Radiographic Tomosynthesis:
Clinical Applications and Dose

John M. Sabol, Ph.D.
GE Healthcare
Radiographic Clinical Applications

- Thoracic
- MSK/Orthopedic
- Abdominal
- Head and Neck
Radiographic Clinical Applications

- Thoracic
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- Abdominal
- Head and Neck
Pulmonary Nodules

Images Courtesy of
Eriko Guda
Department of Radiology,
University of Texas (Austin)
Lung Apex Lesion

Images Courtesy of
Simon Cules
Department of Radiology
University of Toronto (Rays)

John. M. Sabol, Ph.D.
AAPM 2012
Lung Nodule Detection with Tomosynthesis

Comparison of Chest Tomosynthesis and Chest Tomography for Detection of Pulmonary Nodules

89 Patients, 3x more nodules detected, highly significant.
JAFROC FOM Significantly Superior

Digital Tomosynthesis of the Chest for Lung Nodule Detection

21 Patients, 175 nodules, 2x-8x sensitivity

<table>
<thead>
<tr>
<th>Size</th>
<th>DR</th>
<th>DTS</th>
<th>X</th>
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<tr>
<td>&lt;5 mm</td>
<td>7%</td>
<td>53%</td>
<td>8x</td>
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<td>5-10 mm</td>
<td>20%</td>
<td>71%</td>
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<td>&gt;10 mm</td>
<td>53%</td>
<td>90%</td>
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Impact of Tomosynthesis on Radiological Investigation of Patients with Suspected Pulmonary Lesions

339 Patients.
DTS removed need for CT in about 75% of cases.
A 77-year-old male

S/P CCRT and low anterior resection for rectal cancer

Dr. Myung Jin Chung
Samsung Medical Center
Seoul Korea

2008-07-29
Tomosynthesis

Nodule 1:
Suspicious nodule on PA CXR
Nodule 2:
Nodule < 3mm
Nodule 3:
Calcified nodule
Nodule 4.
Retrocardial located nodule
Tuberculosis Detection and Diagnosis

- ~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

Use of Digital Tomosynthesis in Pulmonary Mycobacterial Disease: A Preliminary Experience
Cine loop of tomosynthesis slice images through the chest.
Standard PA chest radiograph (left) and single slice from the tomosynthesis image dataset (right) of a patient presenting with a lesion in the lower left lung. Although the lesion can be seen in the conventional image, it can be better visualized and characterized in the tomosynthesis slice. In particular it can be seen to be cavitated, characteristic of a tuberculosis infection.
Tuberculosis with Small cavity
Conventional PA x-ray (Left) and tomosynthesis slice image (right) of a tuberculosis patient with a small cavitated nodule.

Image courtesy of Dr. M.J. Chung, Samsung Medical Center, Seoul Korea.
Accidental swallowing of a pill in a press-through package. Chest conventional radiograph (left) and tomosynthesis image (right). The tomosynthesis image enables improved visualization of the object as a donut-like lucent area in the esophagus, whereas the foreign object is not visible on the conventional radiograph.
Radiographic Clinical Applications

- Thoracic
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Tomosynthesis image reveals a subtle fracture of the acetabulum, not seen on conventional hip radiograph.
Patient imaged for routine follow-up of treatment for a fracture of the scaphoid. Conventional radiograph (left) appears to show good evidence of healing (increased bone density at fracture site). However, examination of tomosynthesis images shows that despite increased bone density, the fracture still remains indicated by the gap in the bone (arrow in right image). This is a clear example of how overlying structures (in this case increased bone growth) can obscure underlying pathology.
Following a snowmobile accident, a patient was imaged at a rural trauma clinic. The AP radiograph on the left clearly shows a black line or shadow across the odontoid process raising the possibility of a fracture. A single slice from the tomosynthesis dataset (right image) removed the overlying shadow and the odontoid process was readily cleared for fracture. Had the ER physician not been able to clear the spine he would have had to send this patient, via ambulance, to the nearest trauma hospital, over 4 hours away.
13 year old with dislocation of epiphyseal (growth) plate of the femur in extreme hip pain following surgery.

**Left:** A post surgical projection image to determine if the implanted screw had invaded the joint space.

**Center and Right:** Tomosynthesis imaging allows for complete assessment of the joint without overlying structures with minimal metal artefacts. The tomosynthesis images revealed that the screw had not invaded the joint space.
**Left:** Tomosynthesis images of a trauma patient imaged in the ER following a motor vehicle accident. Extensive trauma to lower leg and ankle can be visualized in the tomosynthesis data set, despite the presence of a metal fixation splint. Sufficient information about the extent of the fractures and the location of the bone fragments enabled the surgeon to plan intervention without the need for CT imaging.

**Right:** Postoperative follow-up after total hip replacement: (Left) tomosynthesis slice image (Right) CT MPR coronal image. The cranio-caudal tomosynthesis sweep provides detailed information on potential loosening or peri-prosthetic fracture around the femoral stem prosthesis, compared to the conventional radiograph and with much less metallic artifact than CT. In the tomosynthesis image the minor metallic artifact appears as a low signal level or undershooting only along the sweep direction at the edges of the metallic prosthesis.
Arthritis Imaging

- 25 million Americans have the disease
- Worldwide, 23% of subjects are > age 65
- More prevalent in women than men
- Global annual cost ~$115 Billion
- Incidence related to body mass index (BMI)
- Diagnosis: clinical symptoms, radiographic grade
  - Both Kellgren & Lawrence Grade and OARSI Grade involve radiographic assessment of joint space narrowing (JSN)
  - X-Ray JSN only structural endpoint recognized by FDA and EMEA for Phase III trials
  - Oral Salmon Calcitonin, Phase III trial as a OA disease modifier
**Upper**: Examples of improved visualization and characterization of bone erosions in a patient with rheumatoid arthritis.

**Lower Left**: Example of a conventional PA radiograph and a slice from a tomosynthesis dataset of a patient being imaged for assessment of knee osteoarthritis. As seen on the tomosynthesis image, the patient has a bone chip in the knee joint space. The bone chip is very difficult to detect on the conventional image.

**Lower Right**: Conventional PA radiograph and a slice from a tomosynthesis dataset of a patient presenting with osteoarthritis. The extent of narrowing of the joint space is readily apparent on the tomosynthesis images.
With tomosynthesis imaging, it is possible to extract quantitative information about the joint space. In this case, a semi-automatic algorithm has been developed by Kalinosky et al to segment the edges of the femur and tibia and define the extent of the joint space in the knee. An example tomosynthesis slice image (Left) extracted joint space width profile (center) and reconstructed 2-D map of the joint space (right) are shown for both PA (Upper) and Lateral (Lower) image acquisitions. The extracted joint space profile are compared to values extracted from a CT dataset (center).
Radiographic Clinical Applications

Thoracic

MSK/Orthopedic

Abdominal

Head and Neck
Globally, IVP procedures with traditional x-ray is still a common procedure. Tomosynthesis replaces the need for linear tomography which is prone to fulcrum errors and increased dose. Linear tomography is performed to determine size, location and shape of the kidneys and generally limited to a field of view of 10x12". Tomosynthesis offers an increased FOV when needed, at the same dose as coned FOV’s. This patient has multiple areas of concern that were visualized in the full field FOV mode.
Individual slice images from previously shown patient.

Slice 9 shows a kidney stone formation within the kidney. Slice 15 shows a Greenfield filter in the venacava used to trap blood clots from migrating to the lungs. Slice 18 shows calcification in the Iliac arteries and distal aorta. Slice 22 shows gall stones within the gall bladder.
Tomosynthesis IVU

Single slice interval image from pre-contrast volume dataset. Kidney stone visible in right kidney.

10 minutes post contrast, single slice from volume dataset.
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Temporal Mandibular Joint Imaging

- Common imaging procedure
- Application originally targeted by Ziedses des Plant in the invention of tomography (1932)

Modern digital tomosynthesis enables high resolution reconstruction of slice images through both TMJ joints after a single acquisition sweep.
Chronic maxillary sinusitis with obstruction of the natural ostia clearly visible on the tomosynthesis images (left). The complete obstruction of the patient’s right maxillary sinus can be seen, in comparison with the patent left sinus. Similar results can be seen on the much higher dose MDCT image (right).
Acute maxillary sinusitis as demonstrated on sinus tomosynthesis and MDCT MPR coronal images. The tomosynthesis images (left) well delineates the air-fluid level in the left maxillary sinus more easily and with less radiation dose than CT. Note that tomosynthesis enables imaging in both the upright and supine positions which changes the appearance of the air-fluid level, unlike in CT.
Pre-Surgical Sinus Assessment

Prior to functional endoscopic sinus surgery, tomosynthesis reveals normal anatomic variants.

Asymmetric cribiform plate
Mandibular cyst imaged with both conventional mandibular radiography (left) and tomosynthesis (right). The tomosynthesis radiograph better delineates the cyst (arrows) as well as the mandibular canal than the conventional radiograph. Note that there is minimal metallic artifact produced as a result of the dental fillings.
Example of a blow-out fracture on both tomosynthesis and CT MPR coronal images. The tomosynthesis image clearly delineates the fracture of the right orbital floor. Tomosynthesis offers easier imaging at less cost and radiation exposure than with CT. However, due to relatively lower contrast sensitivity, it is more difficult to differentiate the content prolapsing into the maxillary sinus with tomosynthesis than it is with CT. Note that the air-fluid level (arrowhead) resulting from the hemorrhage is visible in the right maxillary sinus in the tomosynthesis image due to the upright position acquisition.
Factors Determining Tomosynthesis Dose

X-ray Beam Quality Factors
- kVp
- Filtration

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

Projection Factors
- Number of projections
- mAs per projection
- Dose Ratio
  - (Total mAs / mAs of standard PA)
- System technical limits (minimum mAs)
**Left:**
Linear path of x-ray source changes SID, decreases relative exposure to the patient at extremes of the sweep

**Middle:**
Collimation is adjusted with projection angle. Dose area changes, excess dose is not delivered to the patient. Relevant to possible organ-specific dose effects at different views

**Right:**
mAs or dose may be changed as a function of view angle. Total tomosynthesis mAs is often expressed as a ratio of the mAs for the standard projection view.
Monte Carlo Dose Simulation

- 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, 0.3 mm of Cu
- Use 3 different dose ratios (5:1, 8:1, 10:1)
- Measure incident air Kerma (mGy) for all 84 techniques

- Use FCXMC 2.0 Monte Carlo tool
  - 10^4 x-ray photon histories per view less than 0.1% error
  - Assume patient of average size
- Calculate effective dose for PA and Lateral Views
- Calculate effective dose for each projection of DTS scan
- Sum for total effective dose for DTS

84 different techniques investigated
Absorbed Dose for Selected Organs
Low Dose Techniques

Effective Dose per projection

Total Effective Dose (mSv)

<table>
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<tr>
<th>kVp</th>
<th>Additional Filtration</th>
<th>5:1</th>
<th>8:1</th>
<th>10:1</th>
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<tr>
<td>100</td>
<td>0.3</td>
<td>0.057</td>
<td>0.090</td>
<td>0.114</td>
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<tr>
<td>120</td>
<td>0.0</td>
<td>0.103</td>
<td>0.103</td>
<td>0.131</td>
</tr>
<tr>
<td>120</td>
<td>0.2</td>
<td>0.074</td>
<td>0.095</td>
<td>0.118</td>
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Standard 2-View CXR

| 120 | 0.0 | 0.0504 |
The minimum exposure duration and finite mAs increments can prevent the tomosynthesis system from delivering the desired exposure for all desired exposure techniques. This results in a lower dose to the patient for most techniques. However, for some techniques, specifically those of high kVp and minimal filtration, the tomosynthesis systems can deliver higher exposures than desired. Similarly, the desired exposures corresponding to very low dose ratios will not routinely be delivered by the system.
Examples of images from thoracic tuberculosis cases shown previously with estimated effective dose for each acquisition. The tomosynthesis images (center and right) were acquired with different techniques demonstrating significant changes in dose possible with tomosynthesis. Further research into the optimization is required to determine the dose required for different tomosynthesis exams.
Other Thoracic Dose Studies

Magnus Båth, Angelica Svallkvist, et al/ Sahlgrenska University Hospital:
- Numerous clinical and dosimetry studies
- Monte Carlo simulations and assessment of dose in clinical practice
- Found dose values within ~10% of expected levels from equivalent total air-kerma of standard exam
- ~0.13 mSv including std. PA view
- ~2% of average chest CT

E. Quaia, et al/ University of Trieste:
- Clinical study of 339 patients
  - CXR: 0.06 mSv (range 0.03–0.1 mSv)
  - DTS: 0.107 mSv (range 0.094–0.12 mSv)
  - CT: 3 mSv (range 2–4 mSv)

Shuji Koyama et al/ Nagoya University:
- Shimadzu SONIALVISION Sofire
- 0.92 mSv using anthropomorphic phantom and photodiode dosimeters

Yoshitake Yamada, et al/ Nippon Koukan Hospital
- Shimadzu RADspeed
- 0.215 mSv using Monte Carlo simulation of standard patient obtained from a 120 patient study

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)
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

<table>
<thead>
<tr>
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<th>MDCT (µGy)</th>
<th>Tomosynthesis (µGy)</th>
<th>MDCT/DT Dose Ratio</th>
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<tbody>
<tr>
<td>Eye</td>
<td>32500 ± 2500</td>
<td>112 ± 6</td>
<td>290</td>
</tr>
<tr>
<td>Skin</td>
<td>20000 ± 9300</td>
<td>1160 ± 2100</td>
<td>17</td>
</tr>
<tr>
<td>Submandibular gland</td>
<td>17000 ± 2300</td>
<td>1400 ± 80</td>
<td>12</td>
</tr>
<tr>
<td>Brain</td>
<td>14300 ± 2200</td>
<td>1770 ± 560</td>
<td>8</td>
</tr>
<tr>
<td>Thyroid gland</td>
<td>1230 ± 160</td>
<td>230 ± 90</td>
<td>5</td>
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Comparison of Clinical Dose

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

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<tr>
<th>Average</th>
<th>X-Ray</th>
<th>Tomosynthesis</th>
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<tr>
<td>Sensitivity</td>
<td>50%</td>
<td>79 %</td>
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<tr>
<td>Specificity</td>
<td>86 %</td>
<td>94 %</td>
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<tr>
<td>Accuracy</td>
<td>76 %</td>
<td>89 %</td>
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<table>
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<th>Modality</th>
<th>Effective Dose</th>
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<tr>
<td>X-Ray</td>
<td>29 ± 6 μSv</td>
</tr>
<tr>
<td>Tomosynthesis</td>
<td>48 ± 10 μSv</td>
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<tr>
<td>MDCT</td>
<td>980 ± 250 μSv</td>
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# Other Tomosynthesis Dose Studies

*Gislason, King, Elbakri, and Reed, Winnipeg Children’s Hospital:*
- Tomosynthesis in pediatric spine, knee, facial, imaging
- 2-10 times dose of radiographic exam dose
- ~2.16% of CT exam dose
- Tomosynthesis dose less than total DR dose for some exams

*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

*Hayashi, Guermazi et al Boston University:*
- Clinical study of bilateral knee imaging
- 0.0072 mSv for DTS (~4X DR)

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

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

- Tomosynthesis offers access to volume data for many clinical applications
- Increasing global and application use
- Dose advantages compared to both projection x-ray and CT
- Further dose and clinical technique optimization is required
Thanks to Many Colleagues
for sharing of cases and data, collaborations, and helpful discussions

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