Digital Radiographic Tomosynthesis QA/QC, Dosimetry, and More

John M. Sabol

April 19th, 2021

1

Disclosures

John Sabol is:
- Former employee of Sterling Diagnostic Imaging, now owned by Agfa Healthcare.
- Former employee of GE Healthcare.
- Currently employed by Konica Minolta Healthcare.

Input for this presentation has been kindly received from employees of Agfa, Carestream Health, GE Healthcare, and Shimadzu Medical Systems

The views expressed on this presentation are my own and do not necessarily reflect those of any commercial entity.

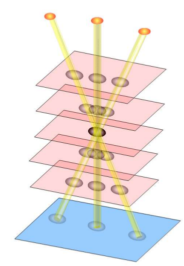
2

- Tomosynthesis Imaging
- Parameters and Artifacts
- Clinical Applications
- Dosimetry
- Features of Available Systems
- QA/QC

3

Classical Tomography

Synchronously move the x-ray source and detector so that one plane of the object remains in focus

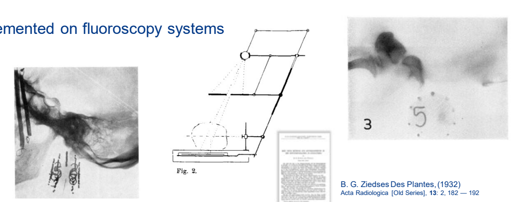


4

Classical Tomography

Technique invented by Ziedses des Plant in 1932 for Temporal Mandibular Joint Imaging

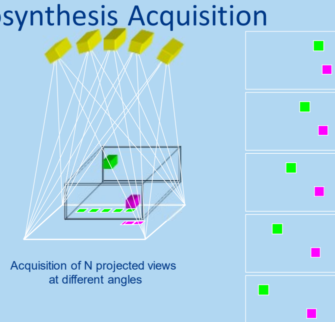
Implemented on fluoroscopy systems



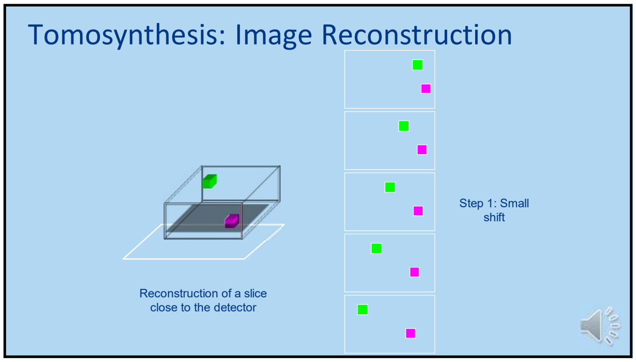
B. G. Ziedses Des Plantes, (1932) Acta Radiologica [Old Series], 13: 2, 182 — 192

5

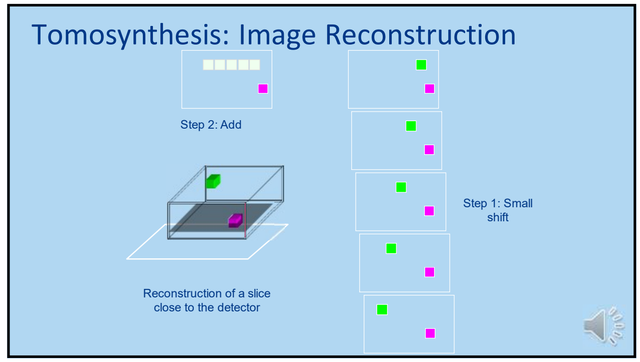
Tomosynthesis Acquisition



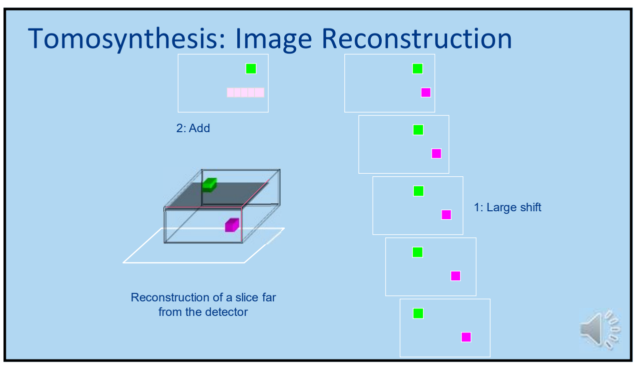
6


Tomosynthesis: Image Reconstruction
Step 1: Small shift
Reconstruction of a slice close to the detector

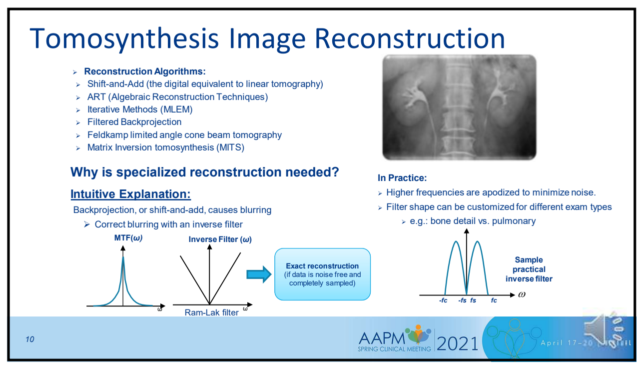
7


Tomosynthesis: Image Reconstruction
Step 2: Add
Step 1: Small shift
Reconstruction of a slice close to the detector

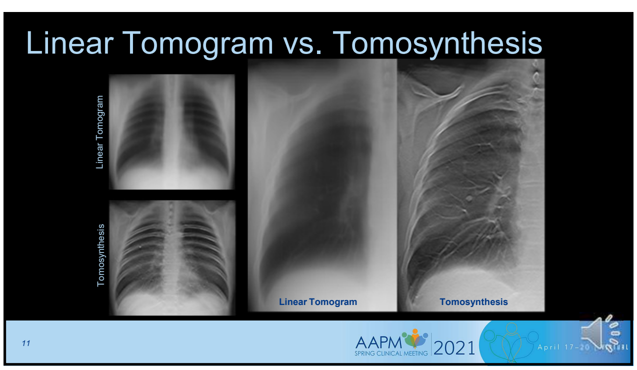
8


Tomosynthesis: Image Reconstruction
2: Add
1: Large shift
Reconstruction of a slice far from the detector

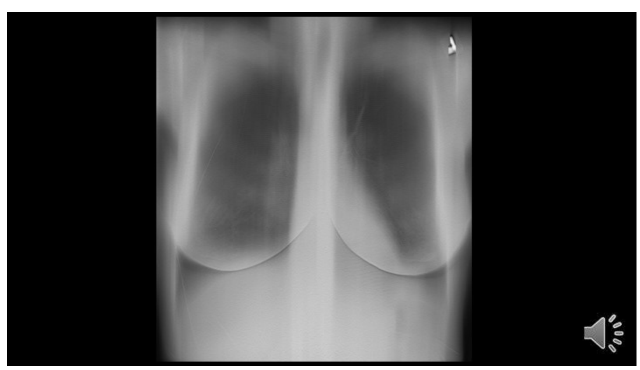
9


Tomosynthesis Image Reconstruction
Reconstruction Algorithms:
Shift-and-Add (the digital equivalent to linear tomography)
ART (Algebraic Reconstruction Techniques)
Iterative Methods (MLEM)
Filtered Backprojection
Feldkamp limited angle cone beam tomography
Matrix Inversion tomosynthesis (MITS)
Why is specialized reconstruction needed?
Intuitive Explanation:
Backprojection, or shift-and-add, causes blurring
Correct blurring with an inverse filter
MTF(ω)
Inverse Filter (ω)
Ram-Lak filter
Exact reconstruction (if data is noise free and completely sampled)
In Practice:
Higher frequencies are apodized to minimize noise.
Filter shape can be customized for different exam types
e.g.: bone detail vs. pulmonary
Sample practical inverse filter
-fc -fs fs fc
10
AAPM SPRING CLINICAL MEETING 2021

10

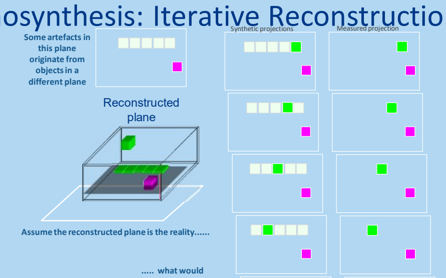

Linear Tomogram vs. Tomosynthesis
Linear Tomogram
Tomosynthesis
Linear Tomogram
Tomosynthesis
11
AAPM SPRING CLINICAL MEETING 2021

11



12

Tomosynthesis: Iterative Reconstruction



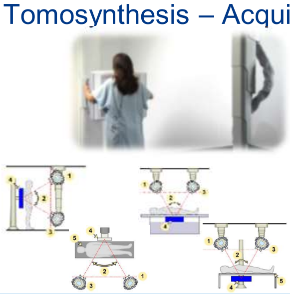
The differences between the measured projections and the synthetic projections are used in the next iteration to reduce image imperfections

13

- Tomosynthesis Imaging
- Parameters and Artifacts
- Clinical Applications
- Dosimetry
- Features of Available Systems
- QA/QC

14

Tomosynthesis – Acquisition Parameters



- Sweep Angle
- Number of Projections
- Sweep Direction
- Sweep Speed
- Pixel Binning
- Dose

15

Tomosynthesis – Reconstruction Parameters

- Start & stop heights – anatomy covered
- Slice pitch and thickness
- Slice averaging, slab thickness
- Pixel Binning
- Reconstruction method (e.g.: FBP, Iterative, …)

16

Potential Artifacts & Adjustable Parameters

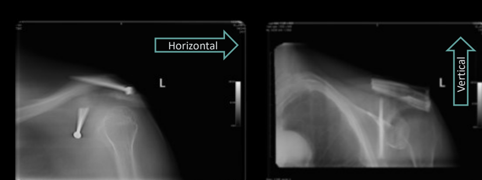
Image artifacts	Imaging parameters
Blurring artifact	**Slice interval**
Ripple artifact	**Sweep direction** **Projection density** $\left(=\frac{Number\ of\ Projections}{Sweep\ Angle}\right)$
Ghost artifact	**Sweep direction**
Metallic artifact	**Sweep direction**
Motion artifact	**Number of Projections, Sweep speed**
Limited depth resolution	**Sweep angle**

Machida, Haruhiko, Toshiyuki Yuhara, Takako Mori, Eiko Ueno, Yoshio Moribe, and John M. Sabol. "Optimizing parameters for flat-panel detector digital tomosynthesis." **Radiographics 30**(2) (2010): 549-562.

17

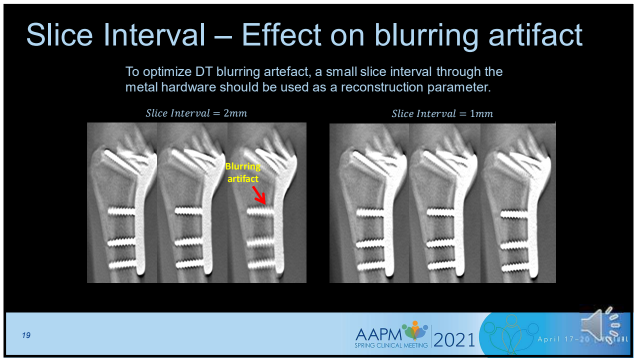
Blurring

Blurring occurs along the sweep direction and results from imaging a high contrast structure that exists out of the slice plane continuously perpendicular to the sweep direction.

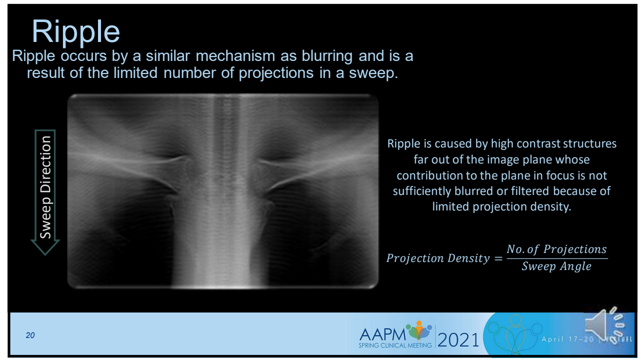


Note the two surgical nails.
Blurring appears different depending on the sweep direction

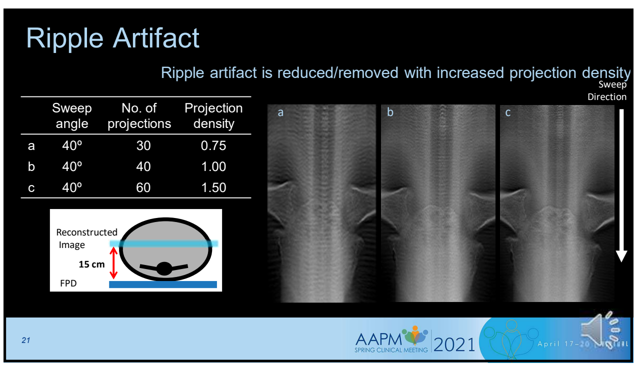
18



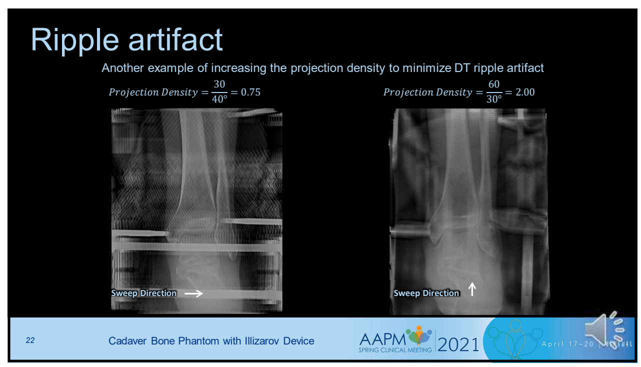
19



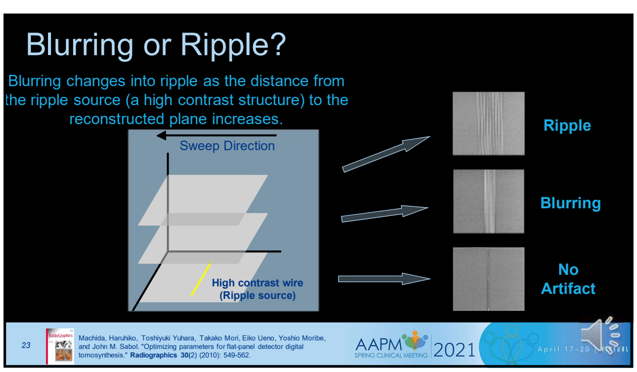
20



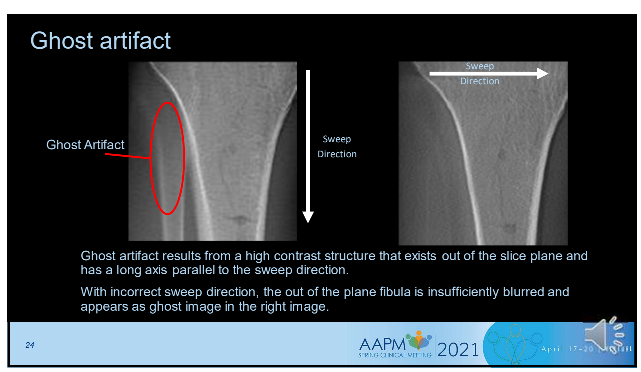
21



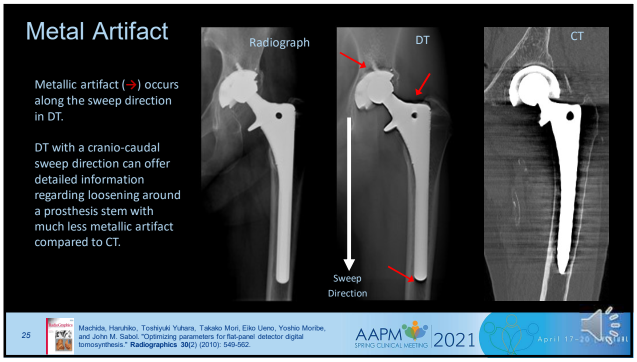
22



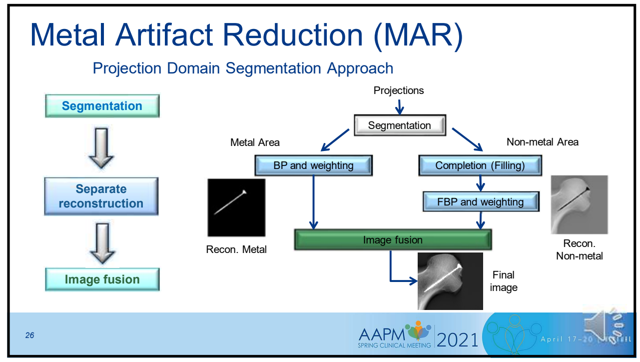
23



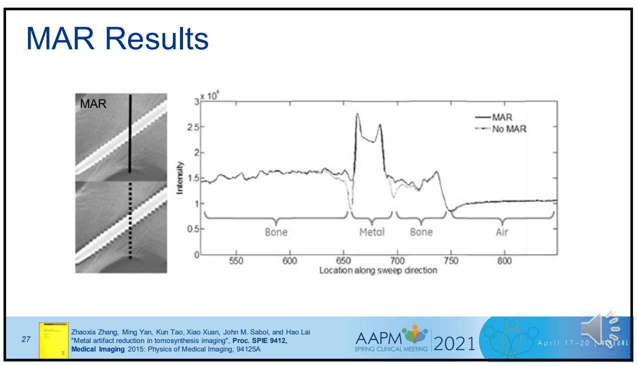
24



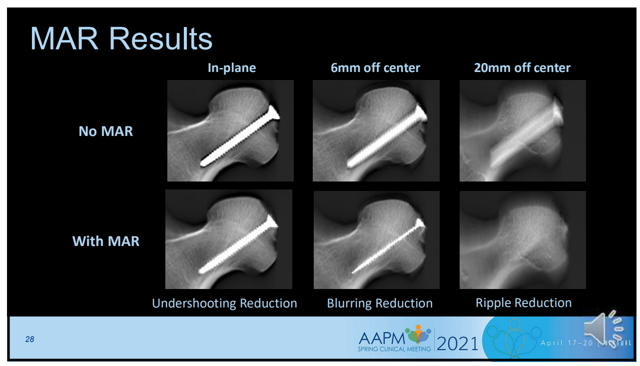
25



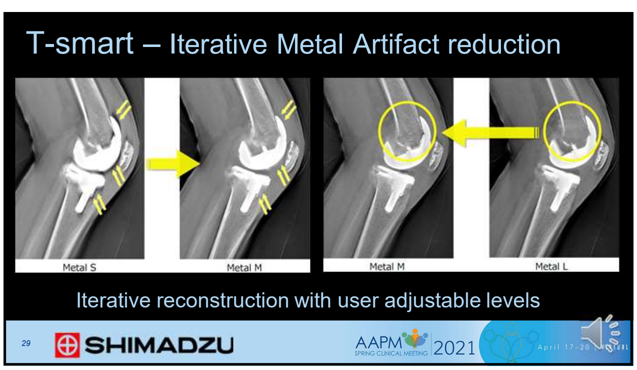
26



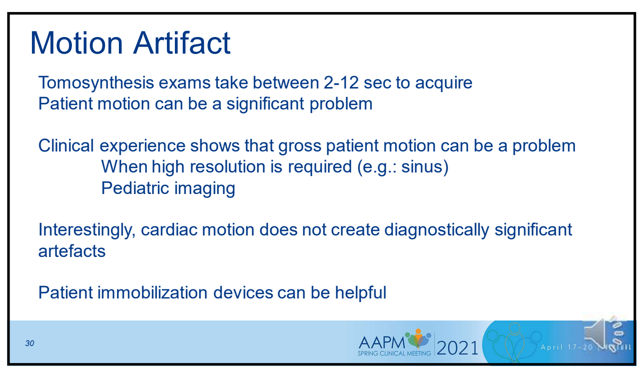
27



28



29



30

High Speed Acquisitions

If patient immobilization is not feasible, high speed acquisition may help

Carestream and Shimadzu offer high speed acquisitions using fewer projection images

e.g.: Shimadzu Multi-purpose G4 system:
- Default exam: 17” FOV, 76 projections, 2 x 2 binning, (5.0 sec)
- Fast Exam: 17” FOV, 38 projections, 2 x 2 binning, (2.5 sec) half dose of default

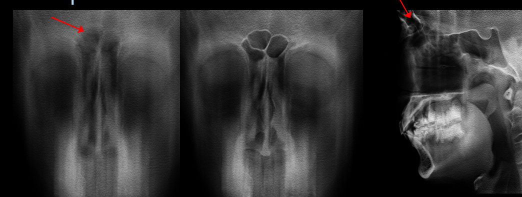
Can be combined with other parameters:
e.g.: Shimadzu Multi-purpose G4 system:
- Chest: 40°, ‘fast’
- Broncho: 20°, ‘slow’

Carestream
SHIMADZU

31 AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

31

Limited Depth Resolution



Abnormal opacity (→) seems to exist in the frontal sinus due to partial volume effect of the adjacent bony structure on coronal DT (Left), although this sinus is actually clear (→) on sagittal DT (Right).

32 AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

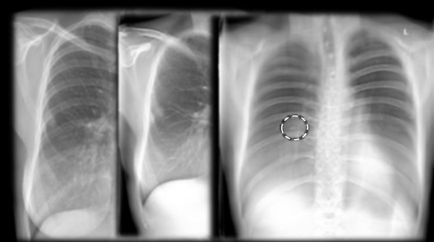
32

- Tomosynthesis Imaging
- Parameters and Artifacts
- **Clinical Applications**
- Dosimetry
- Features of Available Systems
- QA/QC

33 AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

33

Case 52: Multi-Center Clinical Trial



True Positive Nodule Finding

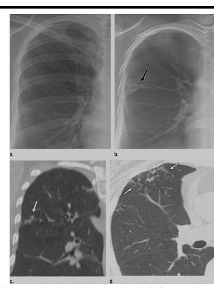
Dobbins III JT, McAdams HP, Sabol JM, Chakraborty DP, ... & Båth M. (2017). *Multi-institutional evaluation of digital tomosynthesis, dual-energy radiography, and conventional chest radiography for the detection and management of pulmonary nodules.* **Radiology, 282**(1), 236-250.

34 AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

34

TB Detection

- ~3 million deaths per year…
  - more than any other infectious agent
  - leading cause of death among people with HIV/AIDS.
  - Significant global health challenge
- Sputum test is current gold standard for diagnosis, but takes weeks
- Chest x-rays are routinely used for detection, but lack sensitivity, specificity
- Kim, Chung, *et al* Radiology 2010 demonstrated:
  - Significantly improved accuracy of Tomosynthesis compared to CXR
  - Greatly improved sensitivity for cavity detection (**76% vs. 19%**)

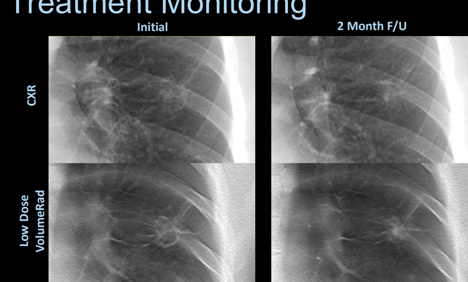


Pulmonary Mycobacterial Disease: Diagnostic Performance of Low-Dose Digital Tomosynthesis as Compared with Chest Radiography
E.Y. Kim, M.J. Chung, et al. **Radiology** 2010; **257**:269–277

35 AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

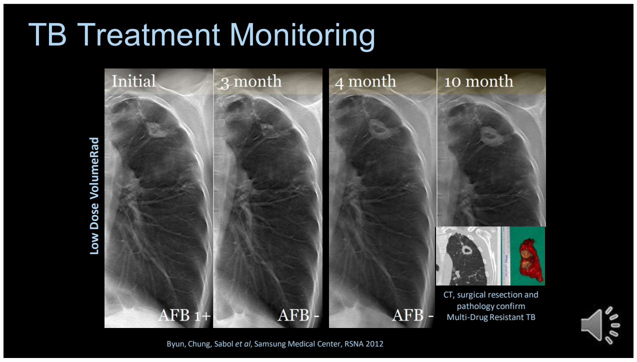
35

TB Treatment Monitoring

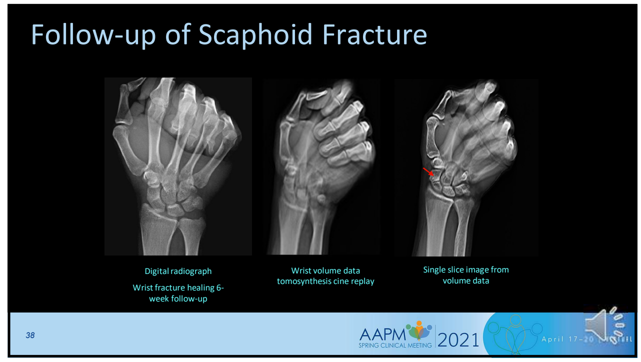


Byun, Chung, Sabol *et al*, Samsung Medical Center, RSNA 2012

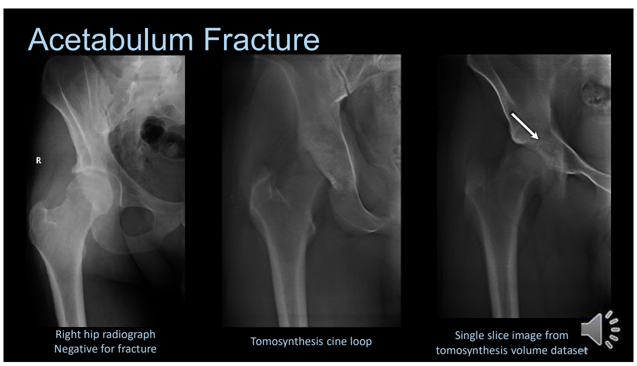
36



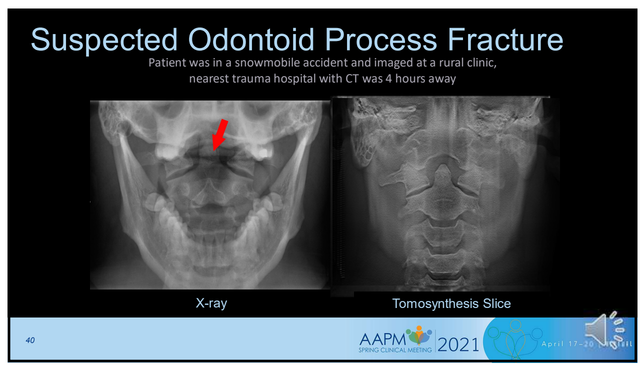
37



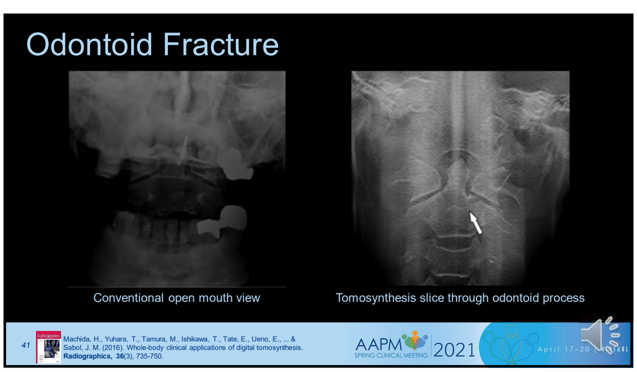
38



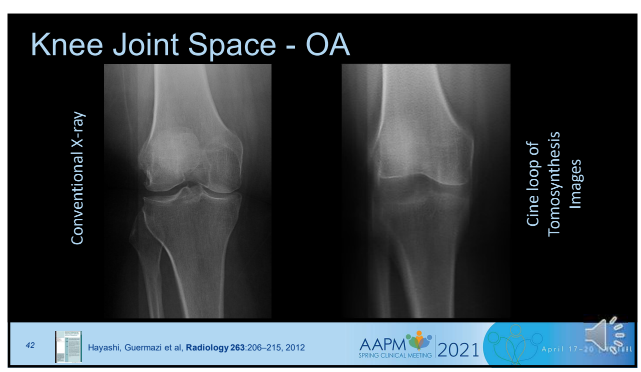
39



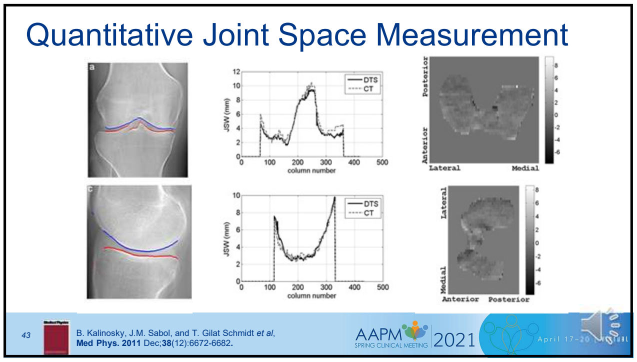
40



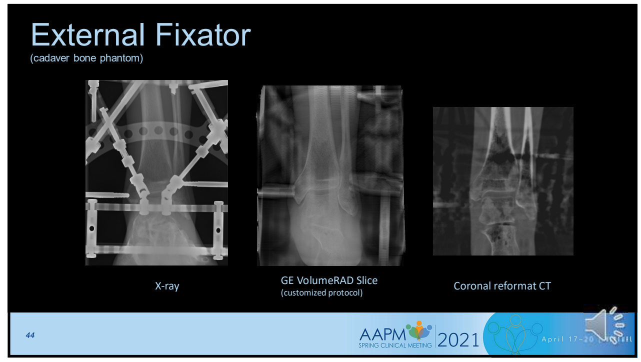
41



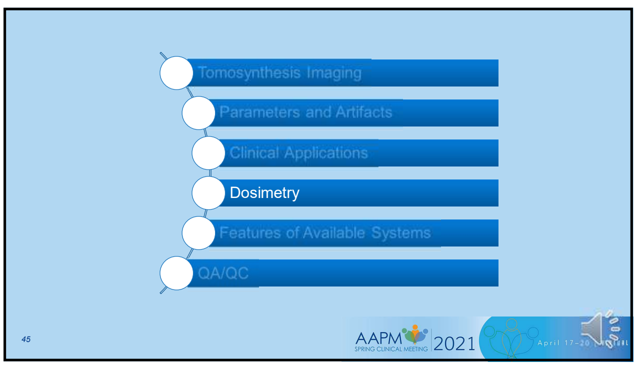
42



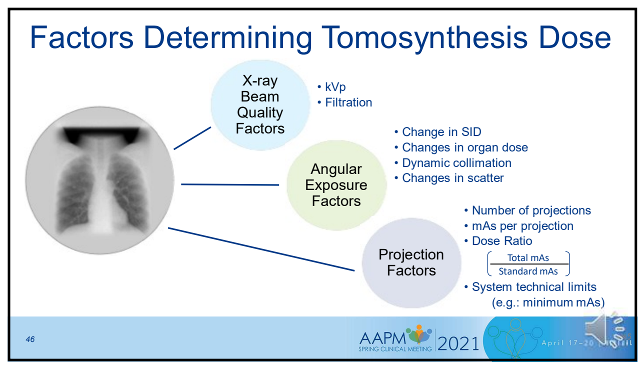
43



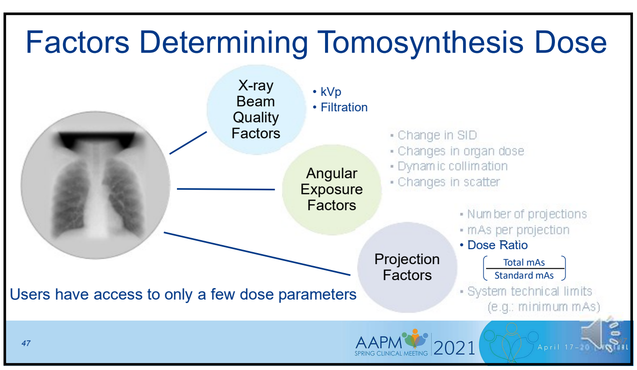
44



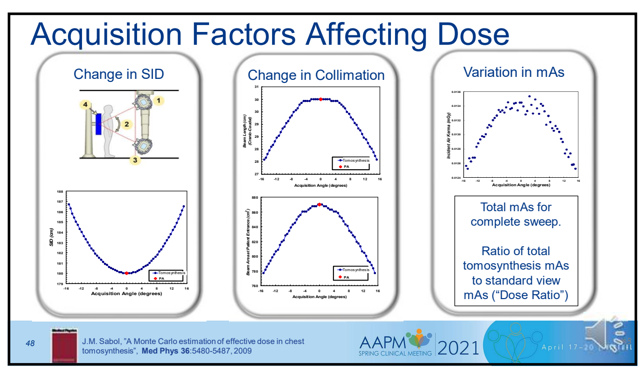
45



46

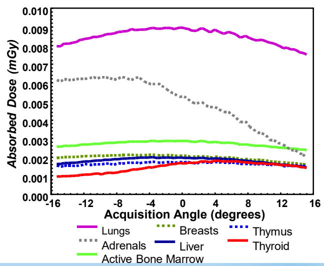


47



48

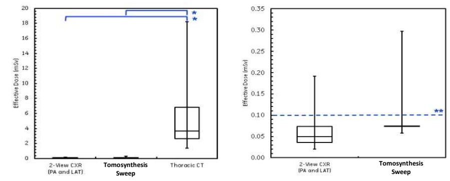
Absorbed Dose for Selected Organs



J.M. Sabol, "A Monte Carlo estimation of effective dose in chest tomosynthesis", **Med Phys 36**:5480-5487, 2009

49

Effective Dose Comparison



Tomosynthesis requires significantly* less dose than CT, same Relative Radiation Level** as 2-view CXR

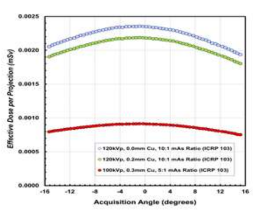
**ACR Appropriateness Criteria® Radiation Dose Assessment Introduction, 2012

Dobbins *et al*, **Radiology July 2016**
http://dx.doi.org/10.1148/radiol.2016150497

50

Low Dose Tomosynthesis Techniques

Effective Dose per projection



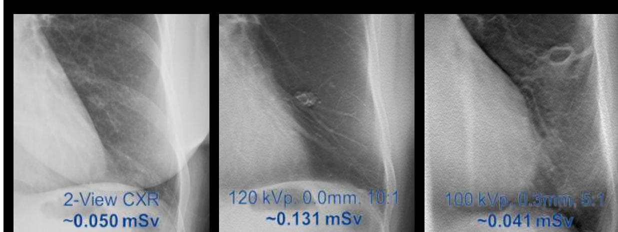
Tomosynthesis Total Effective Dose (mSv)				
kVp	Additional Filtration	Dose Ratio		
		5:1	8:1	10:1
100	0.3	0.057	0.090	0.114
120	0.0	0.103	0.103	0.131
120	0.2	0.074	0.095	0.118

Standard 2-View CXR		
120	0.0	0.0504

J.M. Sabol, Beth Heckel, *"Techniques for Very Low Dose Thoracic Digital Tomosynthesis"*, **Journal of Thoracic Imaging, 27**(5): W115–W163, 2012

51

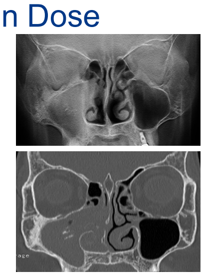
Thoracic Dose Optimization



52

Sinus Imaging and Radiation Dose

- Prevalence of sinusitis is estimated to be ~14% of general population, ~32% in young children
- 31 million individuals diagnosed each year in US
- Definitive diagnosis and treatment recommendations are often based on CT findings
- Increasing recognition of sensitivity of the eye lens to radiation damage
- Radiation cataractogenesis is deterministic with threshold of 0.5 Gy (ICRP ref 4825-3093-1464)

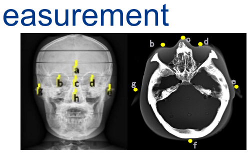


https://rpop.iaea.org/

53

Sinonasal Exam Dose Measurement

- Alderson-RANDO phantom scanned covering frontal to maxillary sinus using the clinically routine protocol by MDCT and tomosynthesis
- Measured the dose of internal organs (brain, submandibular and thyroid glands) and on the surface at various sites including the eyes using glass dosimeters

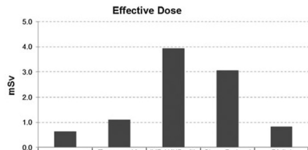


	MDCT (μGy)	Tomosynthesis (μGy)	MDCT/DT Dose Ratio
Eye	32500 ± 2500	112 ± 6	290
Skin	20000 ± 9300	1160 ± 2100	17
Submandibular gland	17000 ± 2300	1400 ± 80	12
Brain	14300 ± 2200	1770 ± 560	8
Thyroid gland	1230 ± 160	230 ± 90	5

Machida *et al*, "Radiation Dose of Digital Tomosynthesis for Sinonasal Examination: Comparison with MDCT", **European Journal of Radiology**, **81**(6), Pages 1140-1145, 2012

54

Dose from Abdominal Exams



	KUB	Tomographic Image	IVP / KUB with Tomograms	Stone Protocol CT	Digital Tomosynthesis
Effective Dose	0.63	1.1	3.93	3.04	0.83

Astroza GM, Lipkin ME.et al, "*Radiation exposure in the follow-up of patients with urolithiasis comparing digital tomosynthesis, non-contrast CT, standard KUB, and IVU*", **J Endourol**. 2013 Oct;27(10):1187-91. doi: 10.1089/end.2013.0255

Mermuys *et al* :
Clinical study of detection of urinary stones:
0.85 mSv for DTS (~1.7 times DR, 7-34% of CT)

K. Mermuys *et al*, ""Digital Tomosynthesis in the detection of urolithiasis: diagnostic performance and dosimetry compared with digital X-ray using MDCT as a reference"" AJR **195**:161–167, 2010

55

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

55

Dose from MSK Exams

Two studies of lateral thoracic spine exam
Effective Dose (mSv)

	Svalkvist	Geijer
AP	0.07	0.10
LAT	0.13	0.11
Scout	0.05	0.11
Tomosynthesis	0.47	0.66
Total T-Spine Exam:	**0.57**	**0.87**
CT		6.6

Geijer, M., *et al*. "Tomosynthesis of the thoracic spine: added value in diagnosing vertebral fractures in the elderly." ***European Radiology*** (2016): 1-7.

Svalkvist A, Söderman C, Båth M. "Effective Dose To Patients From Thoracic Spine Exams With Tomosynthesis" **Radiat Prot Dosimetry.** 2016 Jun;**169**:274-80.

56

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

56

Extremity Dose Results

Noël, A., Ottenin MA, Blum A *et al* Nancy Université:
- Study of wrist imaging
- 2 tomo views, 5 conventional radiography views
- Tomo uses 25% of radiographic exam dose
  - (0.72 compared to 0.96 mGy)
- 28 times lower than CT exam dose

Noël, A., Ottenin MA , Germain C , Soler M , Villani N , Grosprêtre O , Blum A et al. "[Comparison of irradiation for tomosynthesis and CT of the wrist]." **Journal de Radiologie 92**.1 (2011): 32-39.

Canella *et al* Lille FR:
- Clinical study of rheumatoid arthritis of the wrist
- 0.1166 μSv (~2.6 times DR)

Canella et al, "Use of Tomosynthesis for Erosion Evaluation in Rheumatoid Arthritic Hands and Wrists" Radiology **258**:199–205, 2011

R.E. Gazaille, M. Flynn *et al* Henry Ford Hospital:
- Monte Carlo simulation of hip tomosynthesis
- 0.24 mSv per view, (typical exam of 3 views)
- ~3-4 times dose of radiographic exam dose
- ~10% of CT exam dose

R. E. Gazaille et al, "Technical Innovation: Digital Tomosynthesis of the Hip Following Intra-articular Administration of Contrast", **Skeletal Radiology 40**, 1467-1471, 2011

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

57

AAPM TG 223 and TG 321

Dosimetry in Tomosynthesis Imaging

Charge: Develop methods to estimate dose from mammographic and radiographic tomosynthesis exams.

- Compute normalized dose data for relevant acquisitions
- Obtain absolute dosimetry values for anthropomorphic phantoms
- Enable routine QC/QA measurements and information that can be communicated by physicist to physician/patient

Med. Phys. 41 091501 (2014); http://dx.doi.org/10.1118/1.4892600

58

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

58

Body Exam Phantoms and Protocol

Pediatric: 1, 5, 10, 15 yrs
Adult: 10th, 50th, 90th percentile
Both Male and female
28 phantoms in total

Head and Neck	Sinus/Facial Bones	PA Caldwell	Table Wallstand
		PA Waters	Table Wallstand
		Lateral	Table Wallstand
Thoracic	Chest	PA	Wallstand
		Left Lateral	Wallstand
		AP Supine	Table

Spine	C-Spine	AP	Table Wallstand
		Left Lateral	Table Wallstand
	T-Spine	AP	Table Wallstand
		Left Lateral	Table Wallstand
	L-Spine	AP	Table
		Left Lateral	Table
Abdomen	Hip	AP Hip, Proximal Femur	Table Wallstand
	Abdomen	AP Supine	Table Wallstand
Extremity	Knee	PA Bilateral	Wallstand
		AP Bilateral	Table

59

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

59

The dose of body tomosynthesis exams is:

- Dependent on numerous acquisition factors that include:
  - The same factors that impact projection x-ray (spectra, technique etc)
  - Angular exposure factors (changes in SID, dynamic collimation, scatter)
  - Projection factors (Number of projections, dose per projection, …)
- Total dose from all views is comparable for tomosynthesis and projection radiography for most exams
  - In a clinical trial, a chest tomosynthesis acquisition required ~2% of the dose of CT, comparable to a two-view x-ray exam
- More understanding, accuracy, and consistent reporting is required
  - AAPM TG#321 will provide data for research and clinical communication

60

AAPM SPRING CLINICAL MEETING 2021 April 17–20 | VIRTUAL

60

- Tomosynthesis Imaging
- Parameters and Artifacts
- Clinical Applications
- Dosimetry
- **Features of Available Systems**
- QA/QC

61

Comparison of Some Commercial Systems

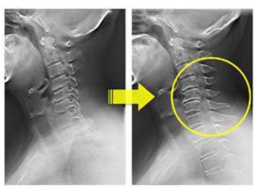
	AGFA	Carestream	Fujifilm Healthcare	GE	SHIMADZU
System Type	Multi-purpose Radiographic	Radiographic	Radiographic	Radiographic	Multi-purpose Radiographic
Sweep angle	15° 22° 30°	40°	10° – 60°	20° – 40°	MP: 8° 20° 30° 40° R: 20° 30° 40° 60°
Maximum Number of Projections	40	80	60	60	76
Binning	1 x 1 (148 um)	1 x 1 (139 μm) 2 x 2 (278 μm)*	N/A	1 x 1 (200 μm)	1 x 1 (139 μm) 2 x 2 (278 μm)
Reconstruction	Iterative	Feldkamp	N/A	FBP	Shift and Add FBP Iterative

* Selected on reconstruction, independent of acquisition

62

Notable system features

- Systems require a scout or prescan image
  - Serves as standard projection image
  - Used to determine mAs technique for sweep
- High Speed acquisition option:
  - Reduced number of projections to minimize motion artefacts
- Change reconstruction post-acquisition
  - Alter layer height, slice thickness, slice pitch, reconstruction method, and dynamic range
- Shimadzu offers Oblique plane reconstruction
- Shimadzu detector can move, preventing collimator cut-off and increasing FOV



Shimadzu oblique plane reconstruction (±20°)

63

- Tomosynthesis Imaging
- Parameters and Artifacts
- Clinical Applications
- Dosimetry
- Features of Available Systems
- **QA/QC**

64

QA/QC

Carestream

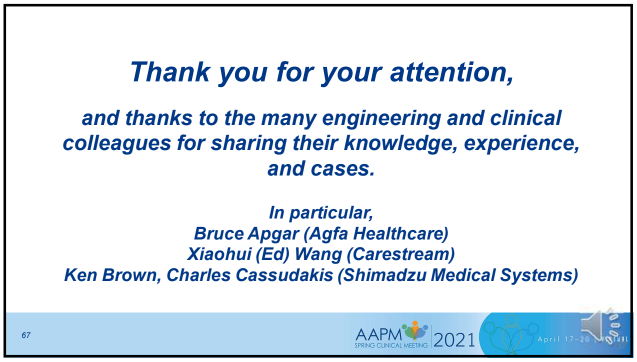
Provides users with a geometry calibration phantom
- Machine calibration
- QC check of overall system tomosynthesis functionality

AGFA, GE, SHIMADZU

No recommended QA or QC procedures
(other than those for regular system and detector functionality)

65

66


Thank you for your attention,
and thanks to the many engineering and clinical colleagues for sharing their knowledge, experience, and cases.
In particular,
Bruce Apgar (Agfa Healthcare)
Xiaohui (Ed) Wang (Carestream)
Ken Brown, Charles Cassudakis (Shimadzu Medical Systems)
67
AAPM SPRING CLINICAL MEETING 2021

67