Day 2 part 2

RADIOLOGY AND DIAGNOSTIC IMAGING

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CT technique
CT technique

CT system

One View

- focal spot
- tube
- rays
- detectors
- profile

Kanal K: RSNA/AAPM web module: CT Systems & CT Image Quality and Protocols
CT technique

CT system

- stationary x-ray tube, rotating multi-row panel of detectors
CT technique

CT system

- stationary x-ray tube, rotating multi-row panel of detectors
- advanced x-ray tube technology: instant current up to 500 mA over 5-40 s
- large heat capacity and fast cooling rates
- mechanical stress due to rotation – up to 13 G
CT technique

CT system

- each detector, along with the focal spot of x-ray tube, defines a ray
- the intensity of the beam within each ray depends on the total attenuation of the tissue through which it passes.
- the data acquired during a CT scan consist of a series of views
- for each view, all detectors make intensity measurements simultaneously over a short period of time. The set of simultaneous measurements constitutes a profile/projection
CT technique

CT system

CT technique

CT system

- a CT reconstruction algorithm is used to produce the CT image
- filtered back projection is most widely used in clinical CT scanners
CT technique

CT scanning

- two basic modes of acquisition

![Diagram showing two basic modes of CT acquisition: Step and shoot / sequential mode and Helical / spiral mode.](image-url)
CT technique

CT scanning

- acquisition parameters
  - determine production of scan data sets

- reconstruction parameters
  - determine presentation of the data

- single slice scanners

- multislice scanners, multi-detector row scanners (MDCT)
CT technique

CT scanning – acquisition parameters

- Tube potential (80-140 kVp) – voltage between cathode and anode; higher potential accelerates electrons more, giving x-rays more energy.

- Tube current (20-500 mA) – current following through cathode; larger current produces more electrons and greater x-ray beam intensity.

- Scan time (0.3-4 s) – time of x-ray production during one rotation; longer scan time increases x-ray count.

- Slice width (0.5-10 mm) – slice thickness in z-axis.

- Beam filtration – beam shaping filter optimized for body parts.

- Helical pitch (0.5-2)
CT technique

CT scanning – acquisition parameters

- pitch = table movement per rotation (mm) / beam width (mm)
CT technique

CT scanning – reconstruction parameters

- helical interpolation – reduces artifacts due to changing structure in z-axis
- interpolation averages data on either side of the reconstruction position to estimate projection at that point
CT technique

**EXERCISE**

- give the effects in patient dose, scan time, and image quality when using
  - a pitch <1
  - a pitch > 1
CT technique

image processing

- **pixel** (picture element) is the basic 2D element of the digital image.
- Each pixel displays brightness information concerning the patient’s anatomy that is located in the corresponding **voxel** (volume element).
- The pixel width and height are equal to the voxel width and height.
- The voxel has a third dimension that represents the slice thickness of the CT scan.
**CT technique**

**CT scanning – reconstruction parameters**

- reconstruction field of view (FOV, 10-50 cm) – total image size in x and y directions
- reconstruction matrix (usually 512x512) – image resolution
- convolution kernel / reconstruction filter – variety of reconstruction settings emphasize different characteristics in the CT image, offering tradeoffs between spatial resolution and noise
  - bone algorithm - fine detail but with increased noise
  - soft tissue filters - smoothing, which decreases image noise but also decreases spatial resolution
CT technique

CT scanning – convolution kernels
CT technique

CT scanning – convolution kernels
CT technique

CT scanning – convolution kernels
CT technique

CT scanning – reconstruction parameters

- isotropic resolution = all sides of the voxel have equal dimensions, which results in better reconstructions and lower artifacts in 3D

- flexible image reconstruction – data from more than one detector row can be summed to reconstruct wider slices:
  - native acquisition 256 slices / 0.625 mm
  - standard head 32 slices / 5 mm
  - thin slice head 160 slices / 1 mm
CT technique

image processing

- CT reconstruction process results in a 2D matrix of floating point numbers in the computer which range from near 0.0 to 1.0
- these numbers correspond to the average linear attenuation coefficient of the tissue contained in each voxel
- The CT images are normalized and truncated to integer values that encompass 4096 values, between -1000 and 3095 (typically)
- CT numbers are rescaled linear attenuation coefficients
CT technique

CT numbers = Hounsfield Units

CT technique

image processing

- CT numbers and hence CT images derive their contrast mainly from the physical properties of tissue that influence Compton scatter
  - the linear attenuation coefficient tracks linearly with density of tissue and plays the dominant role in forming contrast in medical CT

- CT numbers are quantitative,
  - pulmonary nodules that are calcified are typically benign, and amount of calcification can be determined from the mean CT number of the nodule
  - CT is also quantitative in terms of linear dimensions and can be used to accurately access tumor volume or lesion diameter
CT technique

EXERCISE

Why do CT images offer higher contrast than plain films?
**CT technique**

**EXERCISE**

Why do CT images offer higher contrast than plain films?

CT images offer high contrast due to the imaging principle where the contrast depends on local differences in attenuation unlike conventional radiography where signal is a sum of all signal contributions along a ray from x-ray source.

CT technique

image processing

- computer monitors and laser imagers for printing have about 8 bits of display fidelity ($2^8 = 256$)
- the 12-bit CT images must be reduced to 8 bits to accommodate most image display hardware
- the window width ($W$) determines the contrast of the image, with narrower windows resulting in greater contrast
- the level ($L$) is the CT number at the center of the window
CT technique

image processing – window settings

CT technique

image processing – window settings
CT technique

image processing – window settings

W 2700
C 700
CT technique

image processing – window settings
CT technique

image processing

- multiplanar reformatting (MPR) is a method for generating coronal, sagittal, or oblique images from the original axial image data.
- The in-plane pixel dimensions approximate the x-y axis resolution, but the slice thickness limits the z-axis resolution.
CT technique

image processing

- multiplanar reformatting (MPR)
CT technique

image processing

- oblique reformatting is quite similar to sagittal or coronal reformatting, except that the CT voxels in the stack are sampled along an axis that is tilted from either the x or y planes.
CT technique

- image processing
  - oblique reformatting
CT technique

image processing

- curved reformatting
CT technique

image processing

- curved reformatting
CT technique

image processing

- reformatting
  - maximum-intensity projection (MIP)
  - minimum-intensity projection (miniIP)
CT technique

image processing
CT technique

image processing

- adjustable slab thickness
CT technique

image processing

- adjustable slab thickness
CT technique

- image processing
  - volume rendering
CT technique

image processing

- surface rendering, virtual endoscopy
CT basic applications
CT basic applications

brain imaging – stroke
CT basic applications

brain imaging – injury, tumor, infection
CT basic applications

spine – injury, degenarive disease
CT basic applications

chest – injury, cancer,
CT basic applications

abdomen – injury, cancer
CT basic applications

vascular imaging – aorta, carotids
CT basic applications

vascular imaging – renal graft
CT basic applications

bone – injury
CT – contraindications

- to x-ray imaging
- to iodinated contrast media
- inability to hold on the exam (dyspnea, tremor, children)
- lacking indications
CT – complications

complications

- x-rays
- contrast media
CT advanced applications
CT advanced applications

**Perfusion CT**

- Perfusion imaging
  - rBF
  - rBV
  - TTP
  - MTT
  - PS

**Physiological Functions:**
- Blood Flow, Blood Volume
- Permeability
- Mean Transit Time

**Protocol**
- Position 4 sections over region
- Set up low mAs technique
- No table motion
- Begin acquisition just before IV contrast initiation
- Acquire images at same position over time (1 per second for 30-60 seconds)
CT technique 59
CT advanced applications

cardiac CT

Retrospective ECG-gated Helical

Prospective ECG-triggered Axial

A

B

C
CT advanced applications
CT advanced applications
CT advanced applications
CT advanced applications
CT advanced applications
CT advanced applications

- Wall motion
- Wall thickening
- ED wall thickness
CT advanced applications

advances in CT technology

- wide detector panels
- z-flying focal spot
- dual-source CT
- dual-energy CT
- PET-CT
CT advanced applications

advances in CT technology

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CT advanced applications

CT fluoroscopy

- the scanner provides pseudo-real time tomographic images that are most commonly used for guidance during biopsies
- the CT image is constantly updated to include the latest projection data
- images are displayed on a monitor in the cine mode
- low tube currents (20 to 50 mA) used to minimize dose
CT artifacts
CT artifacts

- **physics-based artifacts** – result from the physical processes involved in the acquisition of CT data
- **patient-based artifacts** – caused by such factors as patient movement or the presence of metallic materials in or on the patient
- **scanner-based artifacts** – result from imperfections in scanner function
CT artifacts

physics-based artifacts

beam hardening – x-ray beam is composed of individual photons with a range of energies. As the beam passes through an object, it becomes “harder,” that is to say its mean energy increases, because the lower-energy photons are absorbed more rapidly than the higher-energy photons.
**CT artifacts**

**physics-based artifacts**

**partial volume artifacts** – caused by a mixture of tissues with very different attenuation coefficients within any given voxel, resulting in tissue shading
CT artifacts

physics-based artifacts

 photon starvation – can occur in highly attenuating areas such as the shoulders. When the x-ray beam is traveling horizontally, the attenuation is greatest and insufficient photons reach the detectors. The result is that very noisy projections are produced at these tube angulations. The reconstruction process has the effect of greatly magnifying the noise, resulting in horizontal streaks in the image.
CT artifacts

**patient-based artifacts**

**metallic artifacts** – severe streaking artifacts that occur because the density of the metal is beyond the normal range that can be handled by the computer, resulting in incomplete attenuation profiles.
CT artifacts

**patient-based artifacts**

**motion artifacts** – patient motion can cause misregistration artifacts, which usually appear as shading or streaking in the reconstructed image
CT artifacts

scanner-based artifacts

ring artifacts – the detector gives a consistently erroneous reading at each angular position when one of the detectors is out of calibration
CT radiation dose
CT radiation dose

rationale

- 1 person / 1000 would develop cancer from 10 mSv (abdomen CT)

Committee to assess health risks from exposure to low levels of ionizing radiation. Washington DC
CT radiation dose

basics

- beam energy 120-140 kVp vs. low-dose imaging
- photon fluence – radiation dose is directly proportional to the milliampere-seconds value

<table>
<thead>
<tr>
<th>Beam Energy (kVp)</th>
<th>CTDI&lt;sub&gt;w&lt;/sub&gt; in Head Phantom (mGy)</th>
<th>CTDI&lt;sub&gt;w&lt;/sub&gt; in Body Phantom (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>14</td>
<td>5.8</td>
</tr>
<tr>
<td>100</td>
<td>26</td>
<td>11</td>
</tr>
<tr>
<td>120</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>140</td>
<td>55</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tube Current–Time Product (mAs)</th>
<th>CTDI&lt;sub&gt;w&lt;/sub&gt; in Head Phantom (mGy)</th>
<th>CTDI&lt;sub&gt;w&lt;/sub&gt; in Body Phantom (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>13</td>
<td>5.7</td>
</tr>
<tr>
<td>200</td>
<td>26</td>
<td>12</td>
</tr>
<tr>
<td>300</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>400</td>
<td>53</td>
<td>23</td>
</tr>
</tbody>
</table>

CT radiation dose

basics

- pitch value (table distance traveled in one 360° rotation/total collimated width of the x-ray beam) has a direct influence on patient radiation dose. As pitch increases, the time that any one point in space spends in the x-ray beam is decreased.

- beam collimation

<table>
<thead>
<tr>
<th>Pitch</th>
<th>CTDI_{vol} in Head Phantom (mGy)</th>
<th>CTDI_{vol} in Body Phantom (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>80</td>
<td>36</td>
</tr>
<tr>
<td>0.75</td>
<td>53</td>
<td>24</td>
</tr>
<tr>
<td>1.0</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>1.5</td>
<td>27</td>
<td>12</td>
</tr>
<tr>
<td>2.0</td>
<td>20</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Collimation (mm)</th>
<th>Total Beam Width (mm)</th>
<th>CTDI_{w} in Head Phantom (mGy)</th>
<th>CTDI_{w} in Body Phantom (mGy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 × 1.25</td>
<td>5</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>2 × 2.5</td>
<td>5</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>1 × 5</td>
<td>5</td>
<td>62</td>
<td>33</td>
</tr>
<tr>
<td>4 × 2.5</td>
<td>10</td>
<td>46</td>
<td>24</td>
</tr>
<tr>
<td>2 × 5</td>
<td>10</td>
<td>46</td>
<td>24</td>
</tr>
<tr>
<td>4 × 5</td>
<td>20</td>
<td>40</td>
<td>20</td>
</tr>
</tbody>
</table>

patient size – when the same technical parameters are used, the appropriate index shows that the smaller object always absorbs the higher dose and that the difference is at least a factor of two

z-axis coverage

scanner dose-reducing systems (tube current modulation, automatic mAs settings, iterative reconstructions)

CT radiation dose

measures

- weighted CTDI
  - x-ray beam often passes directly into the entire surface of the patient’s body
  - primary x-ray beam contains the most photons and is most attenuated by the patient tissue
  - energy delivered to the patient is higher at the skin surface than in the center of the body, even though the x-ray beams from all the way around the gantry pass through the center of the body.
CT radiation dose

measures

- volume CTDI
  - CTDI adjusted for pitch (the gap or overlap of the helical pattern of radiation) = CTDI\textsubscript{w} divided by the pitch
  - scan with a pitch less than 1 would therefore have a CTDI\textsubscript{vol} value larger than the CTDI\textsubscript{w} value
  - scans with a pitch greater than 1 would have a CTDI\textsubscript{vol} value smaller than the CTDI\textsubscript{w} value
CT radiation dose

measures

- dose-length product
  - DLP is calculated to account for the differences in the scan extent for a CT examination
  - the risk of radiation-induced damage to patient tissues increases with the volume of body scanned
  - DLP is calculated by multiplying $\text{CTDI}_{\text{vol}}$ in Gy by the scan extent in cm
CT radiation dose

**measures**

- kVp not only controls the image contrast but also controls the amount of penetration that the x-ray beam will have as it traverses the patient

<table>
<thead>
<tr>
<th></th>
<th>80 kVp</th>
<th>120 kVp</th>
<th>140 kVp</th>
</tr>
</thead>
<tbody>
<tr>
<td>image contrast</td>
<td>best</td>
<td>intermediate</td>
<td>poor</td>
</tr>
<tr>
<td>noise</td>
<td>most</td>
<td>average</td>
<td>least</td>
</tr>
<tr>
<td>penetration</td>
<td>least</td>
<td>average</td>
<td>most</td>
</tr>
<tr>
<td>patient dose</td>
<td>lowest</td>
<td>intermediate</td>
<td>highest</td>
</tr>
</tbody>
</table>
CT radiation dose

- kVp not only controls the image contrast but also controls the amount of penetration that the x-ray beam will have as it traverses the patient
CT radiation dose

- kVp not only controls the image contrast but also controls the amount of penetration that the x-ray beam will have as it traverses the patient.

<table>
<thead>
<tr>
<th>mAs</th>
<th>CTDI$_w$ head</th>
<th>CTDI$_w$ body</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>13 mGy</td>
<td>6 mGy</td>
</tr>
<tr>
<td>200</td>
<td>26 mGy</td>
<td>12 mGy</td>
</tr>
<tr>
<td>300</td>
<td>40 mGy</td>
<td>18 mGy</td>
</tr>
<tr>
<td>400</td>
<td>53 mGy</td>
<td>23 mGy</td>
</tr>
</tbody>
</table>
CT radiation dose

doses

Table 3
European Guidelines for the Diagnostic Reference Levels in Various CT Examinations

<table>
<thead>
<tr>
<th>Examination</th>
<th>CTDIw (mGy)</th>
<th>DLP (mGy × cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Routine head</td>
<td>60</td>
<td>1060</td>
</tr>
<tr>
<td>Face and sinuses</td>
<td>35</td>
<td>360</td>
</tr>
<tr>
<td>Vertebral trauma</td>
<td>70</td>
<td>460</td>
</tr>
<tr>
<td>Routine chest</td>
<td>30</td>
<td>650</td>
</tr>
<tr>
<td>High-resolution CT (lung)</td>
<td>35</td>
<td>280</td>
</tr>
<tr>
<td>Routine abdomen</td>
<td>35</td>
<td>780</td>
</tr>
<tr>
<td>Liver and spleen</td>
<td>35</td>
<td>900</td>
</tr>
<tr>
<td>Routine pelvis</td>
<td>35</td>
<td>570</td>
</tr>
<tr>
<td>Osseous pelvis</td>
<td>25</td>
<td>520</td>
</tr>
</tbody>
</table>

Source.—Reference 18.
Note.—CTDIw = weighted CT dose index, mGy = milligrays.

CT radiation dose

**recommendations**

- Patient size – relative dose more for smaller patients (Am Coll Radiol)
  - pediatric abdomen CT (5 yr old) < 25 mGy
  - adult abdomen CT < 30 mGy

- FDA notice: for pediatric and small patients
  - reduce tube mA (current)
  - increase pitch
  - develop mA settings based on patient weight or diameter and body region
  - reduce number of multiple scans without contrast
  - eliminate inappropriate referrals for CT
CT radiation dose

**trade-offs**

- decrease mA or current → increase noise
- increase pitch → increase volume averaging
- increase axial increment → introduce gaps

<table>
<thead>
<tr>
<th></th>
<th>eff. dose (mSV)</th>
<th>no. of chest x-rays</th>
<th>period of background radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>chest x-ray</td>
<td>0.1</td>
<td>1</td>
<td>12 d</td>
</tr>
<tr>
<td>mmg</td>
<td>0.4</td>
<td>4</td>
<td>1.6 mo</td>
</tr>
<tr>
<td>abdomen x-ray</td>
<td>0.7</td>
<td>7</td>
<td>3 mo</td>
</tr>
<tr>
<td>chest CT</td>
<td>5-7</td>
<td>50-70</td>
<td>1.6-2.3 y</td>
</tr>
<tr>
<td>abdomen CT</td>
<td>8-11</td>
<td>80-110</td>
<td>2.6-3.6 y</td>
</tr>
</tbody>
</table>
CT radiation dose

**EXERCISE**

- How to reduce the patient dose without decreasing image quality?