Radiographic Tomosynthesis: Acquisition Parameters

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Learning Objectives

1. Appreciate the importance of scan direction.
2. Understand how tomosynthesis (TS) images can have better resolution than CT images.
3. Learn guidelines for performing TS examinations, [with musculoskeletal examples]

Digital Radiography (DR) detectors capable of rapid sequence acquisitions are effective for x-ray Tomosynthesis (TS) imaging:

- High resolution
- No geometric distortion
- High frame rate (pulsed)
- Minimal lag

Accurate mechanical movement of the detector and x-ray tube is required to achieve high detail from TS reconstruction.
The Shimadzu Sonialvision / Safire system integrates the digital detector within a radiographic tilt table. Shown in the tilt position for a lateral knee tomosynthesis acquisition (60°), the detector translates up and the x-ray tube moves downward. The x-ray central beam is directed at the joint surface with an angle that varies from -20 to +20 degrees.

For the GE VolumeRAD system, the tube angle changes as the tube mount moves linearly. The detector remains in a stationary position.

Tomosynthesis requires the acquisition of many views acquired as a very rapid sequence. Minimal lag from frame to frame is required.
B.1 – Transient Response

Rapid Edge Movement Test
- 1.51 mm Cu edge
- High edge position
- Low central layer
- 74 frames
- 30 frames/second

Radiographic technique
- RQA5 'equivalent'
- 70 kVp, 1 mA-S
- 0.5 Cu, 2 mm Al

Edge advances ~ 1 cm per frame
Signal measure from the same region for each frame.
B.1 – Transient Response

High to Low Transient

Linear Image Value vs Time

$T_{1/2} = 2$ frames (66 ms)

Low to High Transient

Linear Image Values vs Time

$T_{1/2} = 1.5$ frames (50 ms)

B.2 - Tomosynthesis Line Response

Tomosynthesis Line Response

- Slice sensitivity
- Resolution (LSF FWHM)
B.2 - TS Wire Phantom

- Wire test phantom
- 80 micron Tungsten

1:10 pitch

B.2 - TS Acquisition Response

<table>
<thead>
<tr>
<th>Acquisition Frame</th>
<th>60 kV, 1 mA-S</th>
<th>0.5 Cu Filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>10 cm</td>
<td>4 mm focal spot</td>
</tr>
</tbody>
</table>

0 degrees

6 degrees

B.2 - TS Reconstructed Response

Tomosynthesis Reconstruction of wire phantom

- Slice intervals of 1 mm
- Well focused over 5 mm thickness
- Slice sensitivity ~ 3 mm (FWHM)
B.2 - TS spatial response

SliceThickness (Sensitivity):
Peak contrast of a thin line vs height
FWHM = 3.02 mm
(rsna 2007)

B.2 - TS response

TS Resolution:
- Thin wire response at maximum contrast
- Re-projection with 1/10th sub-pixels
FWHM = 0.24 mm
(rsna 2007)

B.2 - TS line response

Fourier transform (magnitude) of LSF
- Extended spatial frequency response but no low frequency, DC, information.
B.3 – TS vs CT resolution

- In the x direction, TS resolution is about 3 times better than current CT scanners.
- In the x direction, TS slice thickness about 3 time worse than thin slice CT scans.

B.3 - 3D spatial frequency domain

CT Modern Multi-slice VCT scanners have nearly isotropic response with maximum spatial frequencies of .8 to 1.0 cycles/mm

B.3 - CT Resolution

Clinical Multi-slice scanners
- 64 slice scanners
- GE Lightspeed VCT 64
- Siemens Sensation 32x2
- PSF FWHM
  - Transverse 1.14 +/- 0.05 mm
  - Axial 0.87 +/- 0.11 mm
- 10% MTF Freq.
  - Transverse 0.74 +/- 0.02 cycles/mm
  - Axial 0.92 +/- 0.12 cycles/mm

For purposes of comparison, we express typical VCT performance as:
- 1.00 mm (FWHM PSF)
- 0.83 cycles/mm (10% MTF)
B.3 - 3D spatial frequency domain

Tomosynthesis extends the transverse response at the expense of the slice width (Z).

B.3 - Frozen Cadaver – Tibial Plateau

Nearly matched coronal planes from reformatted 3D CT (GE).

B.3 - Frozen Cadaver – Tibial Plateau

Nearly matched coronal planes from reformatted 3D CT (GE).
In the x direction, TS resolution is about 3 times better than current CT scanners.

In the x direction, TS slice thickness about 3 time worse than thin slice CT scans.

HOWEVER,
the TS image is NOT a tomogram in that large segments of the volumetric spatial frequency domain are un-sampled.

B.3 - Tomosynthesis Reconstruction
Filtered Backprojection
- The reconstruction is similar to cone beam CT but with a limited acquisition angle.
- The tomosynthesis image quality can be understood from the Fourier representation of the acquired data.

A. High signal frequencies in the x,y directions provide in-plane detail.
B. Varied filter cut-off frequencies vs angle limit z signal resolution.
C. Flat surfaces are not sampled along the ω_z direction.

US PAT #s 6643351, 6463116

B.3 - 3D spatial frequency domain
TS vs CT
Unsampled frequencies along the ω_y axis make TS and CT complimentary.
B.3 Orientation effect

Grid phantom made from a fluorescent ceiling light:
- 1 cm aluminum louvers
- 14 mm spacing
- 12 cm x 12 cm
- 45° to scan
- 0° / 90° to scan

B.4 - Multiple TS views

- Because of the large slice thickness and anisotropic spatial resolution, multiple TS views are needed to examine organs in different orientations.
- This is an important distinction relative to CT where sagittal, coronal, and transverse views are obtained from the same acquisition.
B - TS vs CT summary

TS advantages
- Much improved in plane detail.
- More tolerant of metal devices.
- Limited angle acquisition improves the radiographic technique.
  - Low kV due to reduced thickness.
  - Reduced irradiation from cone views.
  - Reduced overall patient dose.

CT advantages
- Quantitative tissue property value.
- Isotropic response.
- Multiple orientations from one acquisition.

C - Knee Tomosynthesis

TS Knee examination

C - Standing PA Views

- Weight bearing examination of the knee permits assessment of cartilage loss, an early indicator of OA.
- Biomechanical studies have shown that the tibia-femur contact stress is greatest with the knee flexed.
- Standing views are obtained with the knee moved forward to press on the table pad.
- A table tilt of 70° with a waist restraint is used for safety reasons.

C - Standing Lateral Views

- Lateral views of individual knees are obtained by placing the opposite foot on a ledge associated with the standing table accessory.
- A table tilt of 60 degrees places a load on the single leg similar to that of normal standing on two legs.
- The lateral view is of interest with respect to the patellar gap. Thus a flexed position is not used.

C - Coronal views - example

- Coronal images are reconstructed from the PA standing acquisition views.
- Each image corresponds to a slice thickness of about 2.5 mm at intervals of 1.0 mm.
- Typically about 80 images are reconstructed.
- Reconstruction takes about 1.5 minutes using a post processing work station (PPWS).

PACS: ERGONOMIC
CONSIDERATIONS
C - Coronal views - example

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42 mm

C - Coronal views - example

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43 mm

C - Sagittal views - example

- Coronal images are reconstructed from the PA standing acquisition views.
- Each image corresponds to a slice thickness of about 2.5 mm at intervals of 1.0 mm.
- Typically about 80 images are reconstructed.
- Reconstruction takes about 1.5 minutes using a post processing work station (PPWS).

29 mm
Coronal images are reconstructed from the PA standing acquisition views. Each image corresponds to a slice thickness of about 2.5 mm at intervals of 1.0 mm. Typically about 80 images are reconstructed. Reconstruction takes about 1.5 minutes using a post processing work station (PPWS).
C.2 - Knee Case – Femoral Insufficiency Fractures

Tomography demonstrates bi-condylar insufficiency fractures.

Coronal Tomosynthesis – Insufficiency Fracture of Medial Femoral Condyle

Coronal Tomosynthesis – Insufficiency Fracture of Lateral Femoral Condyle.

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C.5 - Knee Case – Occult fracture

Patient presented with continued knee pain following a traumatic injury while out of state which was repaired with patellar screws.

Sagittal and coronal views obtained by scanning parallel to the screws minimize overshoot from the high absorption in the metallic material.

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C.5 - Knee Case - Occult fracture

A displaced fibial fracture was clearly demonstrated on the transverse scan.

D - Hip Tomosynthesis

TS Hip examination

D - AP view

AP view obtained with toe in and hip elevated with a boomerang filter.
TS images are in a plane through the head, neck, and shaft.

The neck is rotated by bringing the knee up and out.

TS images are in a rotated plane through the head and neck.
Similar to the standing faux profile radiographic view, the opposing hip is rotated forward by 60 degrees.

TS planes are oblique to the axis of the neck.

Patient presented in the EM Dept with possible hip fx
- Radiographs were inconclusive
- MR edema suggested a near complete fx that requires surgery.
D - Hip Case #1  Trachanter fracture

- Tomosynthesis showed the fracture was restricted to the non weight bearing head of the trochanter.
- The patient was sent home without surgery.

D - Hip Case #2  Trachanter fracture

- Patient presented in the EM Dept with possible hip fx
- CR: 'there is no definite fracture line seen'
- MRI: 'Nondisplaced intertrochanteric fracture'

D - Hip Case #2  Trachanter fracture

- Tomosynthesis showed a transverse fracture from the trochanter through the base of the neck.
- The patient was sent to surgery for a hip screw.
**D - TS Dose, Hip Exam**

TomoSynthesis Dose, Hip Exam

- 82 kVp - Average kV, varies amongst patients.
- 5.87 mGy - Entrance Skin Air Kerma (ESAK)
- 0.24 mSv - Effective dose for one view (ICRP103)
  
  Monte Carlo computation of organ doses.
  (PCXMC, Stuk, Helsinki, Finland)
- 0.72 mSv - Effective dose for 3 view examination

**E - #5 Spine AP, Metabolic Bone Survey**

Tomosynthesis Effective Dose

- Monte Carlo computation of organ doses (PCXMC)
- ICRP 103 organ weights

<table>
<thead>
<tr>
<th>Organ</th>
<th>Median kV (N=30)</th>
<th>ESAK, mGy</th>
<th>Eff. Dose, mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis</td>
<td>80</td>
<td>5.48</td>
<td>0.57</td>
</tr>
<tr>
<td>L Spine</td>
<td>82</td>
<td>5.87</td>
<td>0.96</td>
</tr>
<tr>
<td>T Spine</td>
<td>76</td>
<td>4.76</td>
<td>0.86</td>
</tr>
</tbody>
</table>

**Mettler 2008**

- 6.0 mSv - CT spine exam
- 6.0 mSv - CT pelvis exam

**AAPM 2012**

Dose, Hip Exam

- 5.87 mGy - Entrance Skin Air Kerma (ESAK)
- 0.24 mSv - Effective dose for one view (ICRP103)
- 0.72 mSv - Effective dose for 3 view examination

- 0.7 mSv - Radiographic hip exam
- 6.0 mSv - CT pelvis exam.