Tomosynthesis Body Dose

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August 2nd, 2016

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Not GE Healthcare!

August 2nd, 2016

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Disclosures

John Sabol is an employee of GE Healthcare.

This is a scientific review of medical and physics literature on tomosynthesis imaging.

Some applications analysed for this presentation include off-label use of these medical devices. Regulatory agencies do not regulate medical practice, but they do regulate manufacturers. GE does not advocate for off-label use of GE products.

VolumeRad is cleared by the FDA in the USA, and is intended for generating images of human anatomy including the skull, spinal column, chest, abdomen, extremities, and other body parts in patients of all ages. Furthermore, for patients undergoing thoracic imaging, it is indicated for the detection of lung nodules. VolumeRAD generates diagnostic images of the chest that aid the radiologist in achieving superior detectability of lung nodules versus PA and LAT views of the chest, at a comparable radiation level.

Competitive technologies, similar to GE's, exist.

No medical practice recommendations will be given and nothing said should be considered medical advice.

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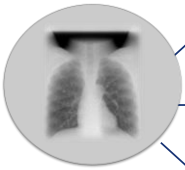
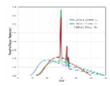
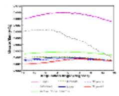
Factors Determining Tomosynthesis Dose



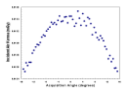
X-ray Beam Quality Factors
- kVp
- Filtration



Angular Exposure Factors
- Change in SID
- Changes in organ dose
- Dynamic collimation
- Changes in scatter



Projection Factors
- Number of projections
- mAs per projection
- Dose Ratio (Total mAs / Standard PA mAs)
- System technical limits (e.g.: minimum mAs)



Legend
Black: Adjusted by users for each exam
Green text: Set by system

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Monte Carlo Dose Simulation

Phantom Experiments
- Use anthropomorphic chest phantom with additional 2.5 cm of Lucite
- Acquire PA and Lateral views to determine standard AEC technique
- Image at 90, 100, 110, … 150 kVp each with 0.0, 0.1, 0.2, 0.3mm of Cu
- Use 3 different dose ratios (5:1, 8:1, 10:1)
- Measure incident air Kerma (mGy) for all 84 techniques

Monte Carlo Simulations
- Use PCXMC 2.0 Monte Carlo tool
- Calculate effective dose for PA and Lateral Views
- Calculate effective dose for each projection of DTS scan
- Sum for total effective dose for DTS

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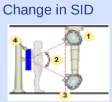
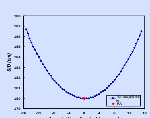
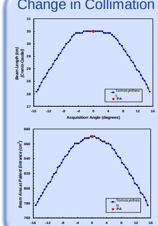
Acquisition Factors Affecting Dose

Change in SID

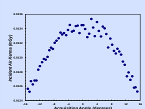




Change in Collimation



Variation in mAs



Total mAs for complete sweep.

Ratio of total tomosynthesis mAs to standard view mAs ("Dose Ratio")

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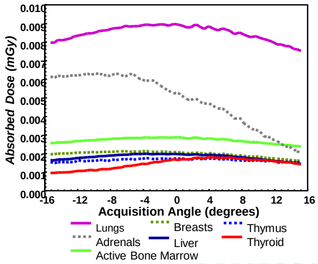
Absorbed Dose for Selected Organs



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

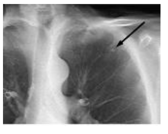
Lung Nodule Detection Clinical Trial

Objectives

Primary Aim: Improved Nodule Detection vs. CXR:
- 3mm-20mm diameter
- <0.1 mSv effective dose

Secondary Aims:
1. Dual energy increases sensitivity & specificity
2. Increased agreement with CT for case management (actionability based on Fleischner Society recommendations)

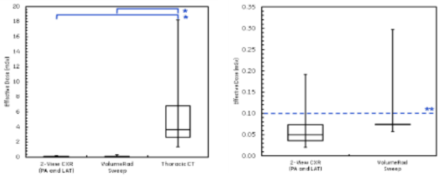
Diagnostic Chest CT **160**
→ **43** without Nodule | **117** with Nodule(s)
→ Conventional PA/LAT Chest X-ray w/ DE
→ Tomosynthesis



Study Details
- 184 Subjects enrolled at 4 sites
  - Duke University (J. Dobbins, P. McAdams)
  - University of Washington (G. Reddy)
  - Sahlgrenska University Hospital, Sweden (J. Vikgren)
  - University of Michigan (E. Kazarooni)
- 3 'Truthers'
- 5 readers
- 3500 image reviews
- ~44000 Data points

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

Effective Dose Comparison

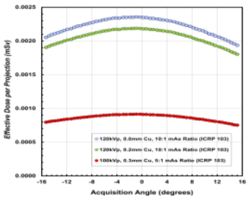


Tomosynthesis requires significantly* less dose than CT, same Relative Radiation Level** as 2-view CXR

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

Low Dose Tomosynthesis Techniques

Effective Dose per projection



VolumeRad 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

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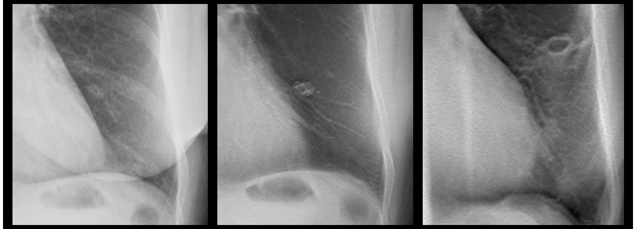
Thoracic Dose Optimization



2-View CXR	120 kVp, 0.0mm, 10:1	100 kVp, 0.3mm, 5:1
~0.050 mSv	**~0.131 mSv**	**~0.041 mSv**

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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)

ICRP IAEA

https://rpop.iaea.org/

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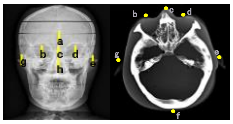
Sinonasal Exam Dose Measurement

- 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

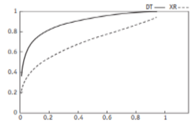
Machida et al, "Radiation Dose of Digital Tomosynthesis for Sinonasal Examination: Comparison with MDCT", **European Journal of Radiology**, **81**(6), Pages 1140-1145, 2012

Clinical Dose and Performance

- 43 Patients
- X-ray (Caldwell and Water's views)
- Single AP DTS acquisition
- MDCT standard clinical protocol

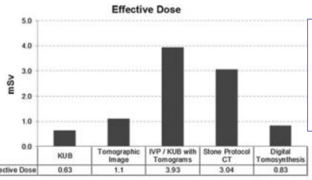
Average	X-Ray	Tomosynthesis
Sensitivity	50%	79 %
Specificity	86 %	94 %
Accuracy	76 %	89 %

Modality	Effective Dose
X-Ray	29 ± 6 μSv
Tomosynthesis	48 ± 10 μSv
MDCT	980 ± 250 μSv



Yoo, *et al*, Korean J Radiol. 2012;**13**(2):136-143.

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

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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.

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 TG#223
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

- Mammography report released Sept. 2014

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

Body Exam Phantoms and Protocol

Pediatric: 1, 5, 10, 15 yrs
Adult: 10^{th}, 50^{th}, 90^{th} percentile
Both Male and female
14 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

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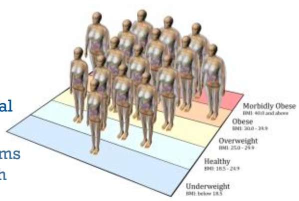
University of Florida Dosimetry

- Dr. Wesley E. Bolch's ALRADS Research Group
  - Dr. Elliott J. Stepusin
- UF/NCI Library of Computational Phantoms
  - Hybrid computational phantoms with implicitly modeled lymph nodes and muscle



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University of Florida Dosimetry

- Monte Carlo based dosimetry
  - Geometry modeled using custom Fortran 90 source subroutine in MCNPX (v 2.70)
  - University of Florida HiPerGator 2.0 (cloud computing resource) utilized for transport
- Post Processing
  - Organ doses normalized to reference air dose (@ 70 cm)
  - Projection data normalized by field size

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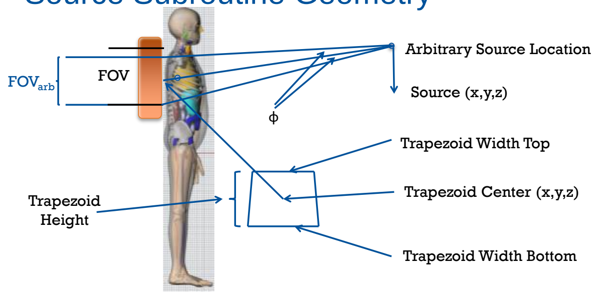
Source Subroutine Geometry



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Exam Modeling Flow Chart

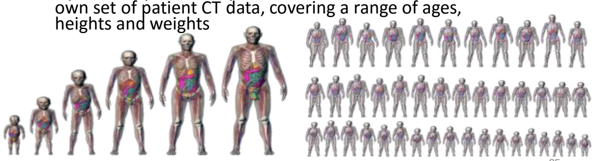
Exam Description
- Used to define FOV
- Based on phantom's organ tags

Raytrace FOV
- Visually confirm the FOV is appropriate for the phantom

MCNPX Inputs
- Automatically generated
- Geometry information saved

| Duke University Dosimetry

- Carl E. Ravin Advanced Imaging Labs (RAILabs)
  - Yakun Zhang, Greeshma Agasthya, Jocelyn Hoye, Paul Segars, and Ehsan Samei
- XCAT Library of 4D Computational Phantoms
  - Hybrid computational phantoms, each based on its own set of patient CT data, covering a range of ages, heights and weights



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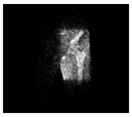
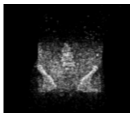
Duke University Dosimetry

- Phantom voxel size = 3.45 mm
- Field of View (FOV) calculated to include relevant organs
- Positioning of anatomy was based on
  - Merril's Atlas of Radiographic Positioning and Procedures 12th edition
  - Bontrager's Handbook of Radiographic Positioning and Techniques, 7th Edition, K. L. Bontrager and J. Lampignano, Mosby 2010
- Monte Carlo Simulation Package: PENELOPE, version 2006
- Post Processing
  - Final organ doses normalized by exposure (mGy/mR)
  - Air exposure simulated in air at 70 cm from source


Hip exam 3D dose map


Abdomen exam 3D dose map

Proposed TG Report Contents

Data will be available for each phantom-exam combination

- Relative organ dose (per starting photon) for each organ at each projection
- Geometry data for each projection of the exam
- Normalization factor for the associated scout scan (dose at 70 cm from scout source)
- Organ doses (per measured dose to air) weighted based on projection geometry i.e. Organ dose for complete acquisition

Adult and pediatric Monte Carlo simulations are underway, at Duke and Florida – results to come!

Summary

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#223 will provide data for research and clinical communication

Thank you, and thanks to many colleagues

for sharing of cases and data, collaborations, and helpful discussions

AAPM TG#223 Members
Dr. Myung Jin Chung, Samsung Medical Center, Seoul Korea
James Dobbins III, Duke University
Dr. Ali Guermazi, Boston University
Drs. Michael Lipkin and Rajan Gupta, Duke University
Dr. Haruhiko Machida, Tokyo Women's Medical University
Ioannis Sechopoulos, Radboud University Nijmegen Medical Center
The VORTEX Trial Team: D. Chakraborty, E. Kazerooni, P. McAdams, G. Reddy, & J. Vikgren,
Toshiyuki Yuhara, Tokyo Women's Medical University

Gerhard Brunst, Katelyn Nye, Nahush Rao, Dharmendra Nadkar, Rowland Saunders, GE Healthcare

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