AAPM Computed Tomography Radiation Dose Education Slides

Many of the terms used in these slides can be found in the CT Terminology Lexicon

http://www.aapm.org/pubs/CTProtocols/documents/CTTerminologyLexicon.pdf

Last updated: 18 November 2013

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Motivation

- These slides are provided to aid in understanding the factors that affect radiation dose in CT studies
- Image patients wisely and gently
  - A CT study should use as little radiation as possible, while still meeting the image quality needs of the exam
  - A CT study that is non-diagnostic because the radiation dose is too low may require rescanning the patient – increasing the total patient dose

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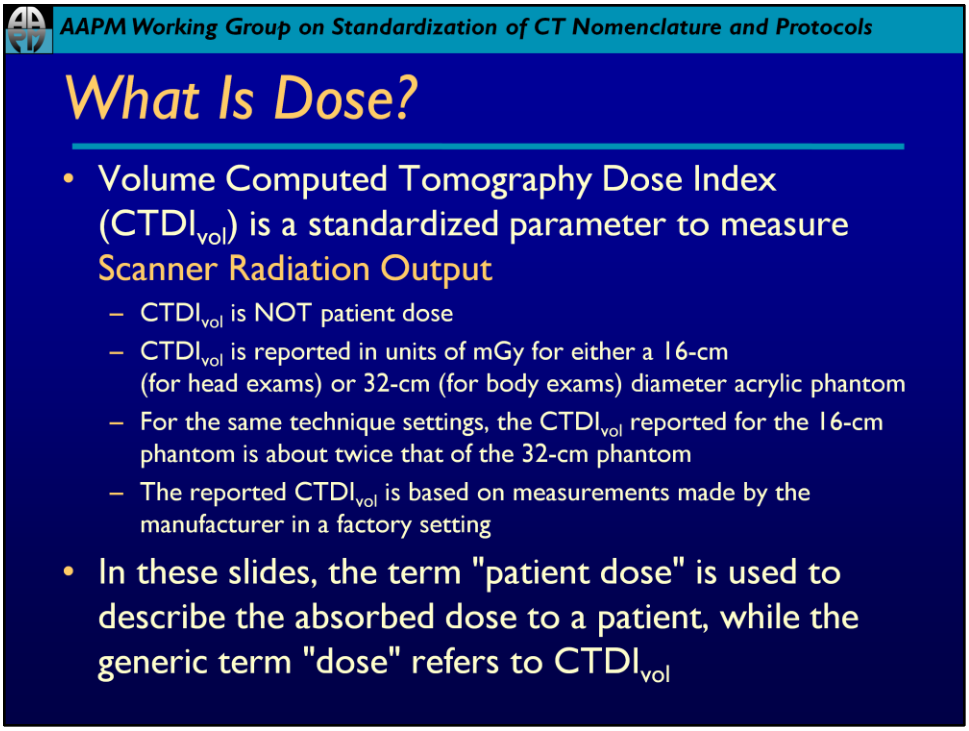
Outline

- What is Dose?
- Acquisition Parameter Settings
- Dose Modulation and Reduction
- Dose Display



1. Bauhs, J. A., Vrieze, T. J., Primak, A. N., Bruesewitz, M. R., & McCollough, C. H. (2008). CT Dosimetry: Comparison of Measurement Techniques and Devices1. *Radiographics*, *28*(1), 245-253. doi:10.1148/rg.281075024
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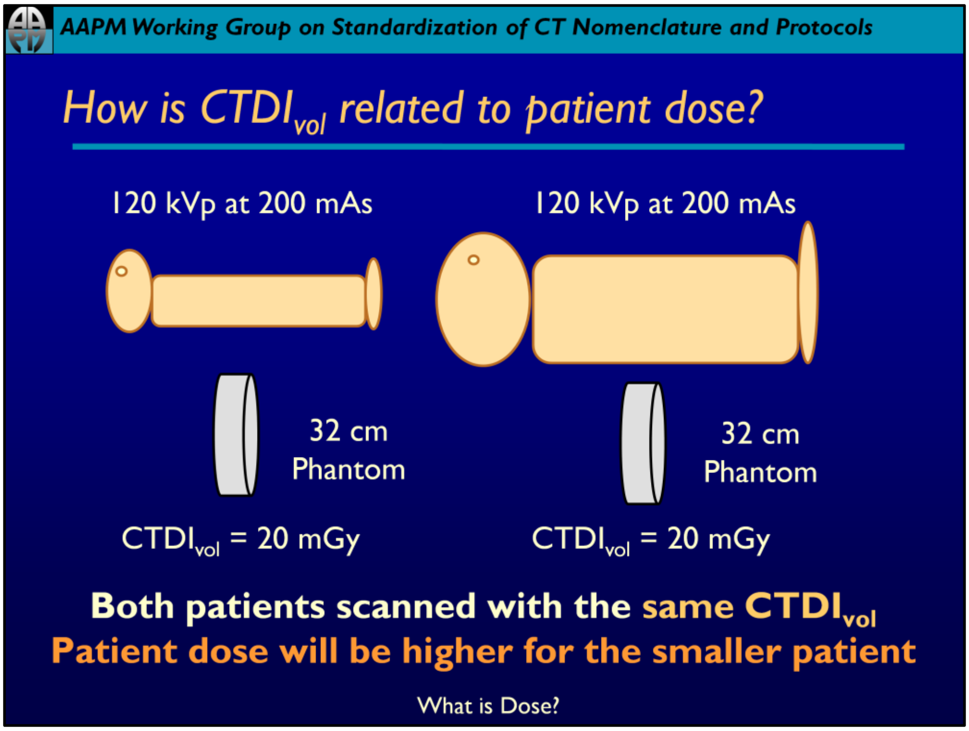
AAPM Working Group on Standardization of CT Nomenclature and Protocols

How is $CTDI_{vol}$ related to patient dose?

- $CTDI_{vol}$ is not patient dose
- The relationship between the two depends on many factors, including patient size and composition
- AAPM Report 204 introduces a parameter known as the Size Specific Dose Estimate (SSDE) to allow estimation of patient dose based on $CTDI_{vol}$ and patient size
- For the same $CTDI_{vol}$, a smaller patient will tend to have a higher patient dose than a larger patient

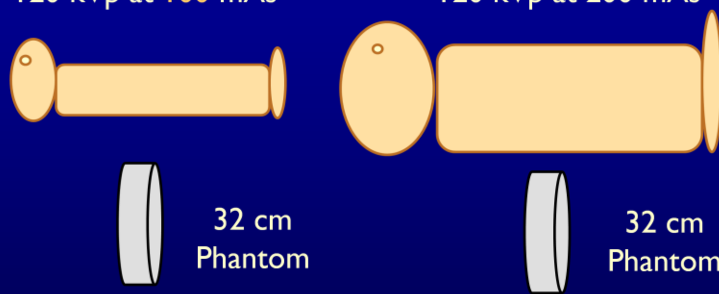
What is Dose?

http://www.aapm.org/pubs/reports/RPT_204.pdf


AAPM Working Group on Standardization of CT Nomenclature and Protocols
How is CTDIvol related to patient dose?
120 kVp at 200 mAs
120 kVp at 200 mAs
32 cm Phantom
32 cm Phantom
CTDIvol = 20 mGy
CTDIvol = 20 mGy
Both patients scanned with the same CTDIvol
Patient dose will be higher for the smaller patient
What is Dose?

How is $CTDI_{vol}$ related to patient dose?

120 kVp at 100 mAs | 120 kVp at 200 mAs



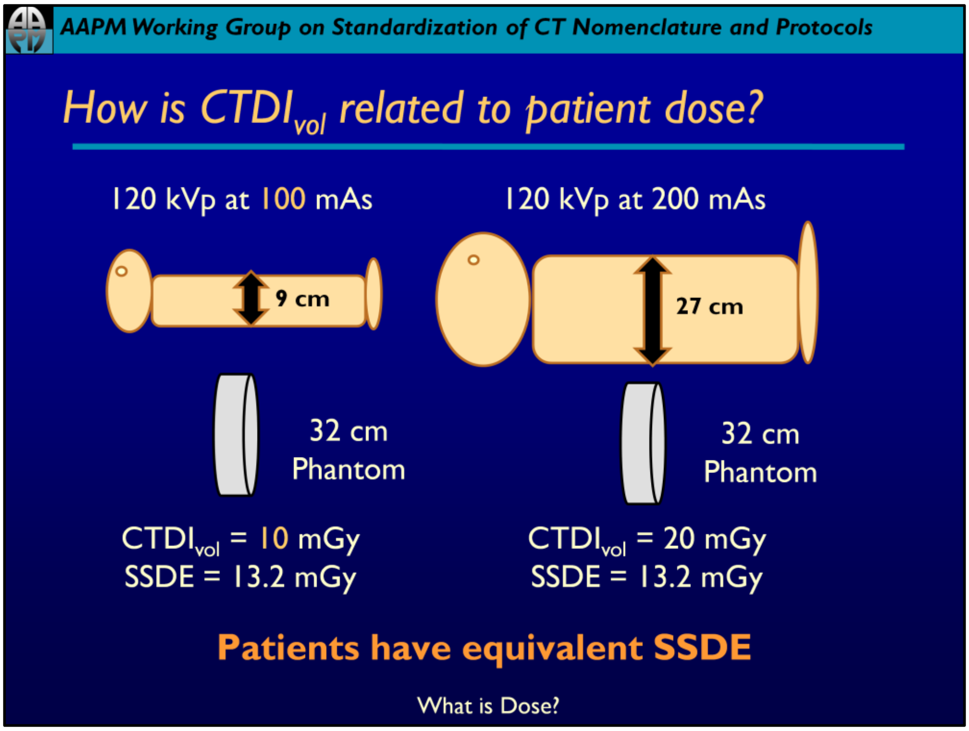
$CTDI_{vol}$ = 10 mGy | $CTDI_{vol}$ = 20 mGy

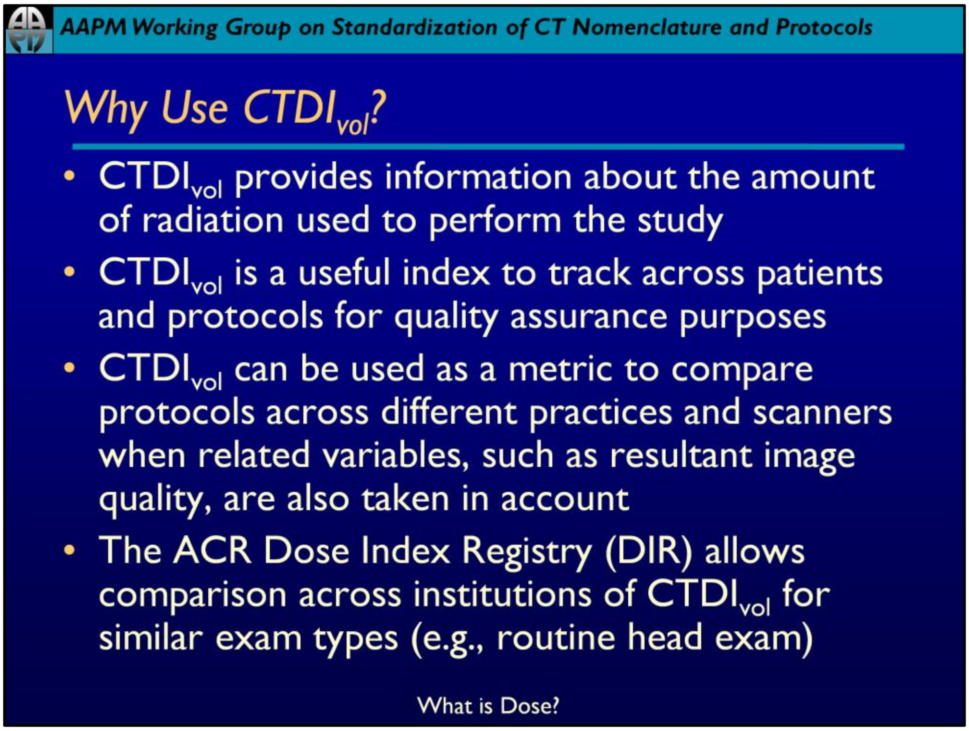
Smaller patient scanned with a lower $CTDI_{vol}$

Patient doses will be approximately equal

Size Specific Dose Estimate (SSDE)

- AAPM report 204 describes a method to calculate SSDE using $CTDI_{vol}$
- Conversion factors based on patient size (e.g., AP or lateral width, effective diameter) are provided to estimate patient dose for a patient of that size
- However, SSDE is still not the exact patient dose, as factors such as scan length and patient composition may differ from the assumptions used to calculate SSDE
- SSDE is not dose to any specific organ, but rather the mean dose in the center of the scanned volume


AAPM Working Group on Standardization of CT Nomenclature and Protocols
How is CTDIvol related to patient dose?
120 kVp at 100 mAs
120 kVp at 200 mAs
9 cm
27 cm
32 cm Phantom
32 cm Phantom
CTDIvol = 10 mGy
SSDE = 13.2 mGy
CTDIvol = 20 mGy
SSDE = 13.2 mGy
Patients have equivalent SSDE
What is Dose?



1. McCollough, C. H., Leng, S., Yu, L., Cody, D. D., Boone, J. M., & McNitt-Gray, M. F. (2011). CT Dose Index and Patient Dose: They are Not the Same Thing, EDITORIAL, Radiology *259*(2), 311-316.

Dose Length Product

- The Dose Length Product (DLP) is also calculated by the scanner
- DLP is the product of the length of the irradiated scan volume and the average $CTDI_{vol}$ over that distance
- DLP has units of mGy*cm

Useful Concepts/Terms

- The relationships between acquisition parameters and $CTDI_{vol}$ described in the following slides assume all other parameters are held constant
- The relationship between a parameter and $CTDI_{vol}$ is often described as **proportional** in some way
  - The symbol $\propto$ is used to indicate "proportional to"
- Directly proportional means that a change in the parameter results in the same change in $CTDI_{vol}$
  - Example: Doubling the rotation time from 0.5 to 1.0 seconds will double the $CTDI_{vol}$
- Inversely proportional means that a change in a parameter has the opposite effect on $CTDI_{vol}$
  - Example: Doubling the pitch from 1 to 2 will reduce the $CTDI_{vol}$ by half

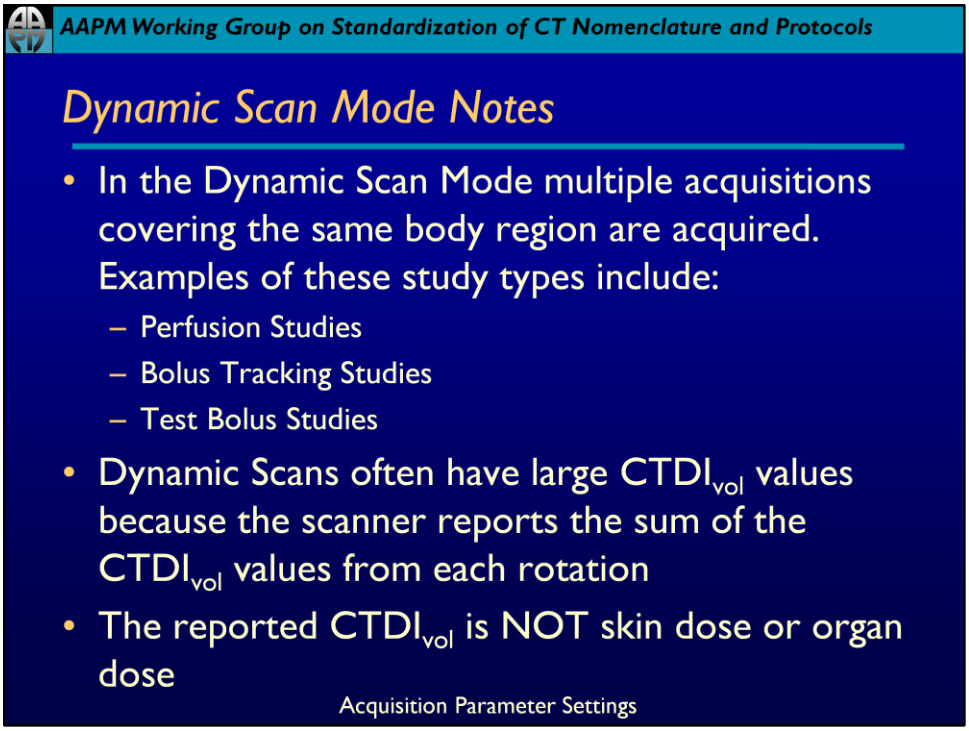
Acquisition Parameter Settings

- Acquisition Parameters define the technique that will be used and how the scan will proceed
- Acquisition Parameters are set in the user interface where scans are prescribed
- Changing a single Acquisition Parameter while holding everything else constant will typically affect the $CTDI_{vol}$ for that scan
- The following slides describe what that affect is for each parameter

Scan Mode

- CT Scanners offer a variety of Scan Modes which describe how the table moves during an exam
- Scan Modes include
  - Axial
  - Helical or Spiral
  - Dynamic

The Acquisition Parameters that affect CTDIvol may change amongst different Scan Modes



1. Bauhs, J. A., Vrieze, T. J., Primak, A. N., Bruesewitz, M. R., & Mccollough, C. H. (2008). CT Dosimetry : Comparison of Measurement Techniques and Devices. *Radiographics*, *28*(1), 245-254.
2. Zhang, D., Cagnon, C. H., Villablanca, J. P., McCollough, C. H., Cody, D. D., Stevens, D. M., Zankl, M., et al. (2012). Peak Skin and Eye Lens Radiation Dose From Brain Perfusion CT Based on Monte Carlo Simulation. *American Journal of Roentgenology*, *198*(2), 412-417.

Table Feed/Increment

- Is the movement of the table through the bore of the scanner over a full 360 degree rotation
- Units: millimeters/rotation or millimeters/second
- The parameter is known both as Table Feed (helical/spiral acquisition) & Table Increment (axial acquisition)

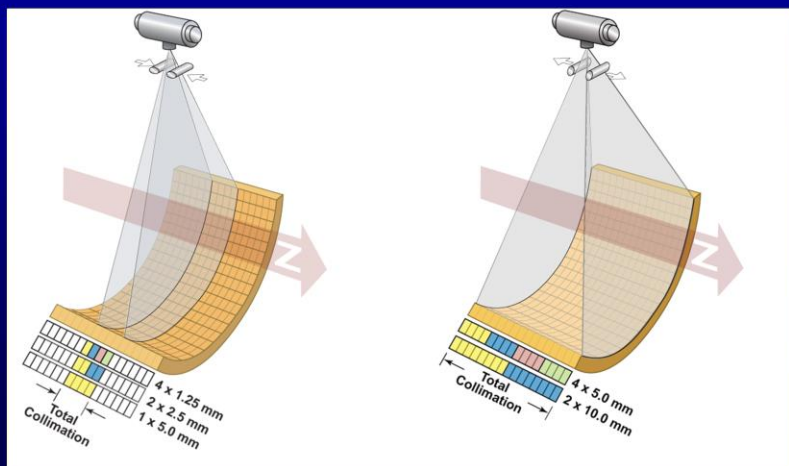
Table Feed affects $CTDI_{vol}$ through its inclusion in Pitch (discussed later)

Detector Configuration

- Is the combination of the number of data channels and the width of the detector associated with each data channel
- The Detector Configuration determines the Beam Width or Beam Collimation (nT), which is the number of channels (n) times the detector width associated with each data channel (T)
- For a selected detector width per data channel, a smaller total Beam Collimation usually has a higher $CTDI_{vol}$ than a larger Beam Collimation
  - Example: On a 16 slice scanner with a detector width per channel of 1.25 mm, a collimation of 4x1.25mm is generally less dose efficient than a collimation of 16x1.25mm

Users should monitor $CTDI_{vol}$ values when changing detector configuration

Detector Configuration



Pitch

- Is the Table Feed per gantry rotation divided by the beam width/collimation
- Pitch is the ratio of two distances and therefore has no units
- Users should monitor other parameters when changing Pitch. The scanner may or may not automatically compensate for changes in Pitch (for example, by changing the tube current) to maintain the planned $CTDI_{vol}$.

$CTDI_{vol} \propto 1/\text{Pitch}$:

Hitachi, Toshiba (no AEC)

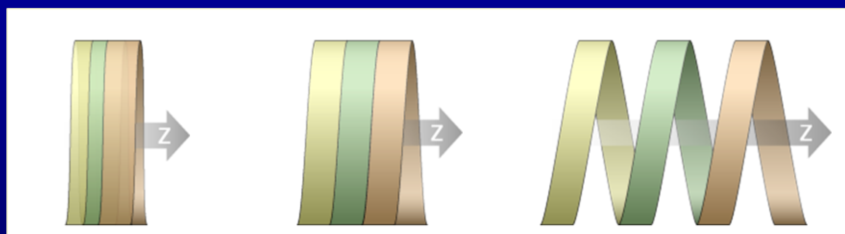
$CTDI_{vol}$ independent of Pitch:

GE, Siemens, Philips, Neusoft, Toshiba (AEC)

Pitch

- $CTDI_{vol}$ may not change in the expected manner if the scanner automatically adjust other parameters when the pitch is changed
- The relationships between CTDIvol and pitch for the different vendors are described below
  - $CTDI_{vol}$ inversely proportional to change in pitch: Hitachi, NeuroLogica
  - $CTDI_{vol}$ constant when pitch is changed due to changes to other parameters: GE, Neusoft, Philips and Siemens
  - The relationship between $CTDI_{vol}$ and pitch depends on scan mode or Software version: Toshiba

Pitch



Pitch < 1
Beam Width has some overlap at each view angle from rotation to rotation

Pitch = 1
No overlap of Beam Width at each view angle and no view angles not covered at certain table positions

Pitch > 1
Some view angles are not covered by the beam width at certain table positions

Exposure Time per Rotation

- Is the length of time, in seconds, that the X-ray beam is "on" during a gantry rotation
  - It takes into account the gantry rotation time and angular acquisition range
- Units: seconds
- Users should monitor other parameters when changing Exposure Time per Rotation. The scanner may or may not automatically compensate for changes in Exposure Time per Rotation(for example, by changing the tube current)

$CTDI_{vol} \propto$ Exposure Time per Rotation

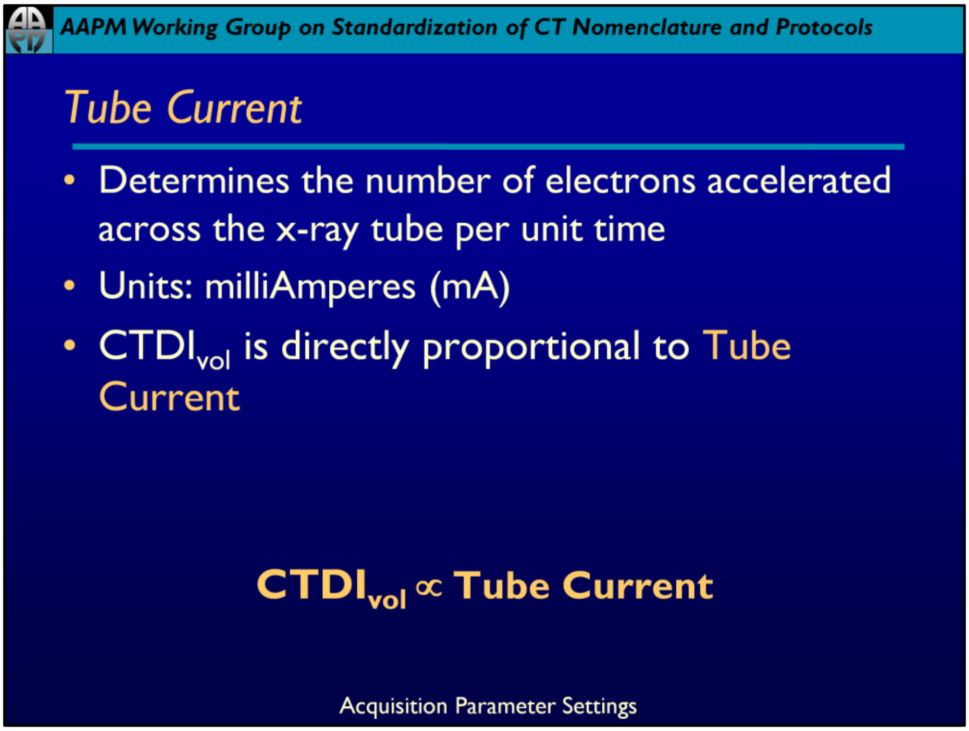
Hitachi, NeuroLogica, Toshiba (no AEC)

$CTDI_{vol}$ independent of Exposure Time per Rotation:

GE, Siemens, Philips, Neusoft, Toshiba (AEC)

Exposure Time per Rotation

- $CTDI_{vol}$ may not change in the expected manner if the scanner automatically adjust other parameters when the exposure time per rotation is changed
- The relationships between CTDIvol and exposure time per rotation for the different vendors are described below
  - $CTDI_{vol}$ proportional to change in parameter: Hitachi and NeuroLogica
  - $CTDI_{vol}$ constant when the parameter is changed due to changes to other parameters: GE, Neusoft, Philips and Siemens
  - The relationship between $CTDI_{vol}$ and the parameter depends on scan mode or Software version: Toshiba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Tube Current
• Determines the number of electrons accelerated across the x-ray tube per unit time
• Units: milliAmperes (mA)
• $CTDI_{vol}$ is directly proportional to Tube Current
$CTDI_{vol} \propto$ Tube Current
Acquisition Parameter Settings

Tube Potential

- Is the electrical potential applied across the x-ray tube to accelerate electrons toward the target material
- Units: kiloVolts (kV or kVp)
- $CTDI_{vol}$ is **approximately** proportional to the square of the percentage change in Tube Potential

$$CTDI_{vol} \propto \left(\frac{kV_{new}}{kV_{old}} \right)^{n}$$

n ≈ 2 to 3

Tube Current Time Product

- Is the product of Tube Current and the Exposure Time per Rotation
- Units: milliAmpere-seconds (mAs)
- $CTDI_{vol}$ is directly proportional to Tube Current Time Product

$CTDI_{vol} \propto$
Tube Current Time Product

Effective Tube Current Time Product

- Is the product of the Tube Current and the Exposure Time per Rotation divided by the Pitch
- Units: milliAmpere-Seconds (mAs)
- $CTDI_{vol}$ is directly proportional to Effective Tube Current Time Product

$$CTDI_{vol} \propto \text{Effective Tube Current Time Product}$$

Field Of Measurement

- Is the diameter of the primary beam in the axial plane at the gantry iso-center
- Units: millimeters (mm)
- $CTDI_{vol}$ may decrease with a decrease in the Field of Measurement
  - The relationship is vendor specific

Users should monitor the $CTDI_{vol}$ values when changing the Field of Measurement

Beam Shaping Filter

- Is the scanner component that modifies the energy spectrum and spatial distribution of the primary beam
- Beam Shaping may include a bow tie filter and/or flat filters
- $CTDI_{vol}$ is affected by a change in Beam Shaping Filters
  - The relationship is vendor and filter specific

Users should monitor $CTDI_{vol}$ values when changing the Beam Shaping Filter

Acquisition Parameter Settings Summary

Parameter	Relationship to $CTDI_{vol}$
Scan Mode	Changes in the Scan Mode may affect $CTDI_{vol}$
Table Feed/Increment	Table Feed affects $CTDI_{vol}$ through its inclusion in Pitch
Detector Configuration	Decreasing the Beam Collimation typically, but not always, increases the $CTDI_{vol}$
Pitch	$CTDI_{vol}$ relationship to pitch is vendor dependent
Exposure Time Per Rotation	$CTDI_{vol}$ relationship to exposure time per rotation is vendor dependent
Tube Current	$CTDI_{vol} \propto$ Tube Current
Tube Potential	$CTDI_{vol} \propto (kVp_1/kVp_2)^n$ n ~ 2 to 3
Tube Current Time Product	$CTDI_{vol} \propto$ Tube Current Time Product
Effective Tube Current Time Product	$CTDI_{vol} \propto$ Effective Tube Current Time Product
Field of Measurement	Changes in the Field of Measurement may affect $CTDI_{vol}$
Beam Shaping Filter	Changes in the Beam Shaping Filter may affect $CTDI_{vol}$

Dose Modulation and Reduction

- Many CT scanners automatically adjust the technique parameters (and as a result the $CTDI_{vol}$) to achieve a desired level of image quality and/or to reduce dose
- Dose Modulation and Reduction techniques vary by scanner manufacturer, model and software version

Automatic Exposure Control (AEC)

- Automatically adapts the Tube Current or Tube Potential according to patient attenuation to achieve a specified image quality
  - Automatic adjustment of Tube Current may not occur when Tube Potential is changed
  - **Centering the patient in the gantry is VITAL for most AEC systems**
- AEC aims to deliver a specified image quality across a range of patient sizes. It tends to increase $CTDI_{vol}$ for large patients and decrease it for small patients relative to a reference patient size

The use of Automatic Exposure Control may decrease or increase $CTDI_{vol}$ depending on the patient size and body area imaged and image quality requested

Image Quality Reference Parameter

- Is the AEC parameter that is set by the user to define the desired level of image quality
- Changing the Image Quality Reference Parameter will affect the $CTDI_{vol}$

The effect on $CTDI_{vol}$ when changing the Image Quality Reference Parameter is vendor dependent

Image Quality Reference Parameter

- A change in the Image Quality Reference Parameter will affect the $CTDI_{vol}$
- Setting the parameter for "increased" image quality (e.g., lower noise) will result in more dose
- Setting the parameter for "decreased" image quality (e.g., more noise) will result in less dose

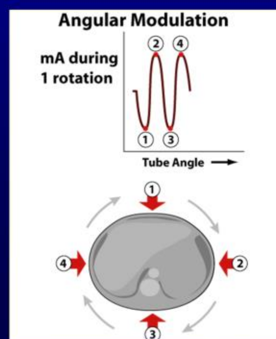
Angular Tube Current Modulation

- Is an AEC feature that adjusts the Tube Current as the x-ray tube rotates around the patient to compensate for attenuation changes with view angle
- Angular Tube Current Modulation is used to adjust the Tube Current to attempt to deliver similar dose to the detector at all view angles

The use of Angular Tube Current Modulation may decrease or increase $CTDI_{vol}$ depending on the patient size and body area imaged and image quality requested

Angular Tube Current Modulation

- Angular Tube Current Modulation uses information from one or two view localizers



Dose Modulation and Reduction

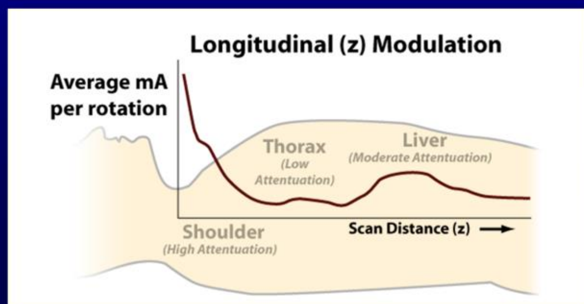
Longitudinal Tube Current Modulation

- Is an AEC feature that adjusts the Tube Current as patient attenuation changes in the longitudinal direction
- The CT Localizer Radiograph is used to estimate patient attenuation

The use of Longitudinal Tube Current Modulation may decrease or increase $CTDI_{vol}$ depending on the patient size and body area imaged and image quality requested

Longitudinal Tube Current Modulation

- Longitudinal Tube Current Modulation uses information from one or two view localizers

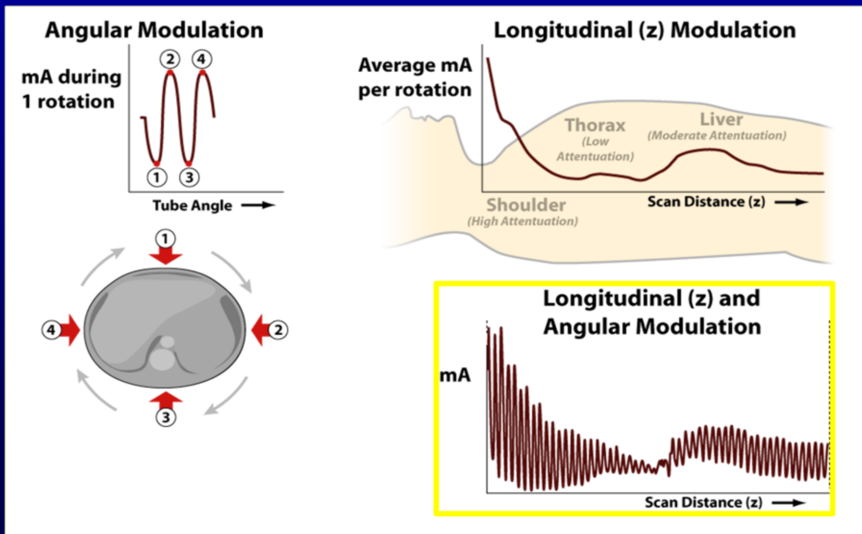


Angular and Longitudinal Tube Current Modulation

- Is an AEC feature that incorporates the properties of both Angular and Longitudinal Tube Current Modulation to
  - Adjust the Tube Current based on the patient's overall attenuation
  - Modulate the Tube Current in the angular (X-Y) and longitudinal (Z) dimensions to adapt to the patient's shape

The use of Angular and Longitudinal Tube Current Modulation may decrease or increase $CTDI_{vol}$ depending on the patient size and body area imaged and image quality requested

Angular and Longitudinal Tube Current Modulation

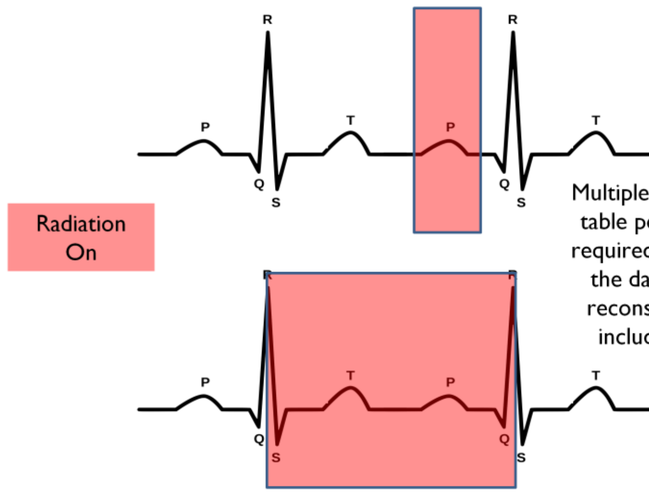


ECG-Based Tube Current Modulation

- Is an AEC feature used with prospectively gated cardiac imaging that adjusts the Tube Current based on the phase within the cardiac cycle
- There are important heart rate considerations to take into account when using prospective gating

The use of ECG-Based Tube Current Modulation with prospective gating will decrease $CTDI_{vol}$ compared to retrospective gating

ECG-Based Tube Current Modulation

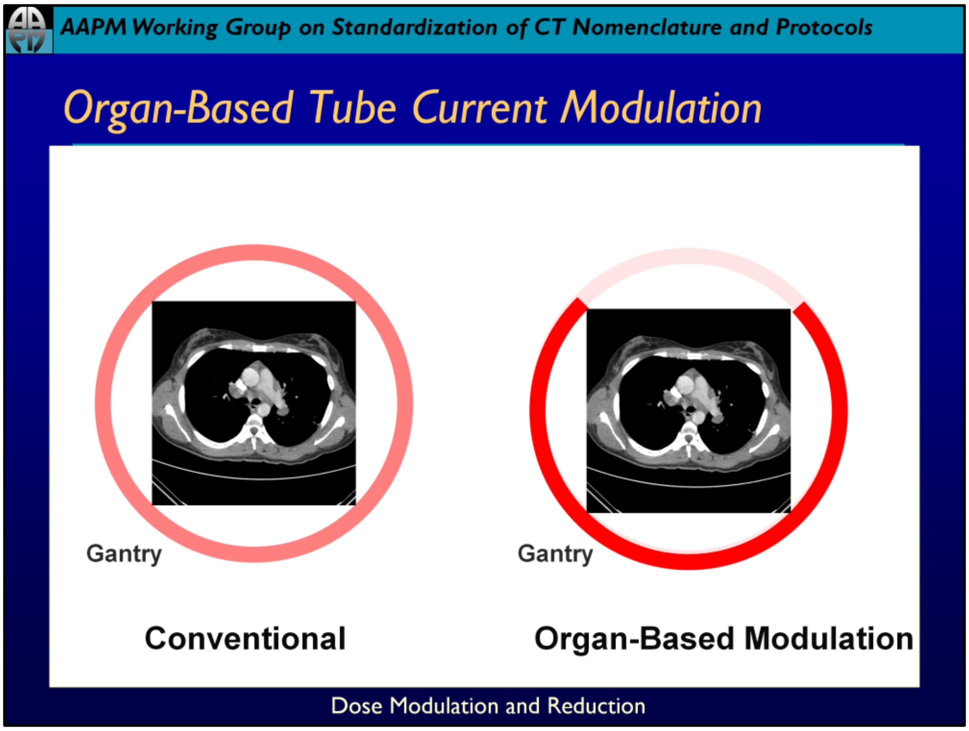


Multiple heart beats and table positions may be required to collect all of the data required to reconstruct the FOV including the heart

Organ-Based Tube Current Modulation

- Is an AEC feature that allows for the tube current to be decreased or turned off over radiosensitive organs on the patient periphery, such as the breasts or eye lenses
- To maintain image quality, tube current may need to be increased at other view angles

The use of Organ-Based Tube Current Modulation may reduce the absorbed dose to organs at the surface of the body but may increase the absorbed dose to other organs



De-Identified Image used with IRB approval

Automatic Tube Potential Selection

- Is an AEC feature that selects the tube potential according to the diagnostic task and patient size in order to achieve the desired image quality at a lower $CTDI_{vol}$

The use of Automatic Tube Potential Selection is intended to decrease $CTDI_{vol}$ while achieving the image quality required for a specific diagnostic task and patient attenuation

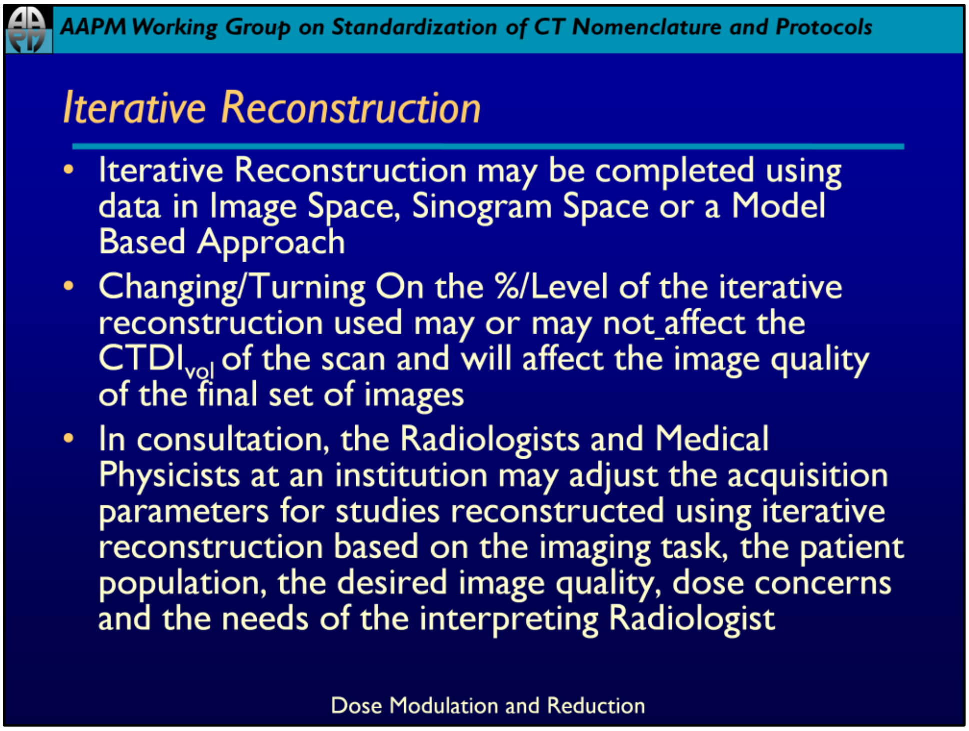
Automatic Tube Potential Selection

- Tube Potential is not modulated in the same fashion as Tube Current
- It does not change with different tube positions (view angles) around the patient
- The Tube Potential for a specific patient, anatomic region and diagnostic tasks is selected and held constant for that acquisition, though it may be changed to a different tube potential for a different diagnostic task

Iterative Reconstruction

- Is a feature that uses the information acquired during the scan and repeated reconstruction steps to produce an image with less "noise" or better image quality (e.g., higher spatial resolution or decreased artifacts) than is achievable using standard reconstruction techniques

The use of Iterative Reconstruction by itself may not decrease $CTDI_{vol}$; with use of Iterative Reconstruction, image quality will change and this may allow a reduction in the $CTDI_{vol}$ by adjusting the acquisition parameters used for the exam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Iterative Reconstruction
• Iterative Reconstruction may be completed using data in Image Space, Sinogram Space or a Model Based Approach
• Changing/Turning On the %/Level of the iterative reconstruction used may or may not affect the $CTDI_{vol}$ of the scan and will affect the image quality of the final set of images
• In consultation, the Radiologists and Medical Physicists at an institution may adjust the acquisition parameters for studies reconstructed using iterative reconstruction based on the imaging task, the patient population, the desired image quality, dose concerns and the needs of the interpreting Radiologist
Dose Modulation and Reduction

Noise Reduction Using Other Post Processing Software

- Other commercially available products can be used to reduce image noise in already reconstructed images
- In consultation, the radiologists and medical physicists may adjust the acquisition parameters to reduce the $CTDI_{vol}$ used for studies that will be processed using these products, taking into consideration the imaging task and patient population, dose concerns, and the needs of the interpreting radiologist(s)

Dose Display

- Information about the $CTDI_{vol}$ planned for each scan is typically displayed before the exam on the user console
- Information about the $CTDI_{vol}$ delivered by each scan is typically reported in a data page or DICOM structured dose report
- Dose information provided after the exam typically also includes the DLP and the CTDI phantom size. These may also be included in information displayed before the scan.

Display of Planned $CTDI_{vol}$

- $CTDI_{vol}$ is displayed before a study is performed based on the selected technique parameters
- It is important to check $CTDI_{vol}$ before a study is performed to ensure that the output of the scanner is appropriate for the specific patient and diagnostic task

$CTDI_{vol}$ is displayed for each planned acquisition

Post Study Data Page

- Following the completion of a study, a Post Study Data Page is created that includes information on the delivered $CTDI_{vol}$ and DLP and the phantom size used to calculate these values
- Information is displayed for each series

Post Study Data Page - $CTDI_{vol}$

- $CTDI_{vol}$ is displayed for each series after a study is performed and is calculated based on the technique factors used to acquire the data
- It is useful to check $CTDI_{vol}$ after a study is performed to ensure that the output of the scanner was as expected

$CTDI_{vol}$ is displayed for each completed acquisition

Post Study Data Page - DLP

- DLP is displayed for each series after a study is performed and is calculated based on the technique factors and scan length used

DLP is displayed for each completed acquisition and is typically summed for all of the acquisitions

Post Study Data Page – CTDI Phantom

- The CTDI Phantom used for each acquisition in the study is typically displayed
- Different phantoms may be used to calculate the $CTDI_{vol}$ for different acquisitions in the same study (and may vary by vendor)
  - Head and C-Spine Example
    - Body Phantom used to report $CTDI_{vol}$ for C-Spine portion of exam
    - Head Phantom used to report $CTDI_{vol}$ for Head portion of exam

Summing Dose Report Values

- $CTDI_{vol}$ values for separate series are NOT to be summed to give a "total" $CTDI_{vol}$ for a study
  - This is especially true if the series cover different anatomic regions
- DLP is typically summed over all series in the Post Study Data Page to provide an estimate of the total patient exposure
  - Extreme care should be taken when considering summed DLPs because different phantoms may have been used to calculate the $CTDI_{vol}$ values used to determine DLP
- A medical physicist should be contacted if patient specific dose estimates are required

Dose Notification Levels

- Notification Levels may be set on a CT scanner for each series within an exam protocol
- If the planned $CTDI_{vol}$ is above the Notification Level and triggers the notification, the user has the opportunity to edit or confirm the technique settings
- Notification Levels may be exceeded when appropriate for a specific patient or diagnostic task (e.g., in very large patients or contrast bolus monitoring scans)

Dose Alert Levels

- Dose Alert Levels require specific action by the operator to continue scanning
- Dose Alert Levels are typically much higher than Notification Levels and take into account all series within the exam
- Triggering a Dose Alert requires that the operator confirm the protocol and settings are correct by entering in his or her name. Optionally, sites may require that the operator provide a brief explanation in the provided field

Radiation Dose Structured Reports

- Radiation Dose Structured Reports (RDSRs) are provided in newer software versions in a defined DICOM format
- They provide the most complete set of information regarding the irradiating events
- The reports are very detailed and require an RDSR viewer for easy visualization of relevant information

Questions

- Please contact the medical physicist providing support for your CT practice, your lead technologist, supervising radiologist or manufacturer's application specialist with questions regarding these important topics and concepts.

AAPM Working Group on Standardization of CT Nomenclature and Protocols

Acknowledgements

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