Improving kV-Cone beam image quality for GYN brachytherapy planning

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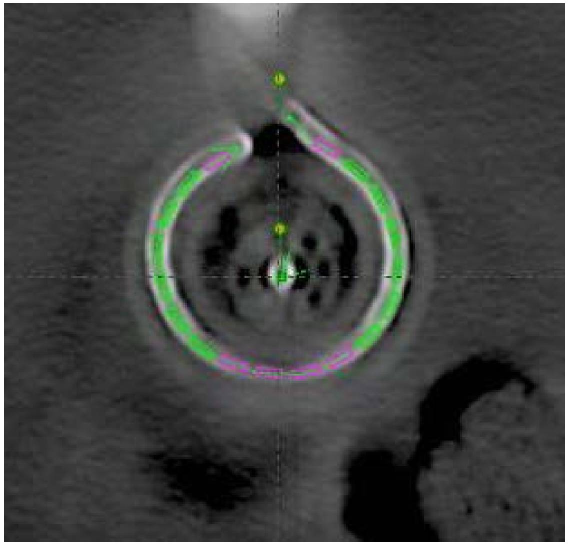
April 2014

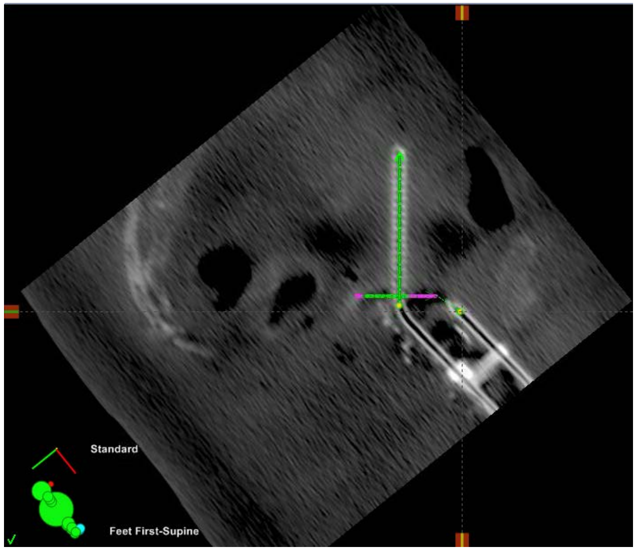
DISCLAIMER

This is a therapy physics resident giving a diagnostic physics talk.

The Problem…

- Suboptimal cone beams often used for brachytherapy planning
- Same acquisition mode used for all patients





- Patient size has a significant effect on image quality

Objectives

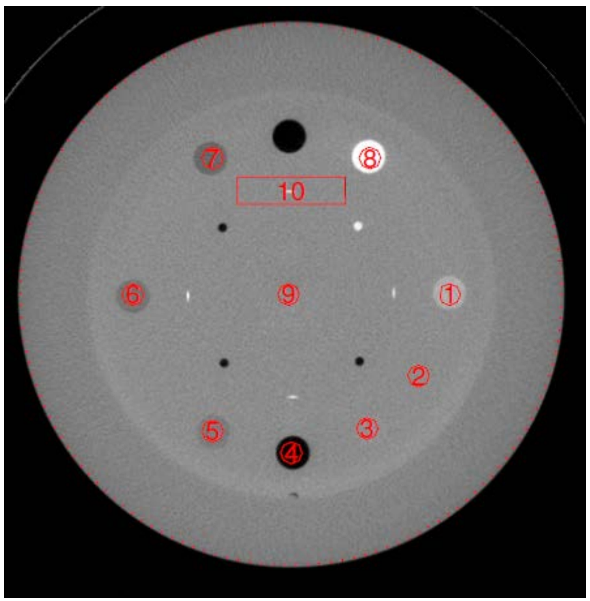
- Improve image quality at an Acuity Conventional Simulator for more accurate soft tissue visualization
- Recommend new imaging protocols for GYN brachytherapy treatment planning

Overview

1. Establish differences in image quality between a TrueBeam kV imager and an Acuity Conventional Simulator
2. Identify most effective parameter change that does not significantly increase dose
3. Establish the best cone beam acquisition mode for our purposes
4. Test how patient size influences image quality
5. Recommend new kV cone beam protocols

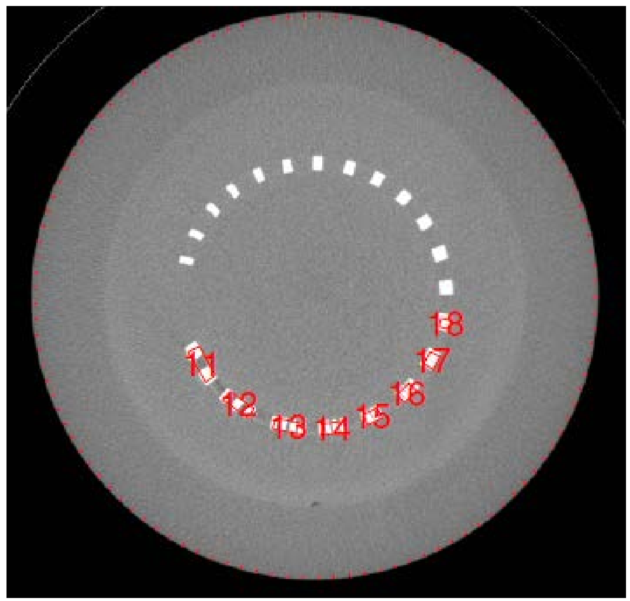
Objective Analysis

CTP 404



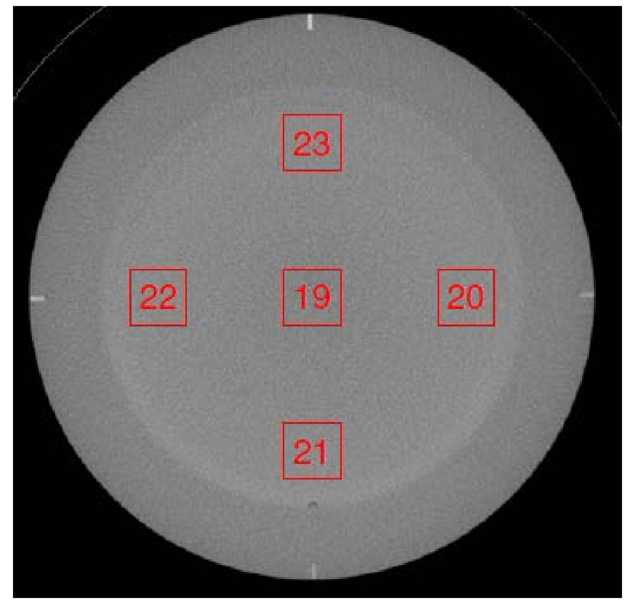
- Contrast
- CNR
- HU uniformity

CTP 528



- Spatial resolution

CTP 486



- Uniformity

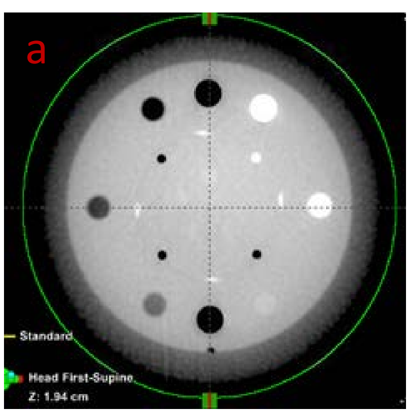
Subjective Analysis

Beam Hardening

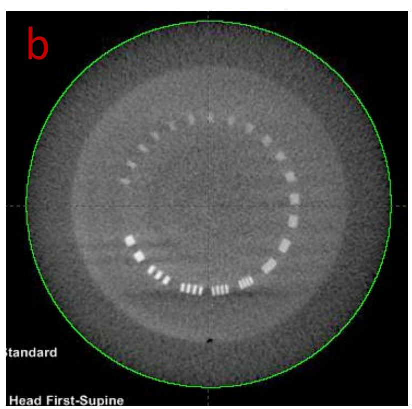
- Streaking artifact
  - Dark streaks between 2 or more dense objects
    - The portion of the beam passing through both objects at certain tube positions becomes harder than when it passes through only one object at another tube position
- Cupping artifact
  - X-rays passing through (thicker) center of the patient harden more than x-rays passing through periphery (17)

Equipment/Settings

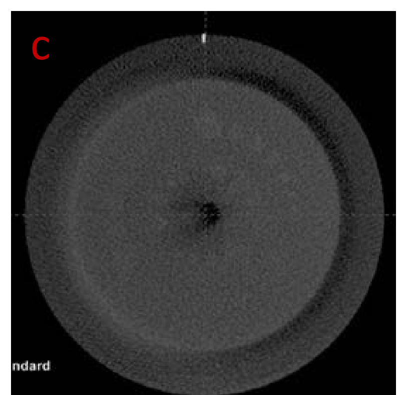
- Ring artifacts
  - Due to poor scanner calibration or a scanner imperfection(15)
  - A ring is produced because the imperfection gives an erroneous reading at every angle (17)
- Loss of skin-line
  - Information about patient periphery is reduced because the outer rows of detectors record less attenuation (15)



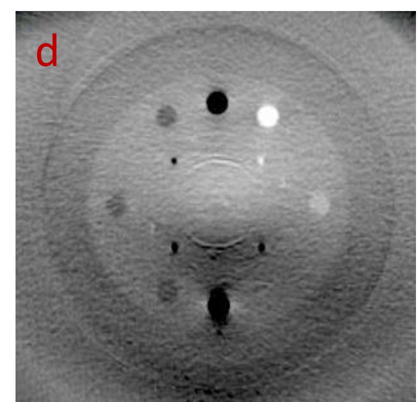
Acuity Pelvis scan, 2.0 mm, 384 matrix



Acuity Head scan, 2.0 mm, 384 matrix



STX Spotlight scan, 2.0 mm, 384 matrix

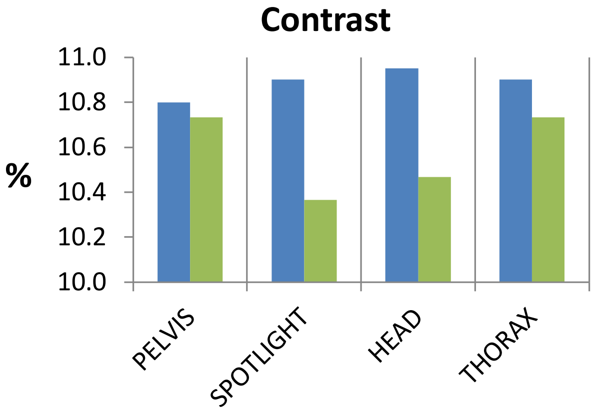


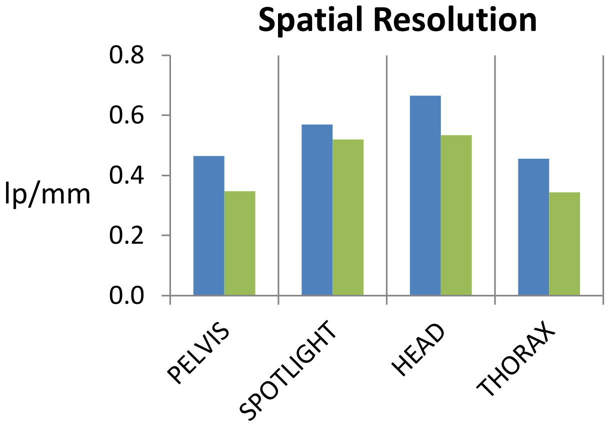
Acuity Pelvis scan, 2.0 mm, 384 matrix

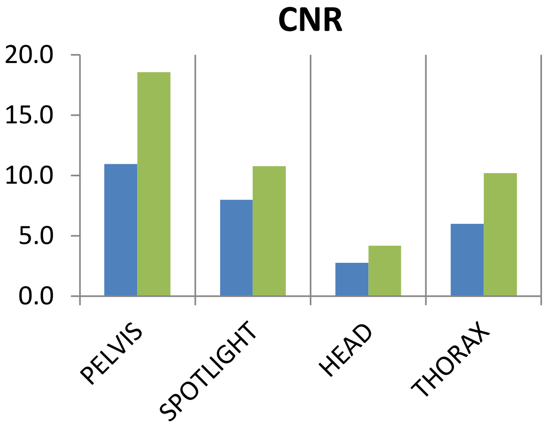
Establishing A Baseline

Acuity Conventional Simulator

TrueBeam kV Imager







Differences

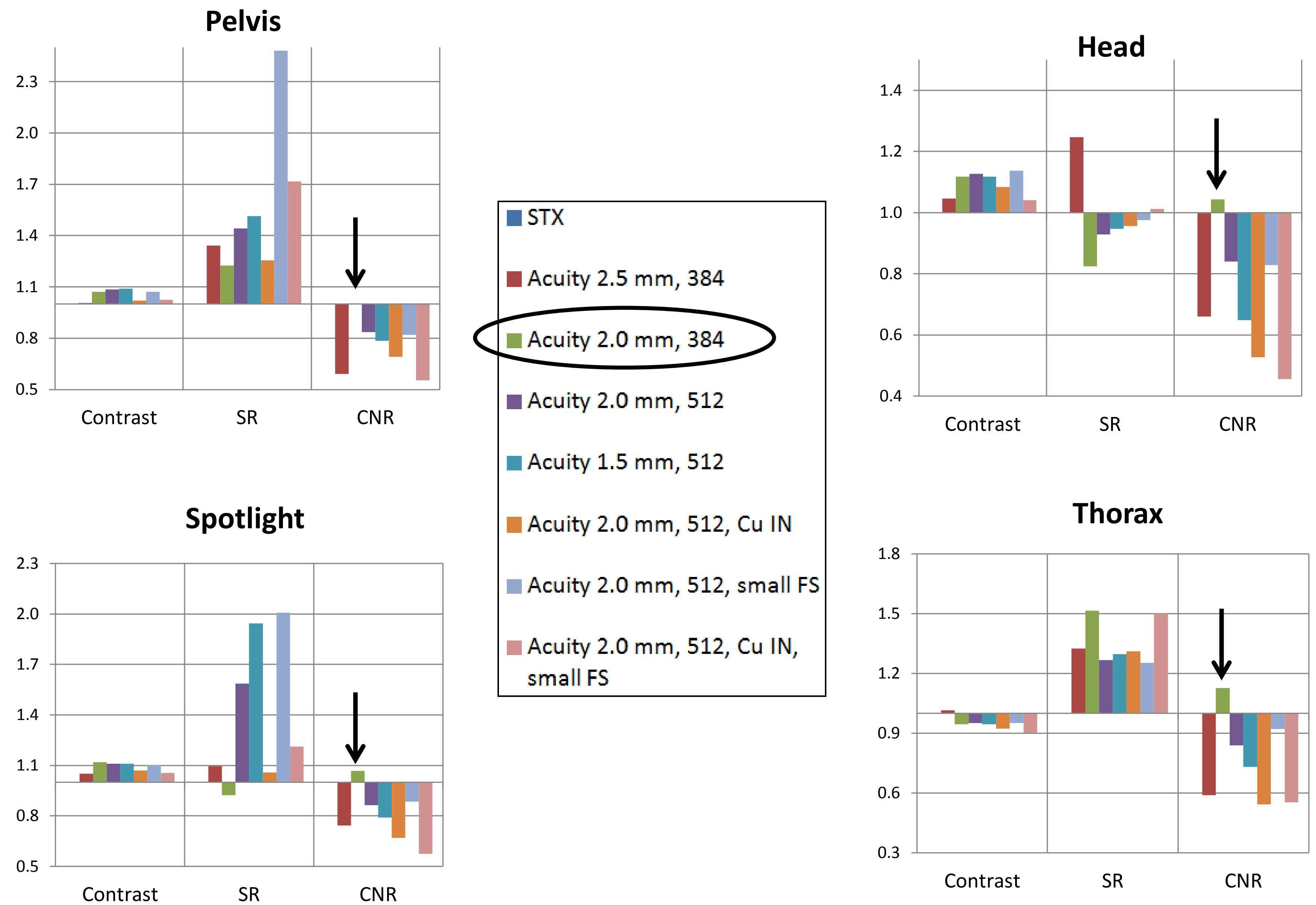
- Filtration
  - Bowtie filters
    - STX: aluminum
    - Acuity: Plastic
  - X-ray tube housing
    - STX: aluminum
    - Acuity: glass
  - Filter insert
    - STX: titanium
    - Acuity: copper
- Data Processing
  - Pre-processing
    - STX: scatter correction, analytical spectrum correction
    - Acuity: none
  - Post-processing
    - STX: HU correction, ring artifact suppression
    - Acuity: ring artifact suppression

Changing Parameters

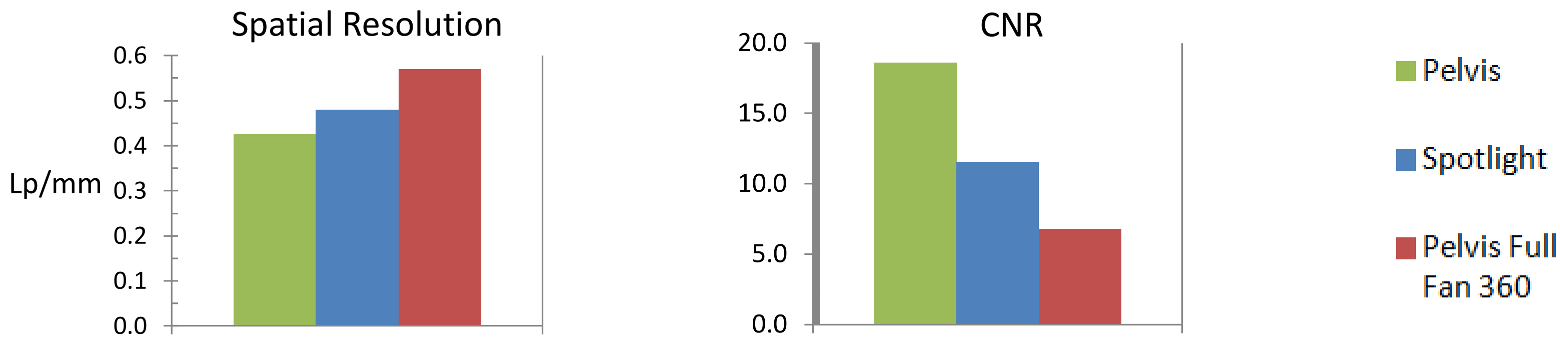
- Exposure parameters were not changed except when calibrating the Acuity to match the STX

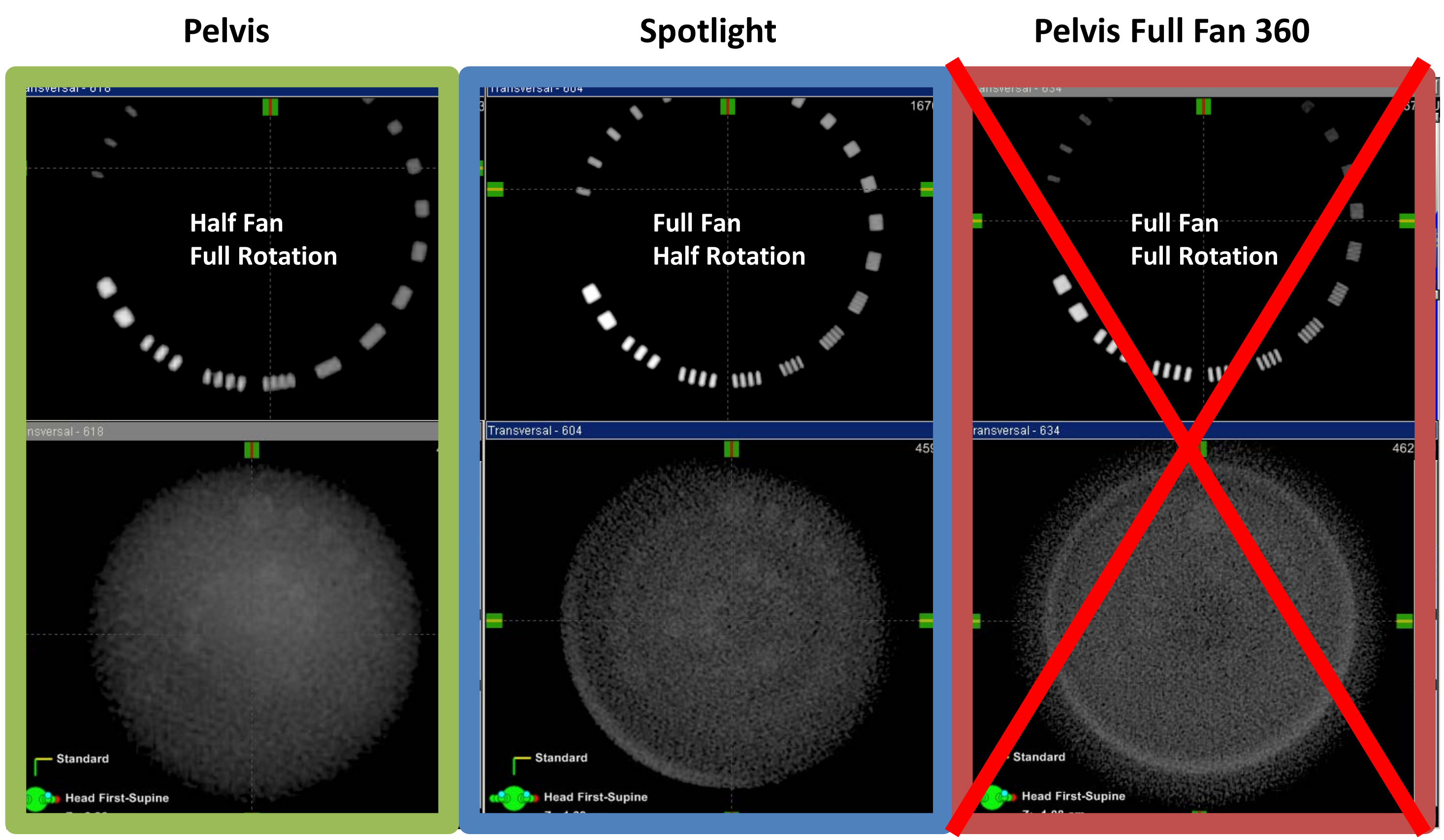
- Parameters that were changed:
    - Slice thickness
    - Matrix size
    - Focal spot size
    - Filter insertion

Changing Parameters



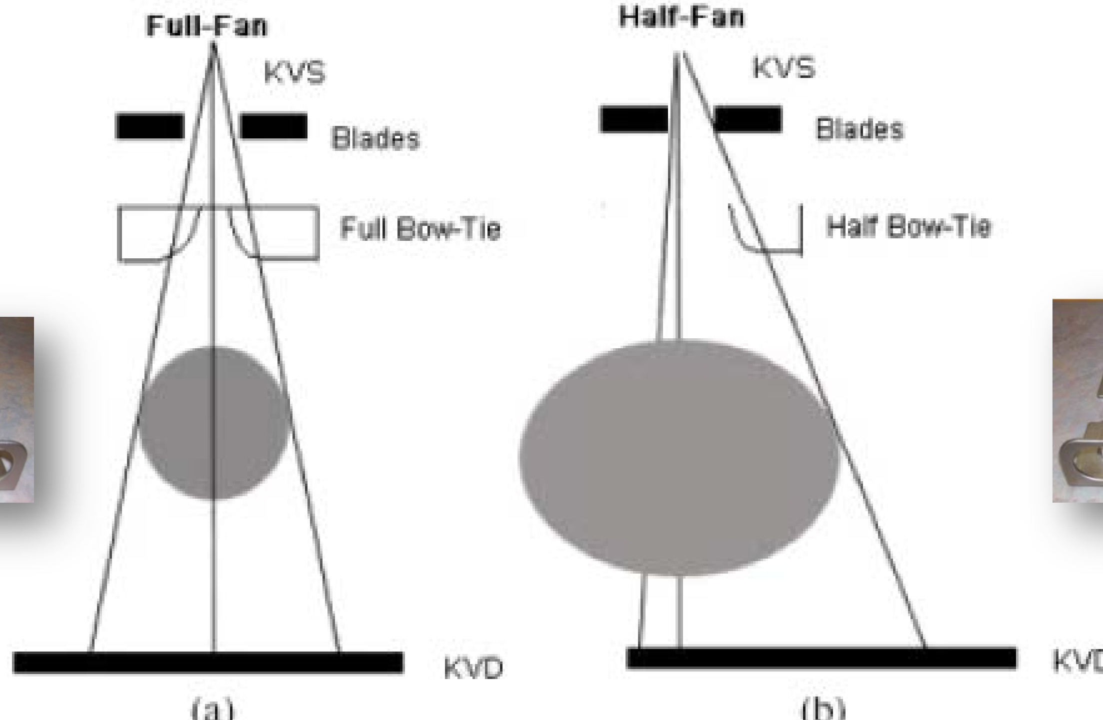
Pelvis vs. Pelvis Spotlight vs. Pelvis Full Fan





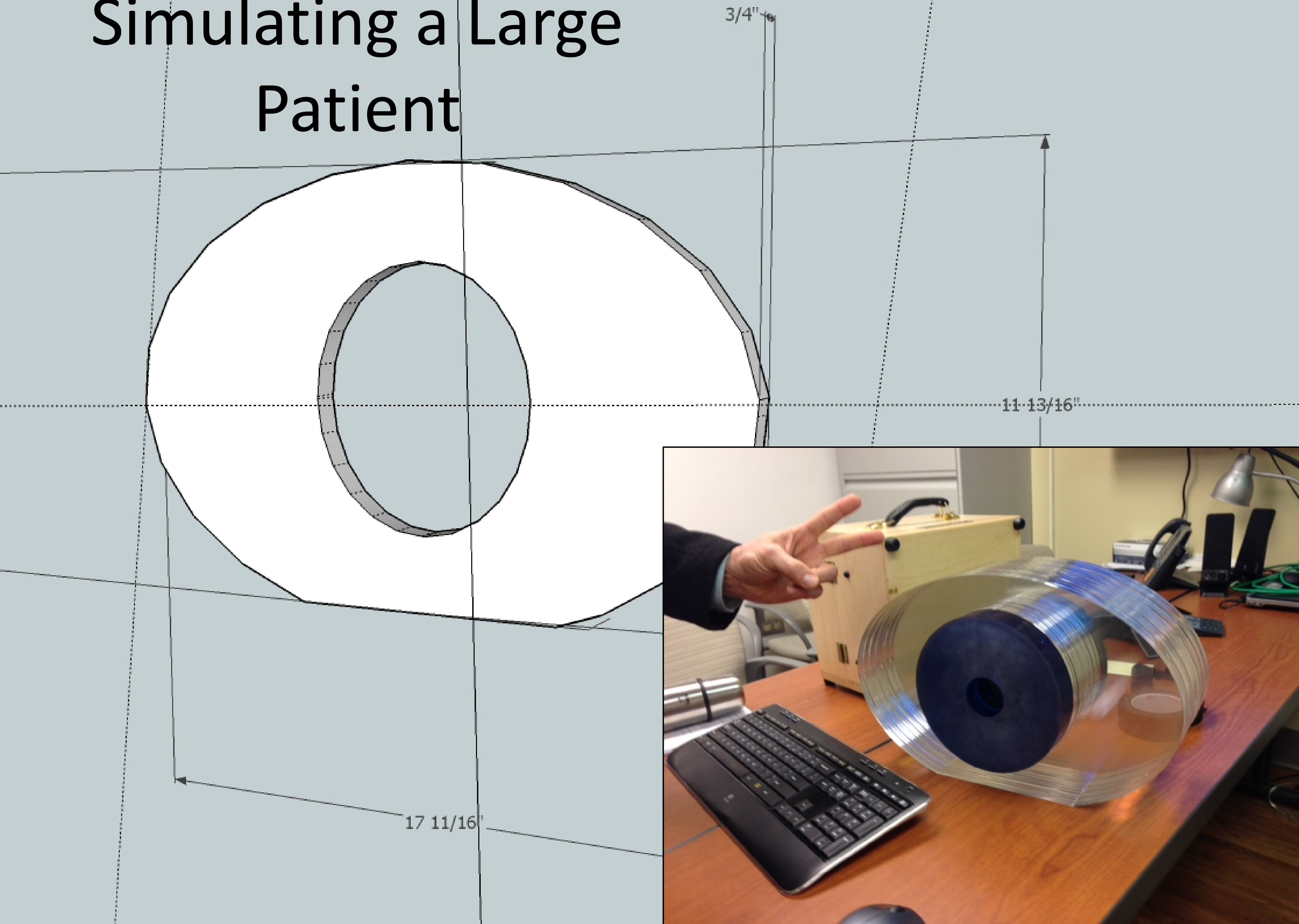
Full or Half Fan?

- Bowtie filters are used to modify the shape of the x-ray beam intensity within the scan field
  - Full Fan
    - Smaller FOV (<24 cm) : better spatial resolution, more noise
  - Half Fan
    - Larger FOV (>24 cm) : poorer spatial resolution, less noise



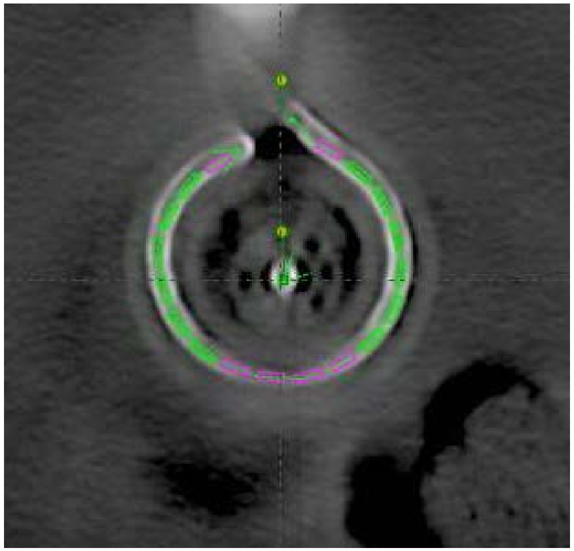
https://medicaldosimetry.org/pub/39774274-2354-d714-51f0-8be87ec1b43b

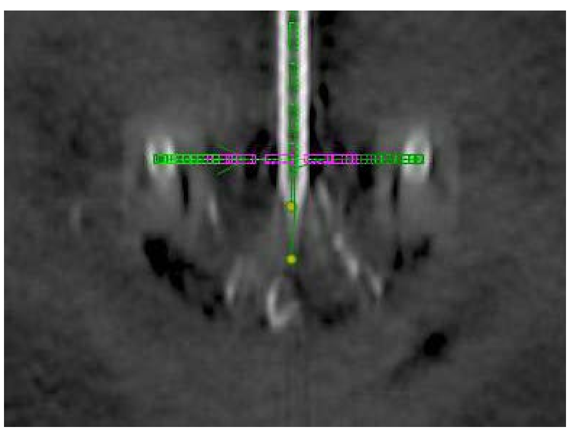
Simulating a Large Patient



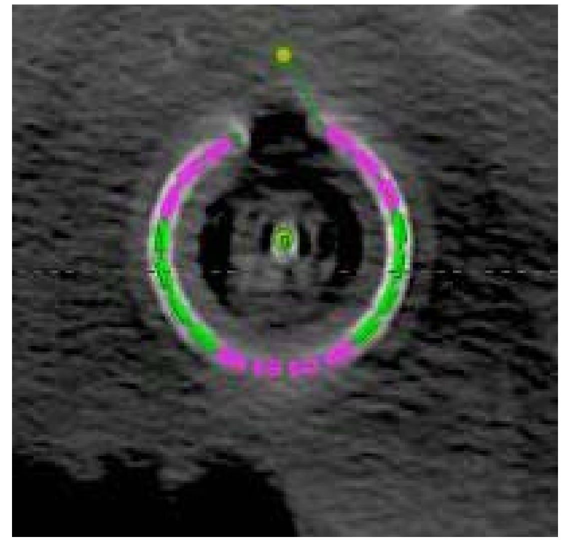
The Effect of Patient Size

BMI: 19.63 kg/m^2





BMI: 34.56 kg/m^2



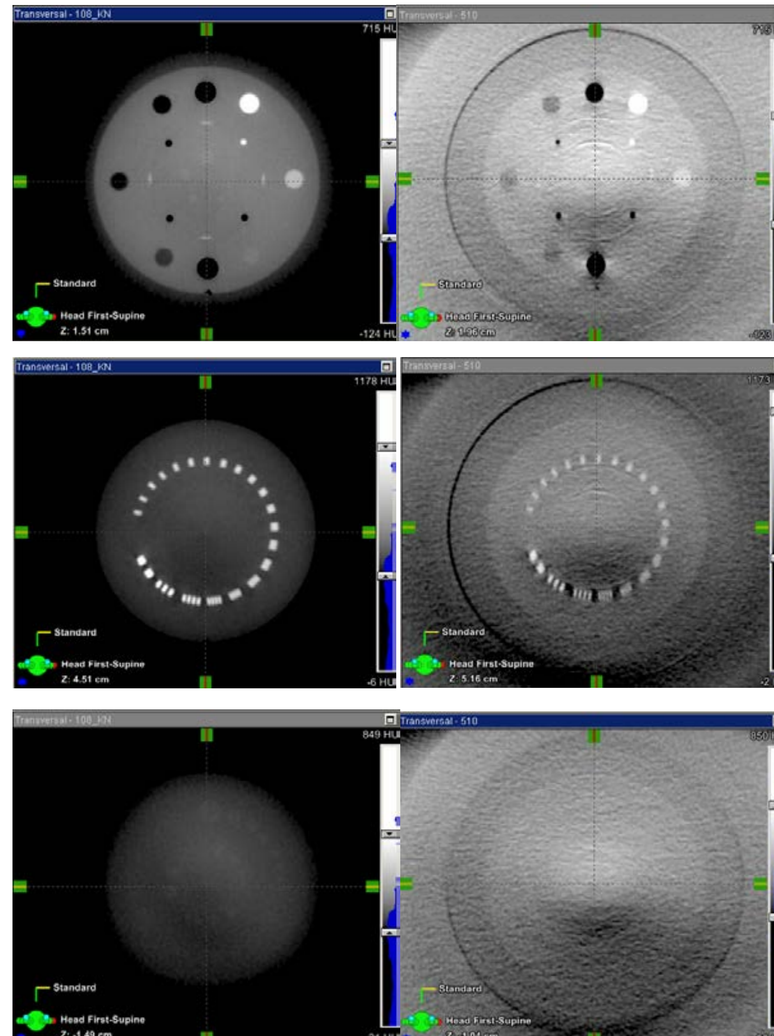
The Effect of Patient Size

- Larger patients attenuate more, resulting in detection of fewer photons
  - Increased noise
  - Reduced signal
  - Increased HU discrepancy

- HU discrepancy
  - One HU calibration curve used for patients of all sizes
  - Computer mistakes a thick absorber for high density material

<u>HU Discrepancy</u>

33.5 HU | 400 HU



mAs

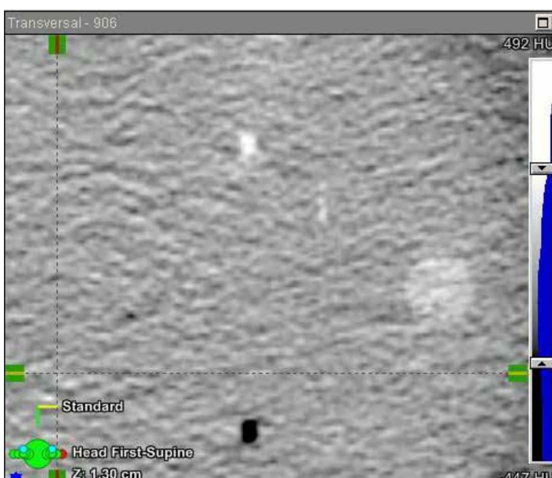
- Increasing mAs can noticeably improve image quality for large patients
  - At the cost of a proportional increase in dose…

Changing Exposure Time

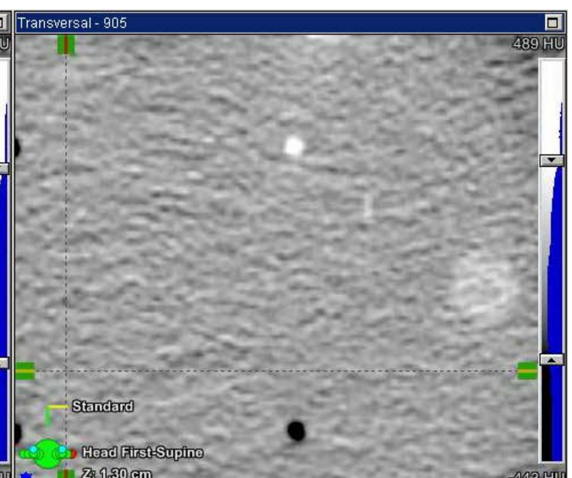
Pelvis
120 kV, 80 mA, **20 ms**

Pelvis
120 kV, 80 mA, **30 ms**

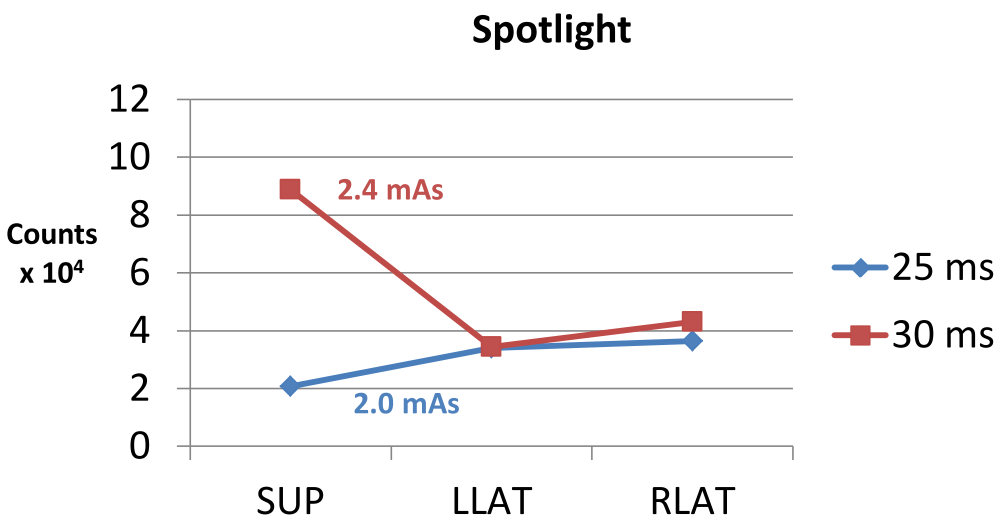
Spotlight
120 kV, 80 mA, **25 ms**



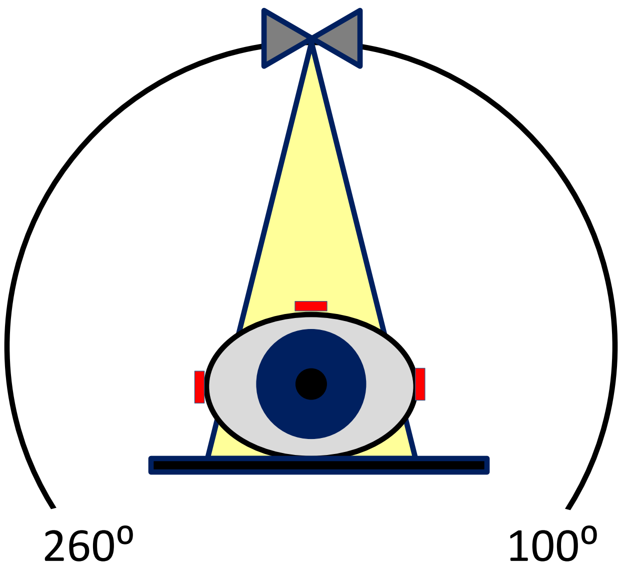
Spotlight
120 kV, 80 mA, **30 ms**



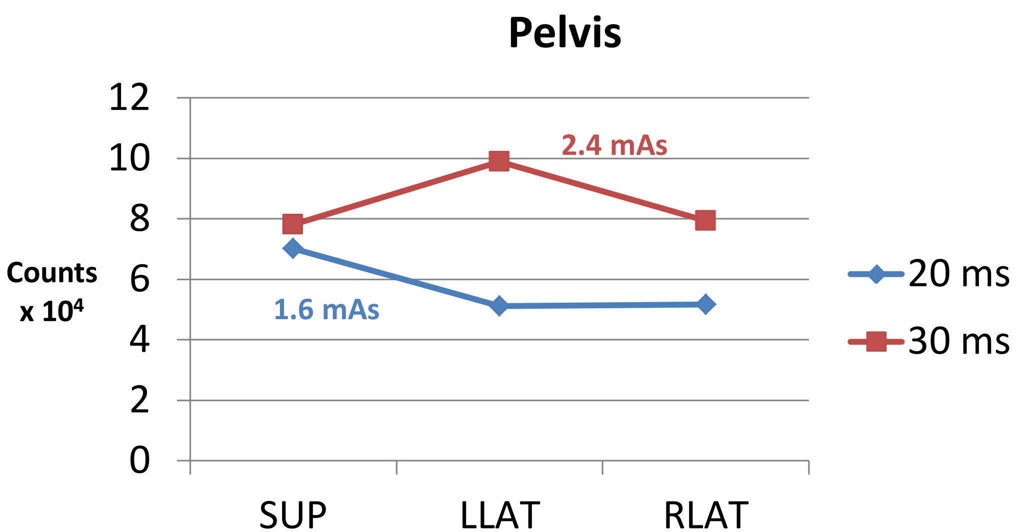
Dose



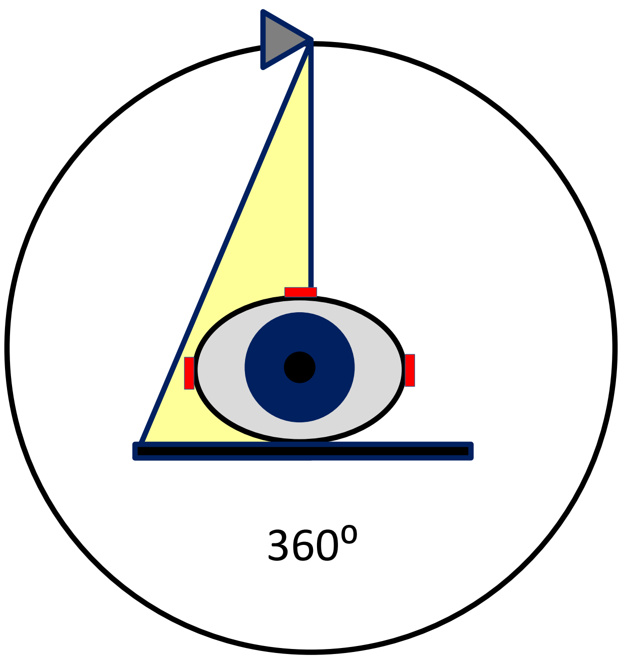
Spotlight
12
10
8
6
4
2
0
Counts x 10⁴
2.4 mAs
2.0 mAs
SUP
LLAT
RLAT
25 ms
30 ms



260⁰
100⁰



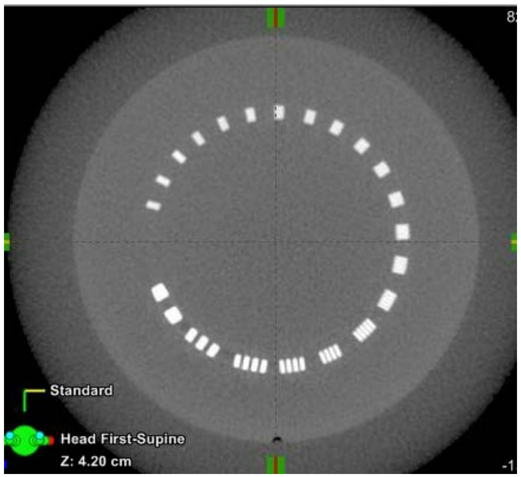
Pelvis
12
10
8
6
4
2
0
Counts x 10⁴
2.4 mAs
1.6 mAs
SUP
LLAT
RLAT
20 ms
30 ms

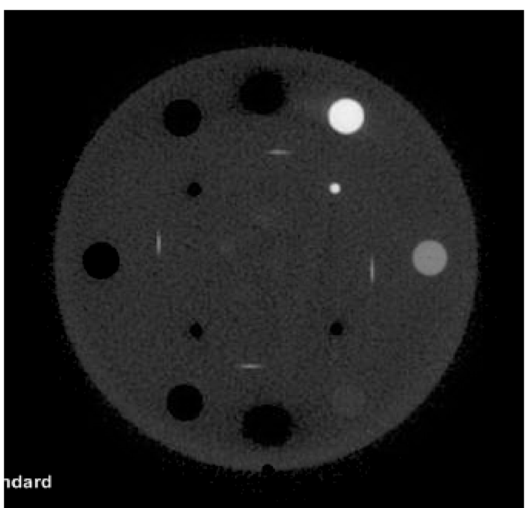


360⁰

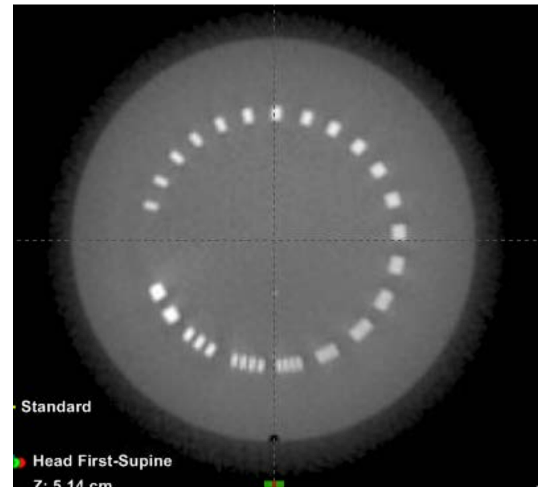
Before and After - Small

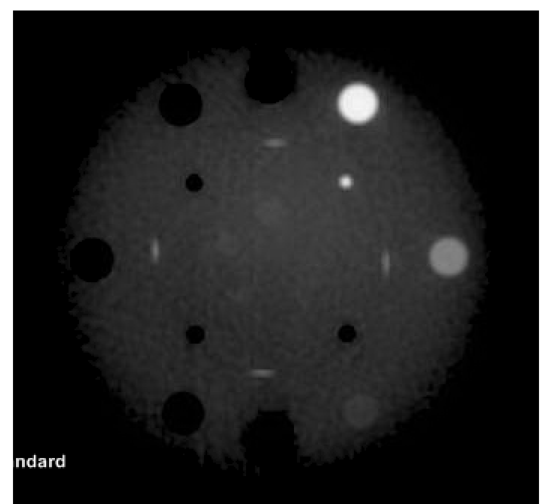
Pelvis Full Fan 360 (2.5 mm, 384)





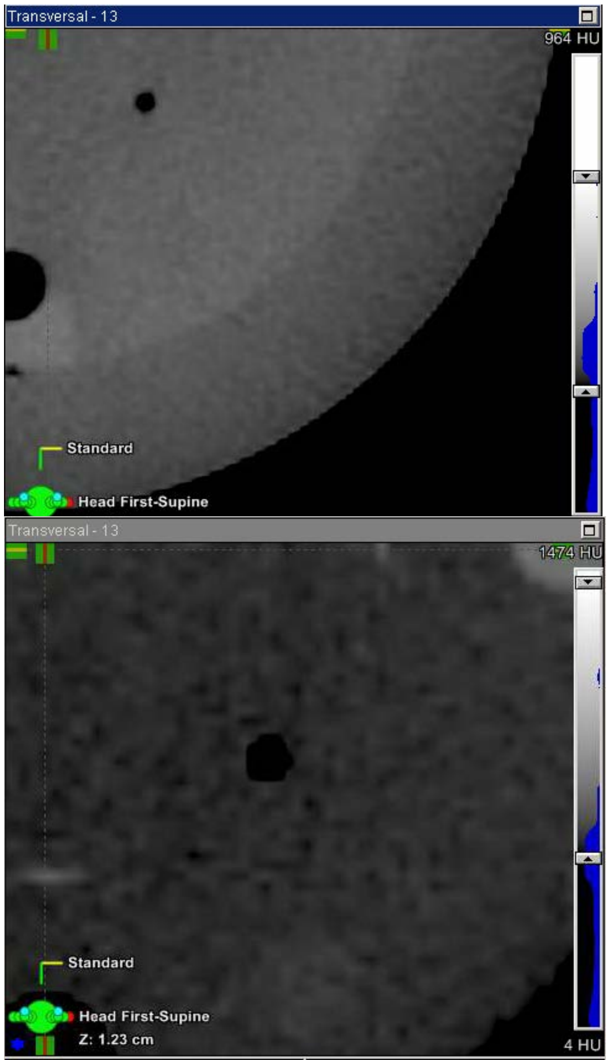
Pelvis (2.0 mm, 384)





Before & After - Small

Acuity Before (2.5 mm, 384)



Acuity After (2.0 mm, 384)

Recommendations

- Small/medium patient:
  - Pelvis @ 120 kVp, 80 mA, 20 ms @2.0 mm, 384 matrix

- Large patient:
  - Further investigation needed

- Calibrate 2 HU curves
  1. Small/medium patients
  2. Large patients

Future Work

- Investigate improving image quality for large patients by changing exposure parameters while maintaining reasonable dose levels

- To investigate the effect of applying offline image processing to raw data

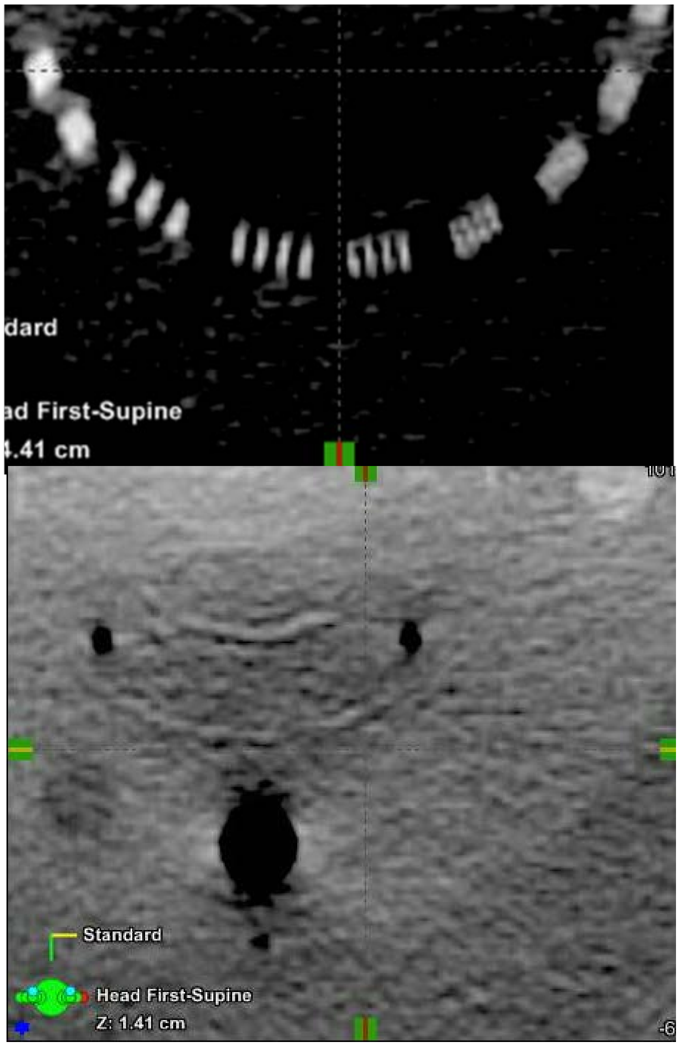
References

1. http://www.aapm.org/pubs/reports/rpt_74.PDF
2. http://www.jacmp.org/index.php/jacmp/article/view/3395/2196
3. http://www.qualitydigest.com/oct03/articles/01_article.shtml
4. http://www.aapm.org/meetings/amos2/pdf/34-8077-2750-150.pdf
5. Principles of Radiographic Imaging: An Art and A Science by Richard Carlton, Arlene Adler
6. Doselab manual
7. Bushberg
8. Catphan 600 Manual
9. The phantom portion of the American College of Radiology (ACR) Computed Tomography (CT) accreditation program: Practical tips, artifact examples, and pitfalls to avoid
10. http://www.jacmp.org/index.php/jacmp/article/view/3888/2806
11. http://www.jhu.edu/istar/pdf/Mail_MedPhys2008_Bowtie.pdf
12. http://www.dpix.com/technology/documents/9812_dpix_tech_paper.pdf
13. http://pratxlab.stanford.edu/PDF/CBCT_MapReduce.pdf
14. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3078158/
15. http://endoexperience.com/userfiles/file/unnamed/New_PDFs/cbCT/CBCT_how_does_it_work_Scarfe_et_al_2008.pdf
16. https://etd.ohiolink.edu/rws_etd/document/get/mco1372413982/inline
17. Artefacts in cone beam CT: Open Journal of Stomatology
18. Truebeam techinical reference guide

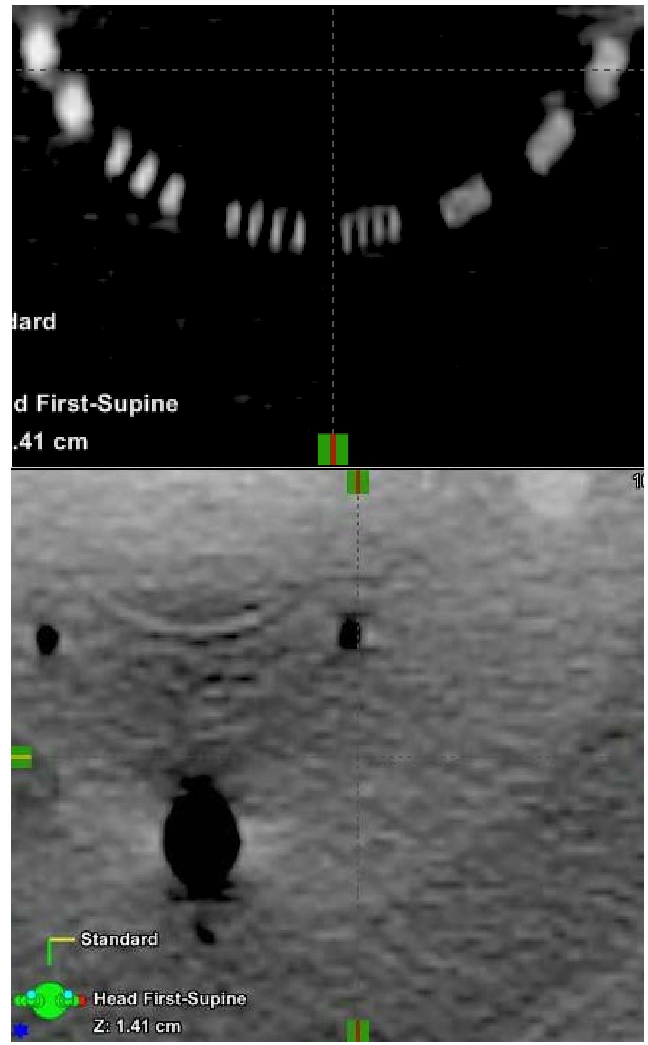
Questions?

Half Fan for Large Patients

Pelvis (2.0 mm, 512)



Pelvis (2.0 mm, 384)



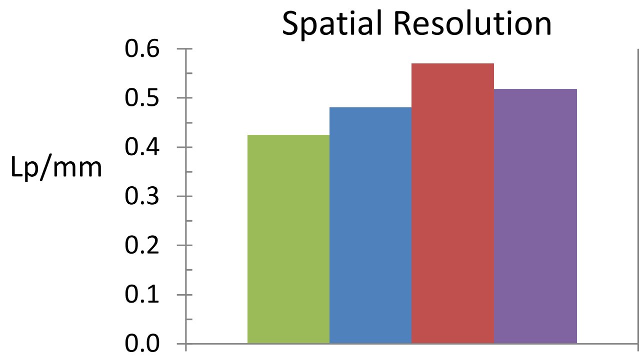
Acuity vs. STX

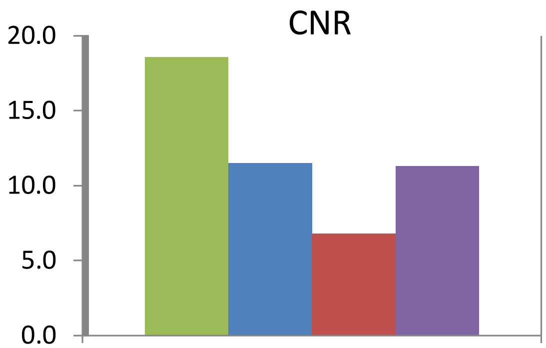
		Head		Pelvis		Pelvis Spotlight		Thorax		Pelvis Full Fan 360	
		Default Acuity	Default STX	Default Acuity	Default STX	Default Acuity	Default STX	Default Acuity	Default STX	Default Acuity	Default STX
Gantry Mode	Fan Type	Full	Full	half	half	full	Full	half	half	full	
	Fan Material	Plastic	Aluminum	Plastic	Aluminum	Plastic	Aluminum	Plastic	Aluminum	Plastic	
	SID	150	150	150	150	150	150	150	150	150	
	# projections	650	366	650	660	650	366	650	660	660	
	Gantry speed (deg/s)	8	6	8	6	8	6	8	6	8	
	Gantry rotation	half	half	full	full	half	half	full	full	full	
Image Processing	Scattering Correction	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	
	Beam Hardening Correction	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-In	Beam hardening calibration	
	Reconstruction Filter	Sharp	auto	sharp	auto	Sharp	auto	sharp	auto	sharp	
	Post-processing	None	HU rescaling	none	HU rescaling	None	HU rescaling	none	HU rescaling	none	
	Ring Artifact Suppression	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	
Exposure Settings	kV	100	100	125	125	125	125	110	125		
	mA	20	20	80	80	80	80	20	20		
	ms	20	20	13	20	25	25	20	20		
Other	Filter	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	
	Filter Material	Cu	Ti	Cu	Ti	Cu	Ti	Cu	Ti	Cu	
	Focal Spot Size	large	large	large	large	large	large	large	large	large	
	Matrix Size	384	512	384	512	384	512	384	512		
	Slice Thickness (mm)	2.5	2	2.5	2	2.5	2	2.5	2	2.5	

Re-calibrated Acuity vs. STX

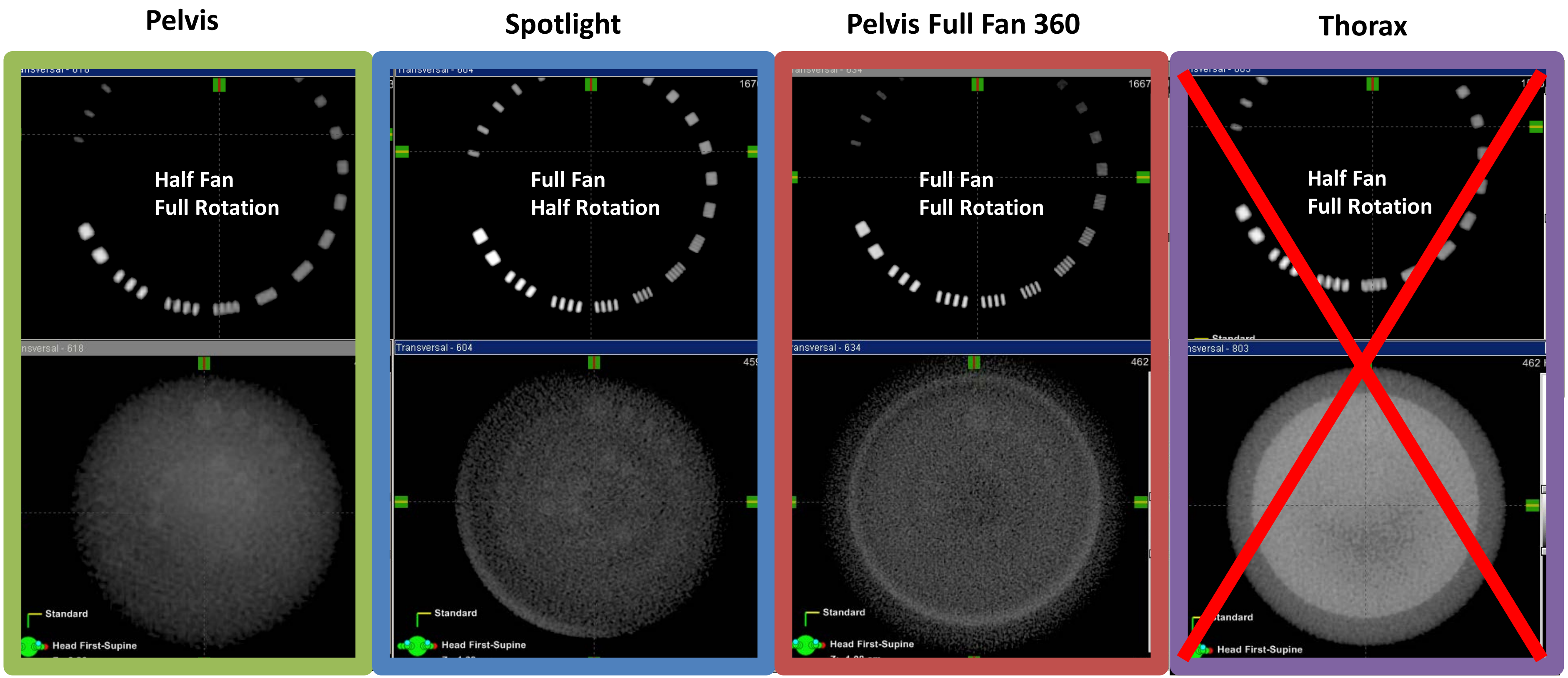
		Head		Pelvis		Pelvis Spotlight		Thorax		Pelvis Full Fan 360	
		Re-cal Acuity	Default STX	Re-cal Acuity	Default STX	Re-cal Acuity	Default STX	Re-cal Acuity	Default STX	Re-cal Acuity	Default STX
Gantry Mode	Fan Type	Full	Full	half	half	full	Full	half	half	full	
	Fan Material	Plastic	Aluminum	Plastic	Aluminum	Plastic	Aluminum	Plastic	Aluminum	Plastic	
	SID	150	150	150	150	150	150	150	150	150	
	# projections	360	366	650	660	360	366	650	660	660	
	Gantry speed (deg/s)	6	6	6	6	6	6	6	6	6	
	Gantry rotation	half	half	full	full	half	half	full	full	full	
Image Processing	Scattering Correction	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	SC plug-in	Norm scan	
	Beam Hardening Correction	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-in	Beam hardening calibration	ASC plug-In	Beam hardening calibration	
	Reconstruction Filter	auto	auto	auto	auto	auto	auto	auto	auto	auto	
	Post-processing	None	HU rescaling	none	HU rescaling	None	HU rescaling	none	HU rescaling	none	
	Ring Artifact Suppression	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	
Exposure Settings	kV	100	100	125	125	125	125	110	125		
	mA	20	20	80	80	80	80	20	20		
	ms	20	20	20	20	25	25	20	20		
Other	Filter	IN	IN	IN	IN	IN	IN	IN	IN	IN	
	Filter Material	Cu	Ti	Cu	Ti	Cu	Ti	Cu	Ti	Cu	
	Focal Spot Size	large	large	large	large	large	large	large	large	large	
	Matrix Size	512	512	512	512	512	512	512	512	512	
	Slice Thickness (mm)	2	2	2	2	2	2	2	2	2	

Pelvis vs. Pelvis Spotlight vs. Pelvis Full Fan



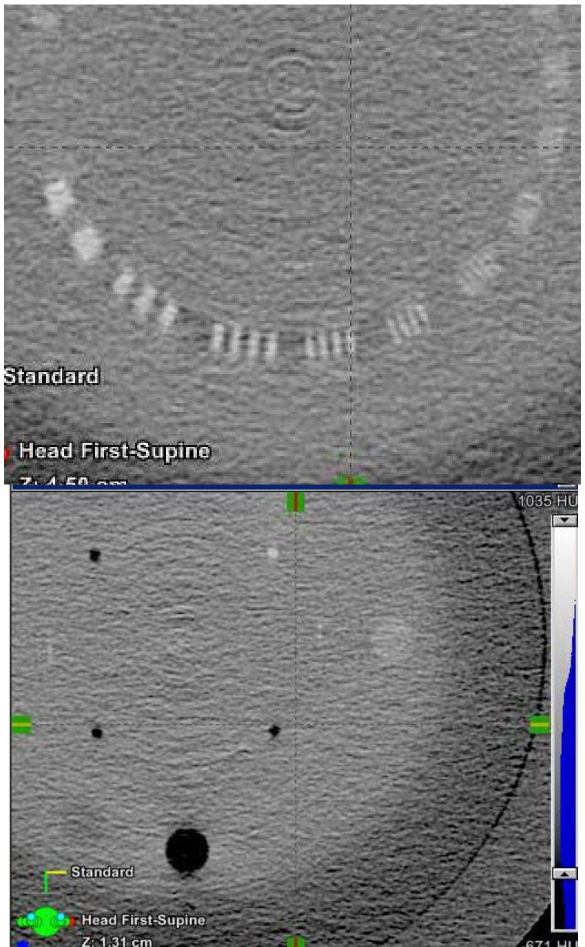


Higher spatial resolution comes at the cost of increased noise

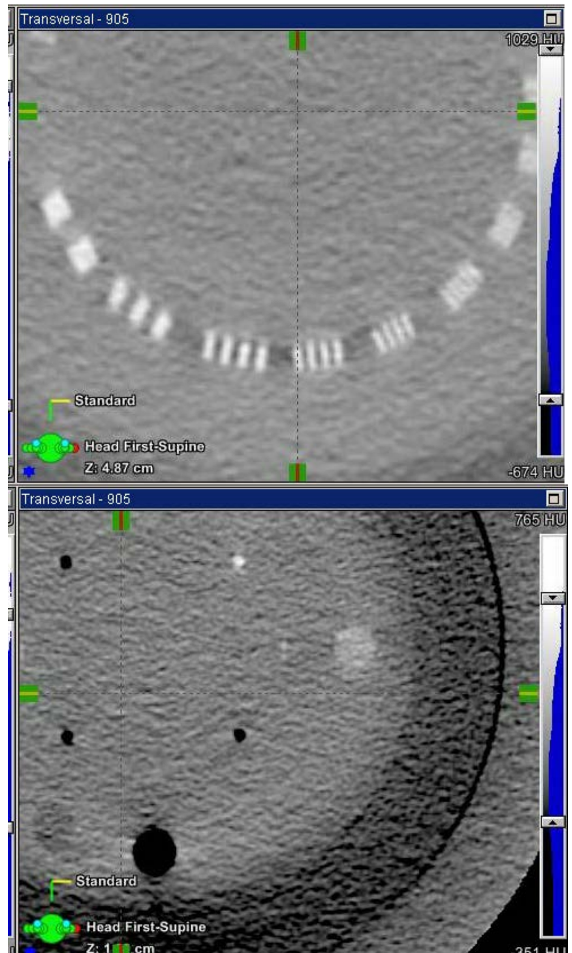


Pelvis vs. Spotlight

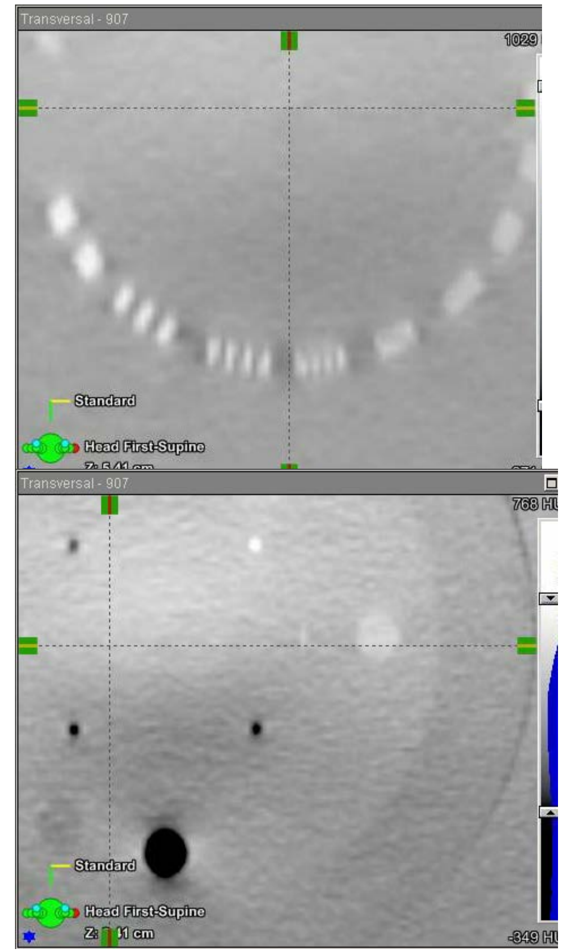
Pelvis Full Fan 360
120 kV, 80 mA, **20 ms**



Spotlight
120 kV, 80 mA, **25 ms**



Pelvis
120 kV, 80 mA, **20 ms**



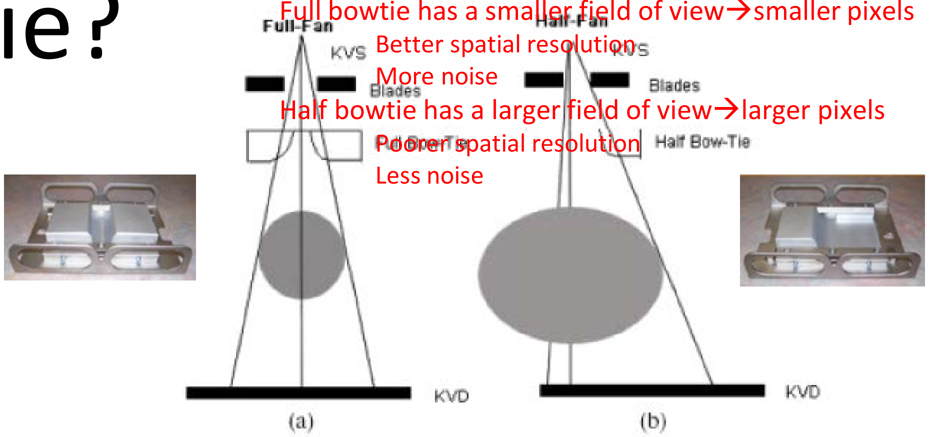
Reconstruction

- CBCT: A 3D volume is constructed from 2D data (15)
  - Convolution-back projection (FDK algorithm)\
  - Entire data set acquired in 1 rotation
- Fan beam CT: each axial slice (1D?)are sequentially (in series) reconstructed (15)
  - Filtered back projection
  - Slices stacked to obtain a 3D representation where each slice requires a separate scan (rotation) and separate 2D reconstruction
- 2D images obtained from each projection
  - 1. sinograms are constructed across each row of the projection image
  - 2. Sinograms are corrected and a reconstruction filter is applied that converts the sinogram into a 2D CT slice
  - 3. These 2D images are combined into a single 3D volume by backprojection

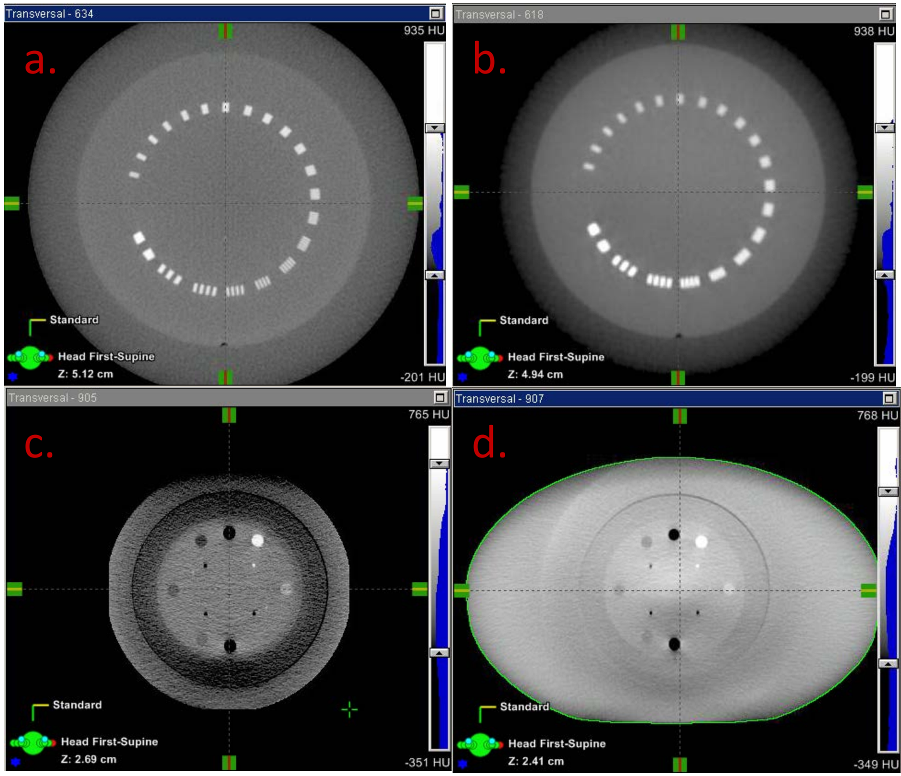
- FDK algorithm applies Shepp-Logan filter to each projection (individually therefore it can/should be parallelized)to help reduce noise
- 1D convolution converts the detector pixel value into a filtered value which is then backprojected to reconstruct the 3D volume

Full or Half Bowtie?

- Bowtie filters are used to modify the shape of the x-ray beam intensity within the scan field
  - They are useful for making the photon fluence more uniform across the field-of-view, which helps to reduce detector saturation
  - Lowers skin dose
  - Increases photon density at the center of the cone and decreases at the periphery
  - Pitfall: decrease in ratio of SNR to the entrance exposure (17)
- Full Fan
  - Entire object can be seen in every projection
  - Higher beam intensity in the center, smaller field of view, good for smaller body parts (i.e. head)
  - Narrower beam→reduces surface/periphery dose, where high image quality is not as crucial
  - Softer beam quality→improves soft tissue contrast
  - Patient diameter < 24 cm: SMALLER FOV
- Half Fan
  - Notice how we have a loss of information at the edge of the phantom (loss of skin line)
  - This is due to saturation of the detector
  - Detector is shifted by 15 cm to increase the field of view
  - If the FOV required in the transverse plane is larger than 25 cm, the half-fan should be used where the imager is offset laterally by 14.6 cm. (16)
  - Patient diameter > 24 cm



https://medicaldosimetry.org/pub/39774274-2354-d714-51f0-8be87ec1b43b



STX Data Processing

- Preprocessing the projections
  - Aimed at accounting for the nonideal nature of the measured projections
    - Scatter correction (SC plugin) reduces scatter induced artifacts, slice uniformity, accuracy of CT numbers. Improves HU accuracy and uniformity
    - Normalization log conversion helps to flatten the beam, helps avoid ring artifacts
    - Analytical spectrum correction (ASC plug-in) improves accuracy of CT numbers, improves slice uniformity
  - I=Ioe-(mu)x is an ideal equation meant only for monoenergetic beams
- Reconstruction (filtered backprojection)
  - Estimates mu(x) from multiple projection measurements of I taken at different angles
  - Uses the FDK (Feldkamp-Davis-Kress) algorithm
- Post-processing of the reconstructed CBCT dataset
  - Aimed at accounting for the nonideal nature of the measured projections
  - 2 corrections
    - HU rescaling
    - Ring artifact correction