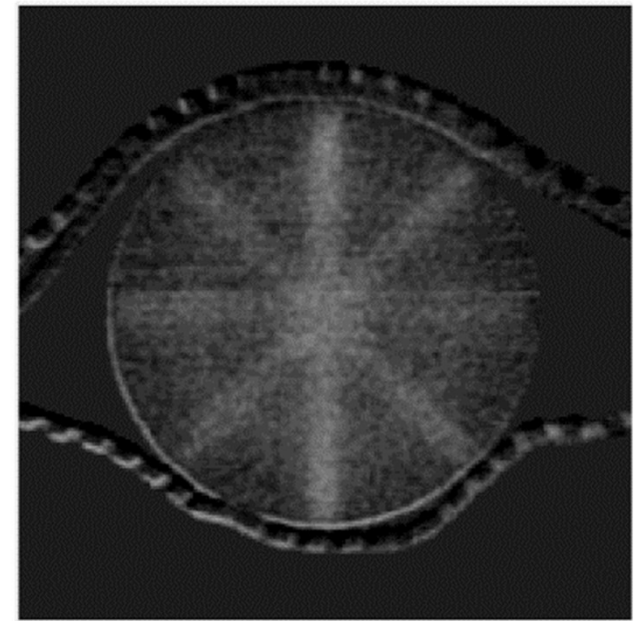


- Best results with full fan, full rotation
- Main limitation is tube heat loading
- Higher kVp decreases noise & increases CNR
- Smooth reconstruction increases CNR with minimal loss of spatial resolution
- Slow rotation CBCT increases CNR

slow rotation
CBCT
(5330 projections)



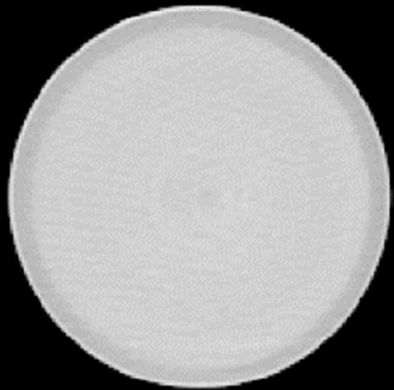
standard
CBCT
(895 projections)



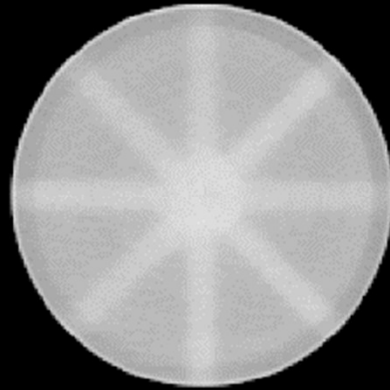
Materials and Methods: Analysis



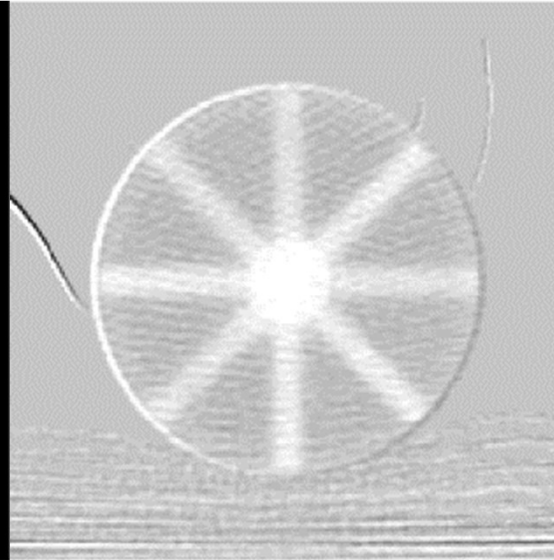
Pre-irradiation
CBCT



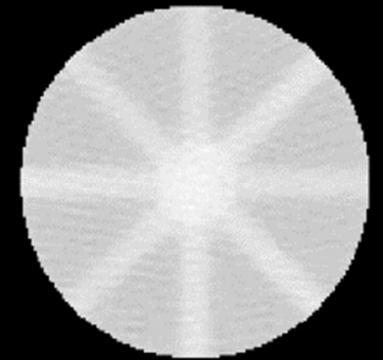
Post-irradiation
CBCT



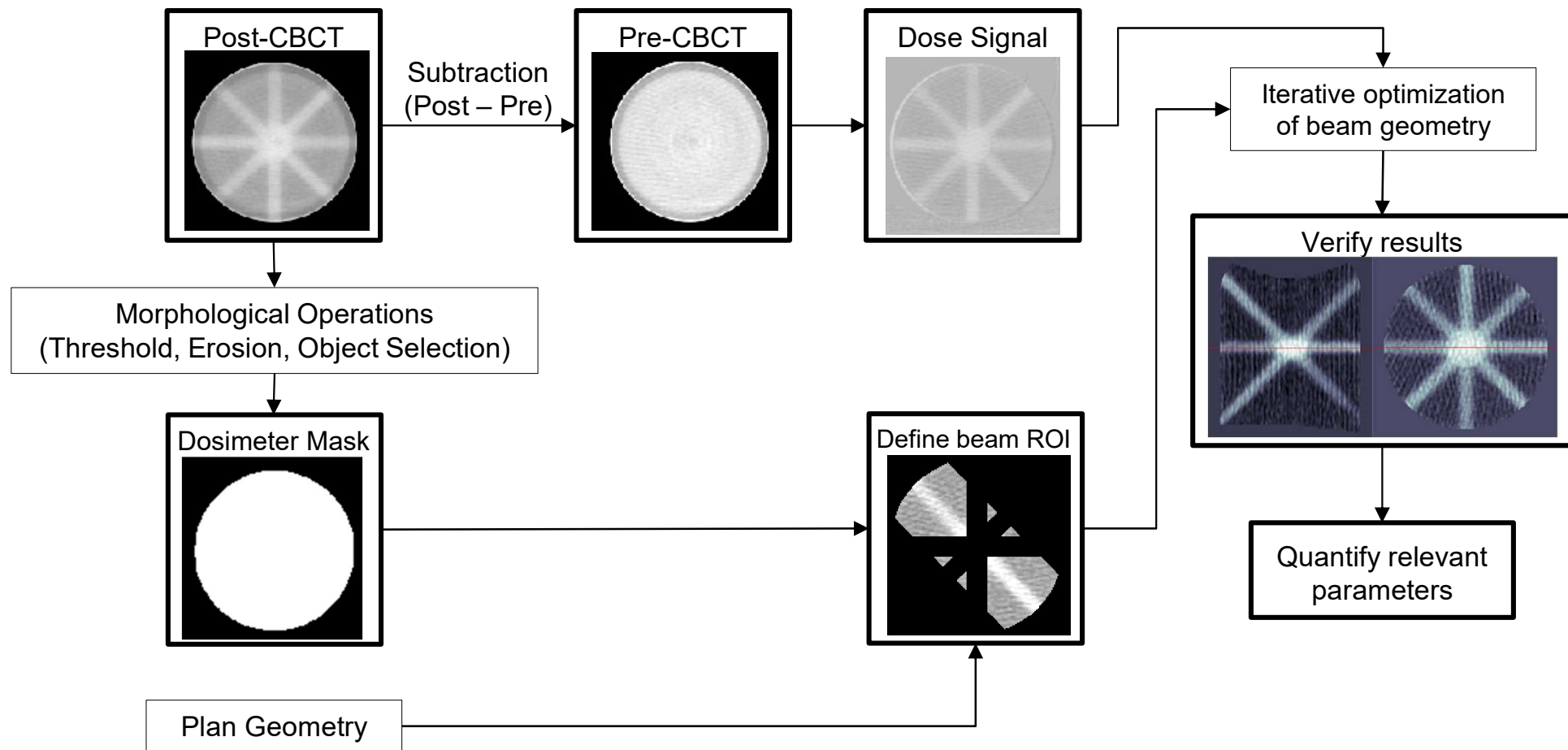
Subtraction
CBCT



Dosimeter ROI
applied



Materials and Methods: Analysis



Results

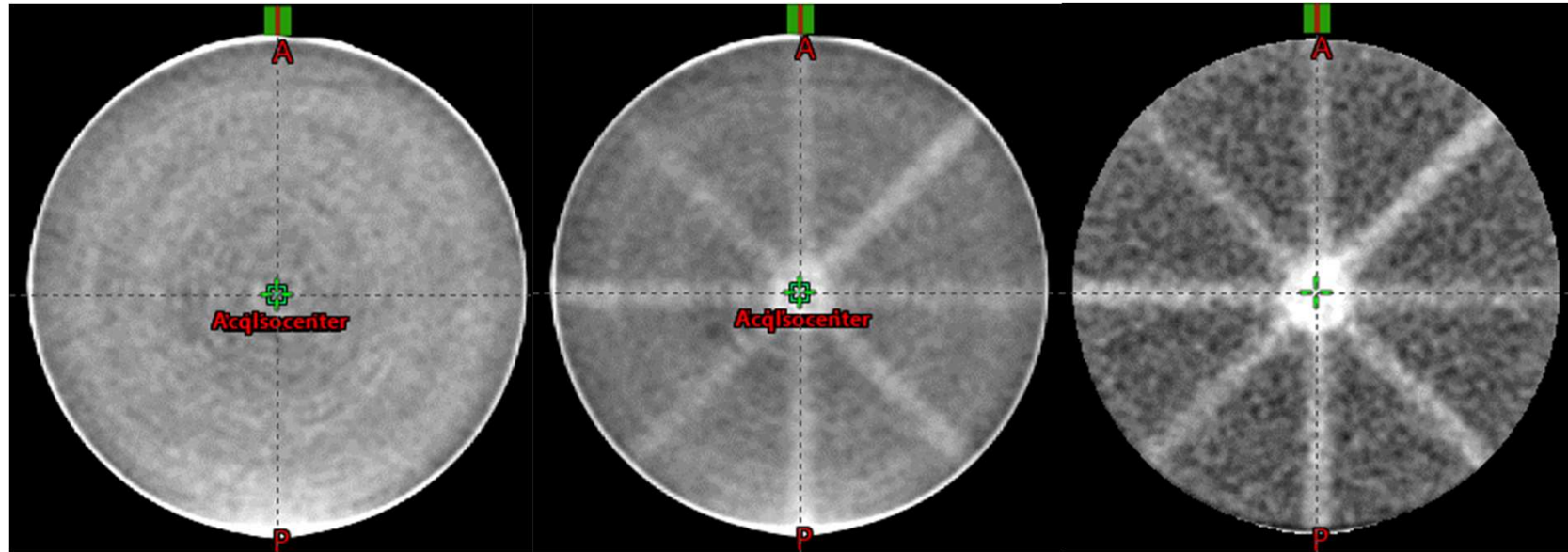


Pant, Kiran, et al. "Comprehensive Radiation and Imaging Isocenter Verification Using NIPAM kV-CBCT Dosimetry." *Medical Physics* (2020)

Isocenter verification: 4mm cone



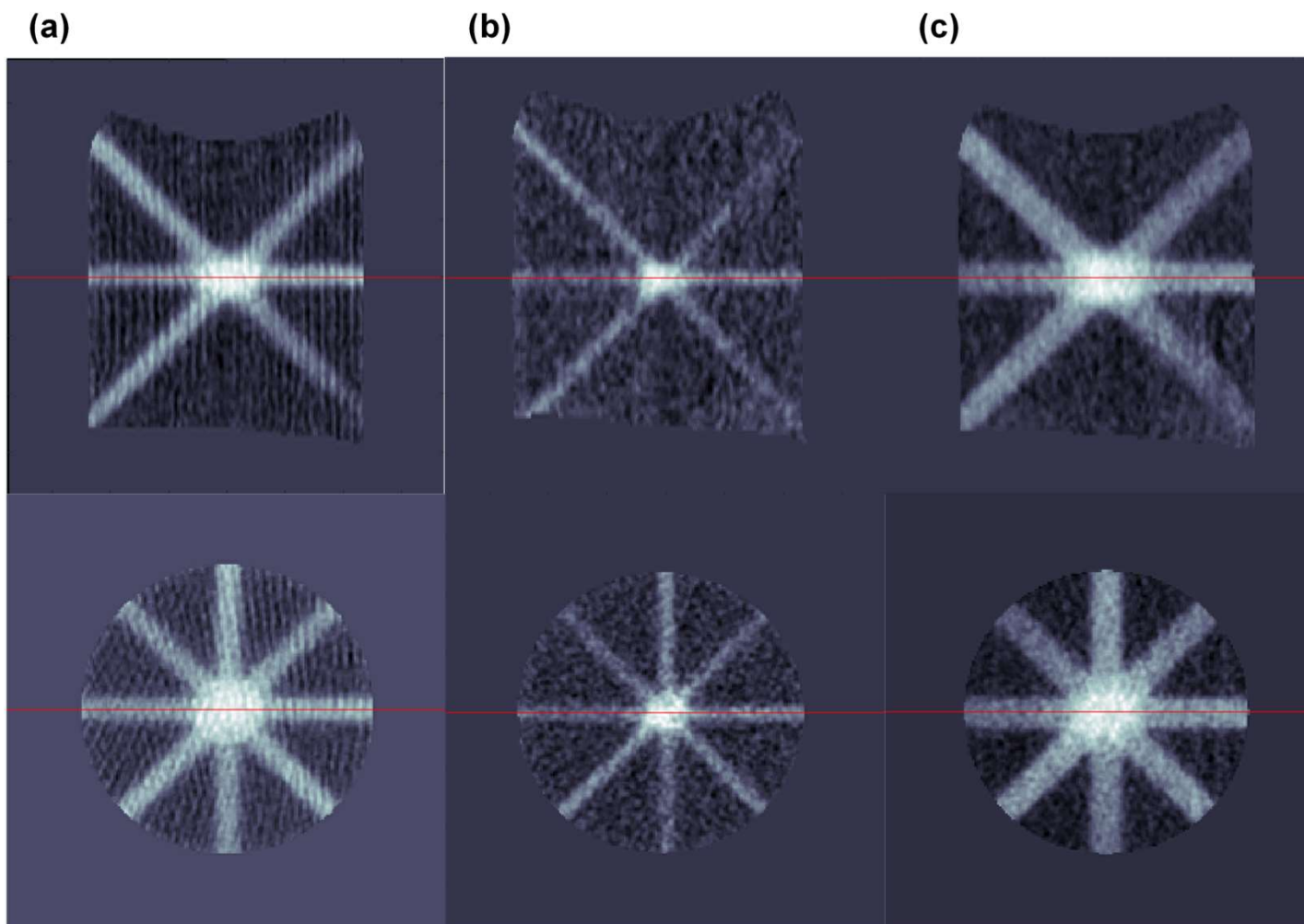
Photo, post irradiation Pre-irradiation CBCT Post-irradiation CBCT Subtraction CBCT₂-CBCT₁



CBCT settings: 80kV, 4025mAs, full rotation
38 minutes for pre-CBCT, irradiation, & post CBCT

Pant, Kiran, et al. "Comprehensive Radiation and Imaging Isocenter Verification Using NIPAM kV-CBCT Dosimetry." *Medical Physics* (2020)

Verification for different collimations



Pant, Kiran, et al. "Comprehensive Radiation and Imaging Isocenter Verification Using NIPAM kV-CBCT Dosimetry." *Medical Physics* (2020)

Results



Automatic analysis results of the isocenter verification test using the MLCs and SRS cones.

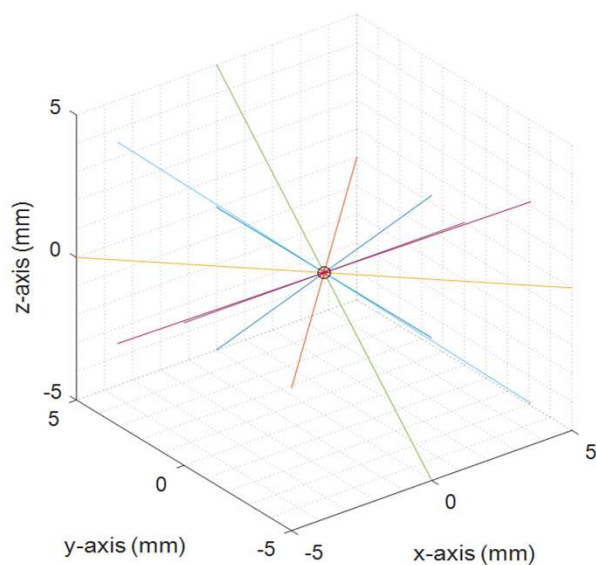
	5mm MLCs	4mm cone	6mm cone	7.5mm cone	10mm cone	12.5mm cone	15mm cone
Dist. radiation iso to CBCT origin (mm)	0.39	0.21	0.23	0.45	0.15	0.65	0.14
Smallest radius intersecting all beams (mm)	0.38	0.44	0.53	0.48	0.75	0.5	0.57
Gantry accuracy mean differences (°)	0.16 ± 0.23	0.13 ± 0.16	0.38 ± 0.42	0.17 ± 0.23	0.56 ± 0.7	0.86 ± 0.74	0.47 ± 0.39
Couch accuracy mean differences (°)	-0.25 ± 0.27	0.04 ± 0.25	0.01 ± 0.45	0.16 ± 0.23	-0.08 ± 0.66	-0.29 ± 1.53	-0.07 ± 0.55

Pant, Kiran, et al. "Comprehensive Radiation and Imaging Isocenter Verification Using NIPAM kV-CBCT Dosimetry." *Medical Physics* (2020)

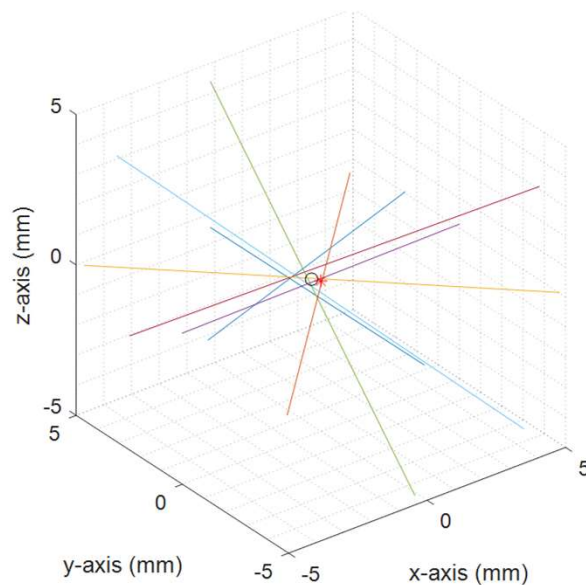
3D Rendering of Results:



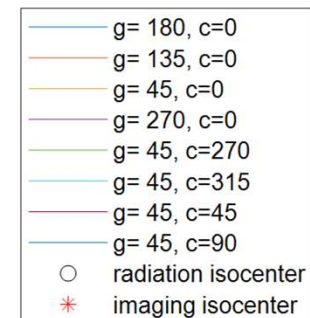
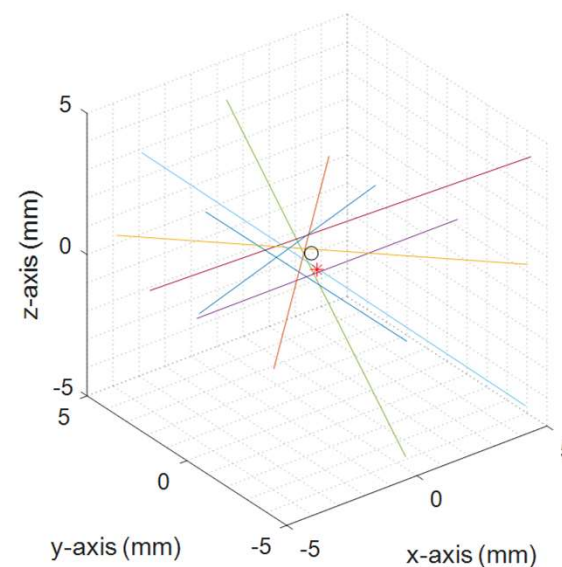
Ideal



Measured
uncertainty



Measured
uncertainty with
intentional error

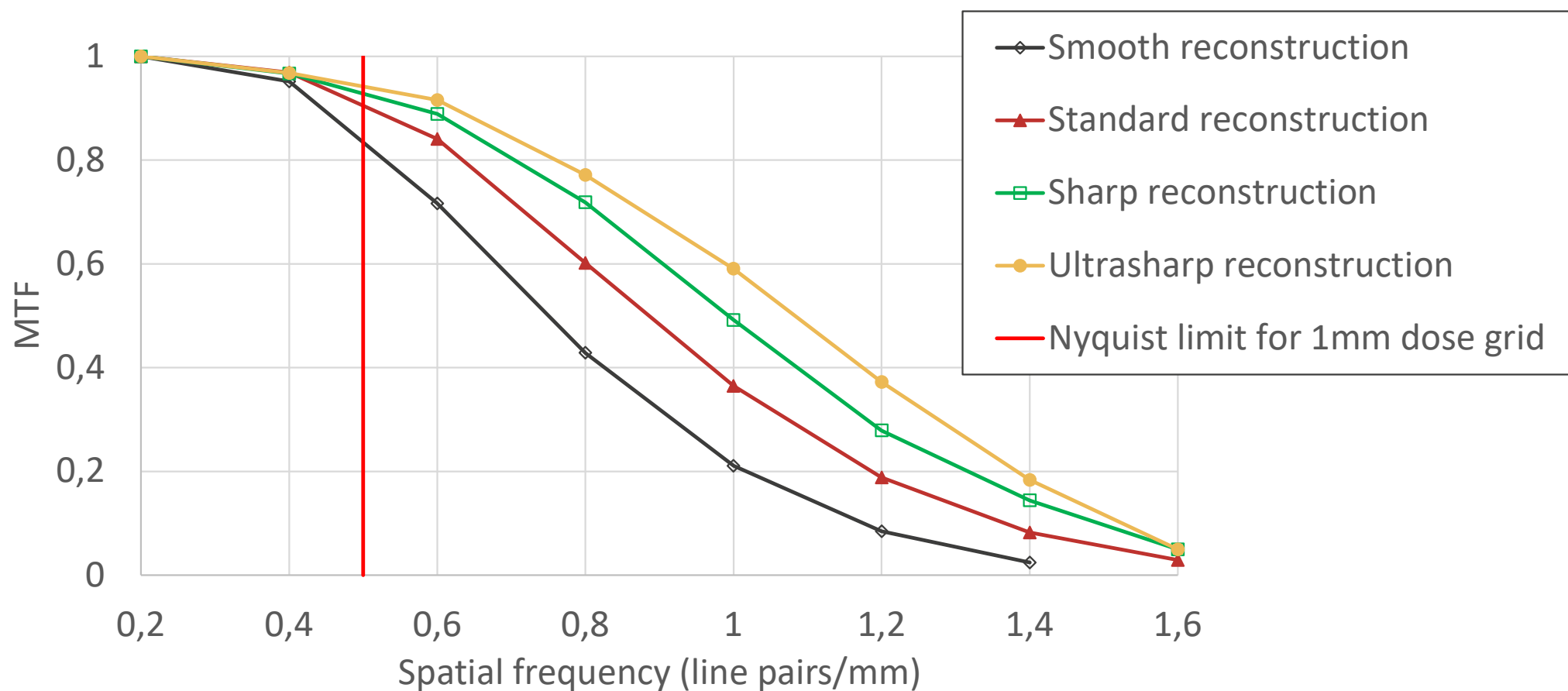


What about Dosimetric Analysis?



- Low Contrast is a challenge
- Potential Improvements to CBCT technique:
 - Increase number of averages
 - Specialized CBCT acquisition technique
 - Full fan, full (360°) rotation
 - Same rotation direction for all CBCTs
 - slow rotation speed (6 minute scan time, 5K+ projections)
 - Smooth reconstruction filter
 - **Iterative reconstruction technique (Varian iCBCT)**

Reconstruction Filter:

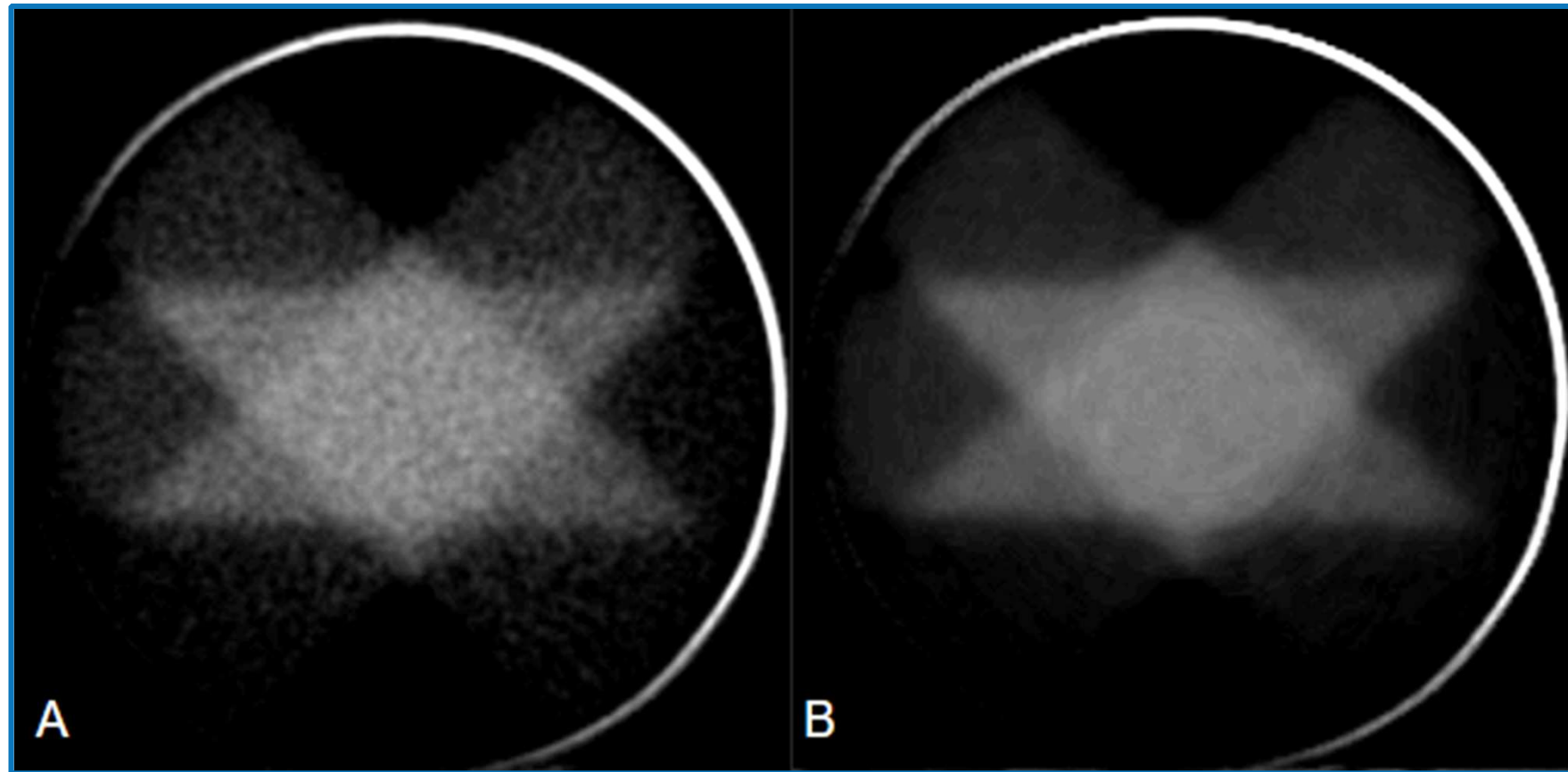


Iterative Reconstruction Technique

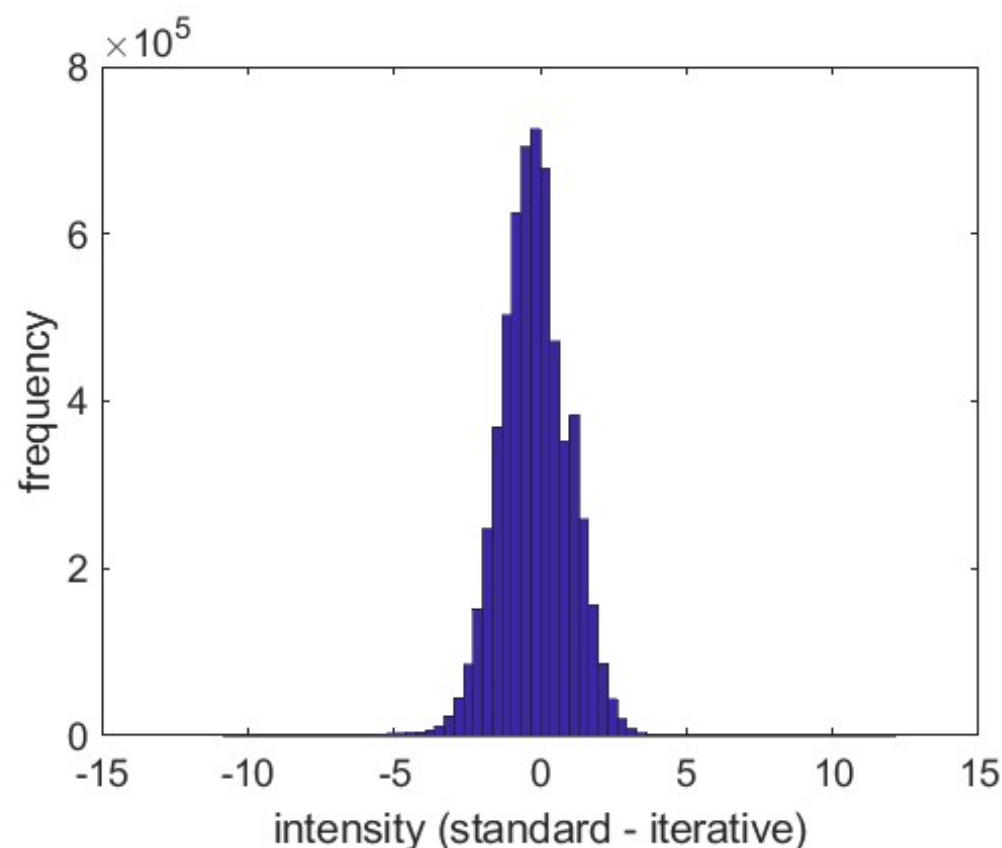
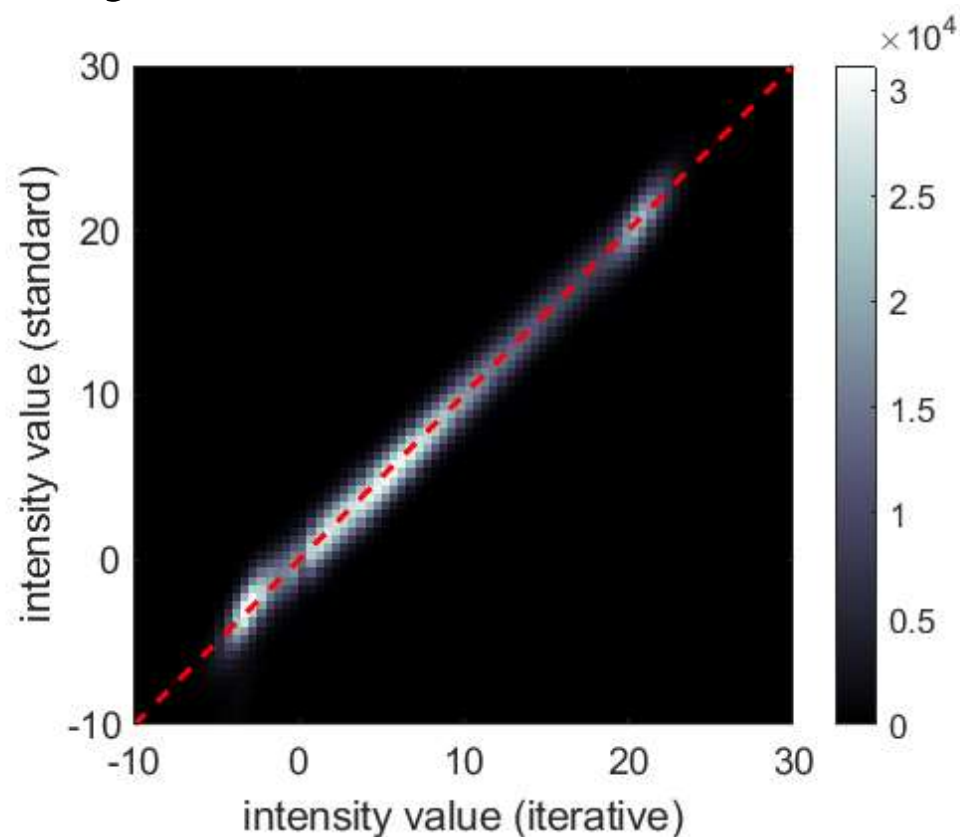


Standard

iCBCT

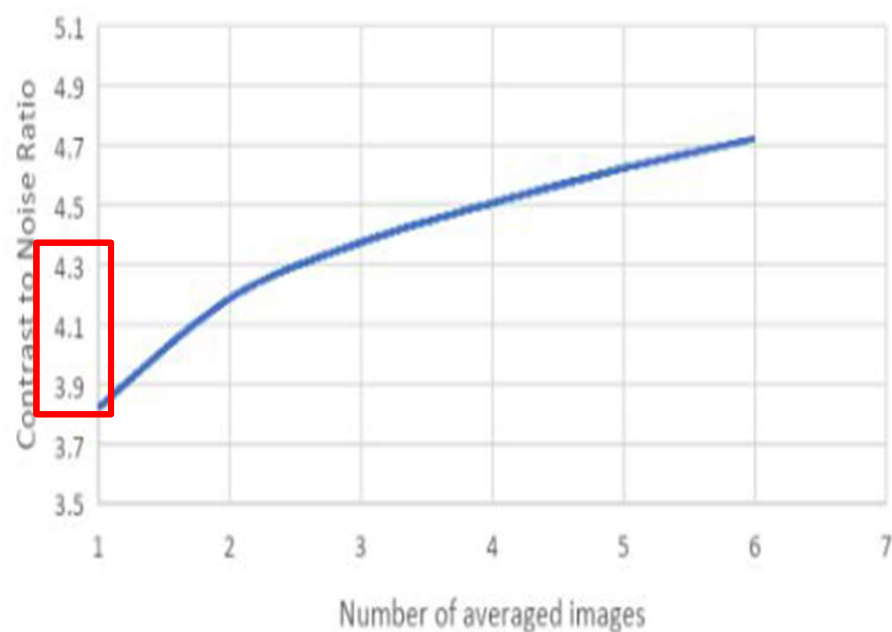


dose intensity relationship unaffected by iCBCT artifact reduction:

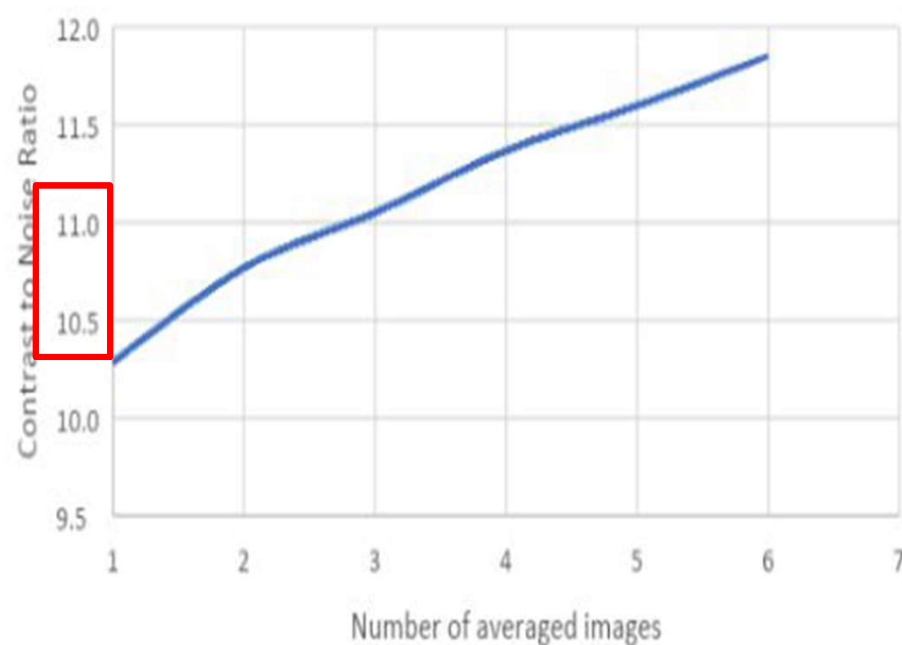


iCBCT: Effect on Contrast to Noise

Standard



iCBCT



Results

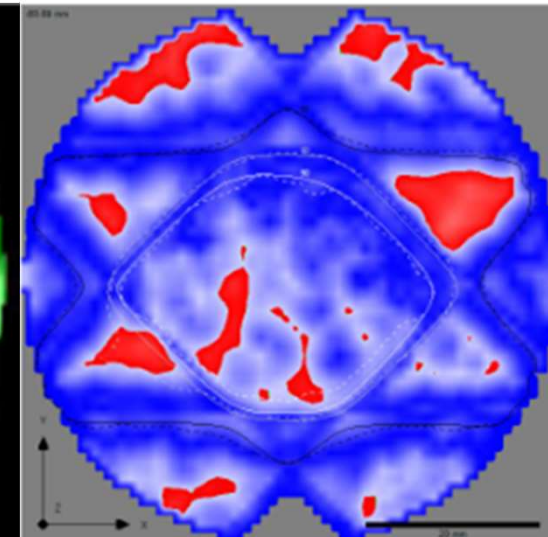
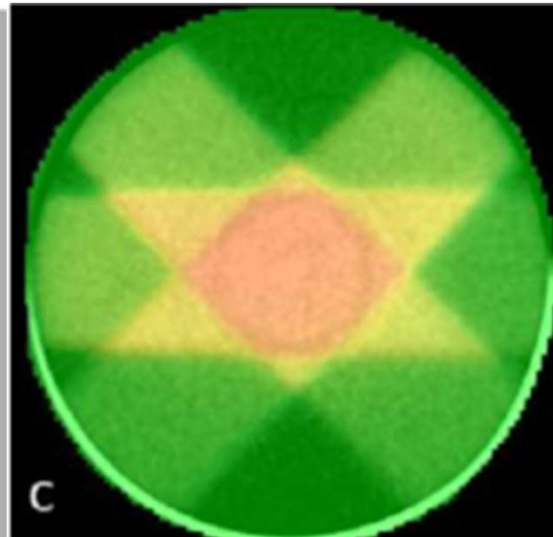
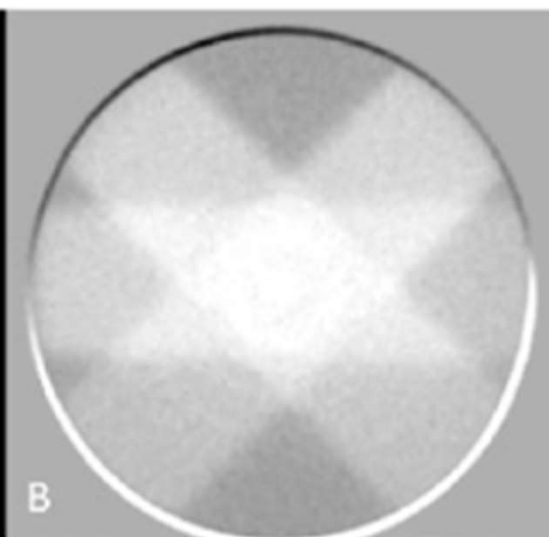
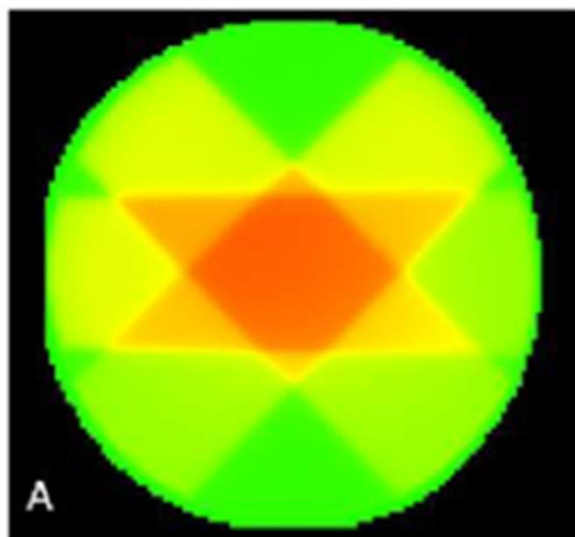


TPS Dose

Measured Dose

Overlay

Gamma



Gamma Index

3%/3mm	5%/2mm	3%/2mm
95.6%	94.5%	88.9%

Conclusions:

- Spatial analysis can be carried out quickly & with high accuracy
 - Isocenter verification test
 - <40 minutes from start to finish
 - Sub-mm isocenter verification
 - Also includes verification of
 - » imaging vs. radiation isocenter
 - » gantry / couch angle
 - Similar for Multi-target SRS
- Dosimetric analysis
 - Improvements to CBCT technique show promise for dosimetric analysis
 - Increased averages, iCBCT, smooth reconstruction filter

Questions?

Collaborators:

- Kawtar Lakrad (Fulbright Scholar, Hassan II University of Casablanca)
- Duke University:
 - Kiran Pant (graduate student)
 - Jaclyn Carrol (graduate student)
 - Michael Trager (graduate student)
 - Mark Oldham (faculty)
 - William Giles (staff physicist)
- Duke Kunshan University Graduate Students:
 - Chibuike Umeh
- University of British Columbia:
 - Andrew Jirasek (faculty)
 - Tenzin Kunkyab (graduate student)
- British Columbia Cancer Agency
 - Michelle Hilts (faculty)
 - Derek Hyde (faculty)

