**Daily kV Localization: Factors Affecting Image Quality**

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### Factors Affecting Image Quality

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### Spatial Resolution

- Factors affecting spatial resolution
  - Focal spot size
  - Detector configuration
    - X-ray converter
    - Pixel pitch
  - System geometry
    - Magnification
  - Recon parameters
    - Recon filter
    - Voxel size

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![Diagram of Spatial Resolution](image)
‘Resolution Length’
(FWHM of the PSF)

Effect of Reconstruction Filter

Modulation Transfer Function (MTF)

Image Noise

Noise is characterized by its:
- Magnitude (standard deviation)
- Spatial frequency content ('texture')
CT image noise depends on:
- Dose
- Detector efficiency
- Voxel size:
  - Axial, $a_y$
  - Slice thickness, $a_z$
- Reconstruction filter

\[
\sigma^2 = \frac{k_F}{D_e} \frac{1}{\eta} \frac{K_{xx}}{a_y a_z}
\]

\[
\sigma \propto \sqrt{\frac{1}{D_e}} \propto \sqrt{\frac{1}{a_y}} \propto \sqrt{\frac{1}{a_z}}
\]

Barrett, Gordon, and Hershel (1976)

Image Noise

\[\sigma \sim a + \frac{b}{\sqrt{X}}\]

Benchtop CBCT Scanner (1998)

Noise-Power Spectrum

Axial Plane $(x,y)$

Sagittal Plane $(x,z)$

Noise-Power Spectrum
Image Quality

Imaging performance depends on:
- Spatial resolution and noise (MTF and NPS)
- Structure of interest (task)
- Artifacts

Detector Configuration
Reconstruction Filter
Voxel Size
Dose

Figure of Merit: Detectability

$$d' = \frac{\int_{-\infty}^{\infty} MTF^2(\mathbf{f}) \tilde{W}_{\text{task}}(\mathbf{f}) d\mathbf{f}}{\int_{-\infty}^{\infty} \frac{NPS(\mathbf{f})}{N_{\text{Nyq}}}}$$

“Frequencies of Interest”
Object size
Object contrast

Soft-Tissue Visualization

Variable Contrast

<table>
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<tr>
<th>Contrast</th>
<th>Dose</th>
<th>170 mAs</th>
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<tbody>
<tr>
<td>0.6 mGy</td>
<td>0.02 mSv</td>
<td>88 HU</td>
</tr>
<tr>
<td>2.9 mGy</td>
<td>0.1 mSv</td>
<td>12.7 mm</td>
</tr>
<tr>
<td>9.6 mGy</td>
<td>0.35 mSv</td>
<td>(2-13) mm</td>
</tr>
<tr>
<td>23.3 mGy</td>
<td>0.8 mSv</td>
<td>(10-100) HU</td>
</tr>
</tbody>
</table>
**Bony Visualization**

- **Paranasal Sinuses**
  - 0.6 mGy
  - 0.02 mSv
- **Skull Base**
  - 2.9 mGy
  - 0.1 mSv
- **Frontal Base**
  - 9.6 mGy
  - 0.35 mSv
- **Sphenoid Sinus**
  - 23.3 mGy
  - 0.8 mSv

**Image Quality**

<table>
<thead>
<tr>
<th>Plane of Visualization</th>
<th>Hanning Filter (&quot;Smooth&quot;)</th>
<th>Ram-Lak Filter (&quot;Sharp&quot;)</th>
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<tr>
<td>Axial (x,y)</td>
<td></td>
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<tr>
<td>Sagittal (x,z)</td>
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**Artifacts**

- Rings
- Shading
- Streaks
- Motion
- Metal
- Lag
- Truncation
- "Cone-Beam"

**Artifacts: X-ray Scatter**

1) Image artifacts
   - Cupping and streaks
2) Reduced contrast
   - Reduction of $\Delta CT$
3) Increased image noise
   - Reduced DQE
   - Reduced soft-tissue detectability

**A big problem for cone-beam CT:**

SPR is very large for large cone angles (i.e., large FOV)
Managing Scatter

- Select
  - Good geometry (gap)
  - Limit FOVz to volume of interest

- Reject
  - Antiscatter grids
  - Bowtie filter

- Correct
  - Estimate and subtract $\phi_{\text{scatter}}(u,v)$
  - Measurement and modeling

Managing Scatter

- Select
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- Correct
  - Estimate and subtract $\phi_{\text{scatter}}(u,v)$
  - Measurement and modeling
Pop-Quiz (1 of 2)

- Which of the following is NOT associated with the use of a bow-tie filter in cone-beam CT?
  
  (a) Improved spatial resolution
  (b) Improved contrast
  (c) Reduced dose to the patient
  (d) Reduced x-ray scatter artifacts

Pop-Quiz (2 of 2)

- CBCT image noise (standard deviation) exhibits which of the following dependencies?
  
  (a) $\sigma \propto \frac{1}{\text{Dose}}$
  (b) $\sigma \propto \frac{1}{\sqrt{\text{Slice Thickness}}}$
  (c) $\sigma \propto N_{\text{projections}}$
  (d) $\sigma$ is independent of filter selection
  (e) $\sigma \propto \text{SPR}$
Take-Home Points

<table>
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<tr>
<th>Metric</th>
<th>Spatial Resolution</th>
<th>Image Noise</th>
<th>Image Quality</th>
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<tr>
<td>Simple Scalar Metric</td>
<td>FWHM of the Spread Function</td>
<td>Standard Deviation in Pixel Values</td>
<td>Contrast CNR</td>
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<td>Fourier-Based</td>
<td>MTF</td>
<td>NPS</td>
<td>NEQ and Task</td>
</tr>
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Artifacts
- X-ray scatter:
  - Often a major factor in CBCT image quality
  - Artifacts, contrast reduction, and noise
  - Select / Reject / Correct

Other artifacts:
- Object motion
- Lateral truncation
- Rings, beam hardening, cone-beam artifacts, ...

Pop-Quiz (1 of 2)
- Which of the following is NOT a factor in the spatial resolution of CT images?
  - (a) Dose
  - (b) System geometry
  - (c) X-ray converter type and thickness
  - (d) Reconstruction filter

The 3-D Noise-Power Spectrum

\[ NPS(f_x, f_y, f_z) \]

- Transverse domain:
  - Filtered-ramp
  - Green NPS

- Axial domain:
  - "Band-limited"
  - Red NPS
Radiation Dose

- Calculation of dose
  \[ D_0 = \left( \frac{mR}{mAs} \right) N_{proj} \frac{mAs}{proj} f_o e^{-\mu_o R} SF \]
  - Tube Output (measured)
  - Total mAs
  - f-factor (cGy/R)
  - Scatter (measured or MC)
  - Attenuation

- Measurement of dose
  - Cylindrical phantoms (16 cm 'Head' or 32 cm 'Body')
  - Calibrated Farmer ionization chamber

Radiation Dose

- Tube-Under
  - Soft-tissue: ~200 mAs
  - Bone: ~30 mAs
  - Dose (mGy/mAs)

- Tube-Over
  - Soft-tissue: ~12 mGy
  - Bone: ~3 mGy

Interventricular catheter CT for guidance of head and neck surgery: Assessment of dose and image quality using a C-arm prototype