Learning Objectives

1. Appreciate the importance of scan direction,
2. Understand the nature of the artifacts associated with tomosynthesis scan acquisition and reconstruction.
3. Learn guidelines for performing TS examinations,

... [with musculoskeletal examples]

A – Shimadzu Sonialvision / Safire

• 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.

B.1 – Acquisition lag

• Tomosynthesis requires the acquisition of many views acquired as a very rapid sequence.
• Minimal lag from frame to frame is required to avoid streak artifacts

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
• .5 Cu, 2 mm Al
Rapid Edge Movement Test
- 1.51 mm Cu edge
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Radiographic technique
- ROAS ‘equivalent’
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• Edge advances ~ 1 cm per frame
• Signal measure from the same region for each frame.

High to Low Transient

Linear Image Value vs Time

0.061 of transient change
$t_{1/2} = 2$ frames (66 ms)
B.1 - Transient Response

Low to High Transient

- Linear Image Values vs Time
  - 0.062 of transient change
  - $T_{1/2} = 1.5$ frames (50 ms)

B.2 - Tomosynthesis Line Response

- The registration of each acquired projection must be accurately known to prevent blur.
- One method to measure the spatial response is to scan a thin wire tilted relative to the scan plane.
  - Slice sensitivity
  - Resolution (LSF FWHM)

B.2 - TS Wire Phantom

- Wire test phantom
- 80 micron Tungsten

1:10 pitch
B.2 - TS Acquisition Response

Acquisition frame: 65 kv, 1 mA-5, .5 Cu filtration
10 cm height, .4 mm focal spot

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

Slice Thickness (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 1/30th sub-pixels.
- FWHM = 0.24 mm (rsna 2007)

**TS reconstruction**
- 80 micron wire
- Cutoff filter #4
- 40 degree acquisition
- 2x2 bin, 300x300 mm

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B.2 - TS line response

**Fourier transform (magnitude) of LSF**

Extended spatial frequency response but no low frequency, DC, information.

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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.
Modern Multi-detector CT scanners have nearly isotropic response with maximum spatial frequencies of 0.8 to 1.0 cycles/mm.

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

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

IEEE VCT
Shimadzu TS

In the x direction, TS resolution is about 3 times better than current CT scanners.
In the x direction, TS slice thickness about 3 times 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.

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 wz direction
Unsampled frequencies along the $\omega_x$ 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.
Multiple TS acquisitions are required to get detail in planes of different orientation.

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
• 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).
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C - Sagittal views - example

- Coronal images are reconstructed from the PA standing acquisition views.
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- Typically about 80 images are reconstructed.
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C - 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.

A displaced fibial fracture was clearly demonstrated on the transverse scan.
• With FBP tomosynthesis reconstruction, significant overshoot artifacts occur on edges perpendicular to the scan direction.

• These can be confused with device loosening

• New reconstruction methods offer significant improvement.

Machida, Radiographics; 36:735 (2016)

Iterative Reconstruction

T-smart, Shimadzu
TS Hip examination

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 60° up and 30° out.

TS image 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.
Patient presented in the EM dept with possible hip fx
- Radiographs were inconclusive
- MR edema suggested a near complete fx that requires surgery.

Tomosynthesis showed the fracture was restricted to the non weight bearing head of the trochanter.
- The patient was sent home without surgery.
E - Hip Case #2  Trochanter fracture

• Patient presented in the EM Dept with possible hip fx
• CR: ‘there is no definite fracture line seen’
• MR: ‘Nondisplaced intertrochanteric fracture’.

E - Hip Case #2  Trochanter 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.

F - #5 Spine AP, Metabolic Bone Survey