III. Automatic Tube Current Modulation and Multiple Series

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Learning Objectives

- Understand the principle of automatic tube current modulation schemes.
- Understand the main differences between various implementations.
- Be familiar with the settings of automatic tube current modulation and their impact on dose and image quality.
- Understand why automatic tube current modulation and multiple series are a pain for dose monitoring and tracking.

Automatic Tube Current Modulation

- Why is ATCM needed?
  - Human body is not cylindrical, nor has the same diameter.
  - Image noise is determined by x-ray quantum in the beam projections (Poisson distribution).
- ATCM techniques adjust tube current attempting to make all images have a similar noise irrespective of patient size and anatomy.

Constant IQ WITHIN the patient

Constant IQ BETWEEN different patients

ATCM Types

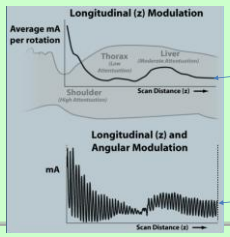
- Longitudinal (Z-axis)
- Angular (X, Y-axis)
- Volume (X, Y, Z-axis)

attenuation/size-based, spatially varying

- Sensitive organ (breast, lens, etc.) ⟹ organ-based, spatially varying
- Cardiac (ECG-gated) ⟹ ECG-based, temporally varying

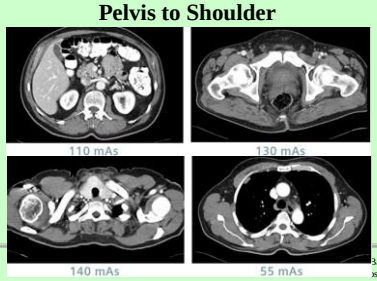
Volume ATCM

James Kofler, PhD,
Mayo Clinic



Pelvis to Shoulder

Robyn Augustyn,
BSRT(CT), Phoenix
Children Hospital



Commercial Implementations

Vendor	Angular (x,y-axis)	Z-Axis	Volume (x,y,z-axis)
GE	SmartmA	AutomA	SmartmA + AutomA
Philips	DoseRight D-DOM	DoseRight Z-DOM	D-DOM + Z-DOM
Siemens	CARE Dose4D*	CARE Dose4D**	CARE Dose4D
Canon/Toshiba		SURE Exposure***	SURE Exposure

* Pre-fixed for Extremities (not user changeable)
** Pre-fixed for Heads (not user changeable)
*** When a single scanogram is used

Commercial Implementations

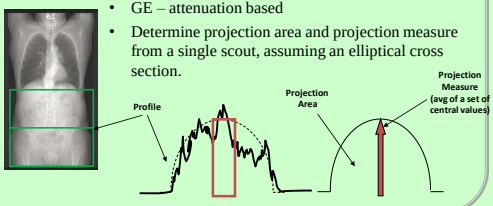
- Determination of patient size
- Determination of average tube current or effective mAs
- Modulation of tube current

Determination of Patient Size

- Patient diameter and attenuation are determined from the x-ray localizer:
  - Scout (GE)
  - Surview (Philips)
  - Topogram (Siemens)
  - Scanogram (Canon/Toshiba)

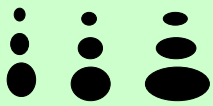
Determination of Patient Size

- GE – attenuation based
- Determine projection area and projection measure from a single scout, assuming an elliptical cross section.



Determination of Average Tube Current

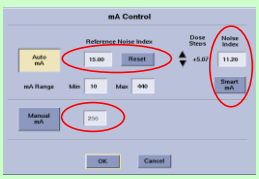
- Compare the patient's projection area and projection measure to a set of **reference phantoms** to predict the noise level.
- Determine the average tube current based on user specified noise level, slice thickness, gantry rotation time, and helical pitch factor.



Same principle works for different patients, as well as within the same patient

Modulation of Tube Current

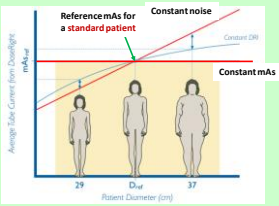
- The mA table is pre-determined prior to the acquisition.



Determination of Patient Size

- Philips – diameter based
- Determine diameter from a single surview

Determination of Average Effective mAs



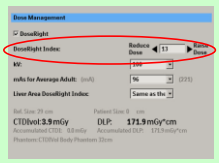
Adult Reference Diameters:
- Slim: 29 cm
- Average: 33 cm
- Obese: 37cm

Reference mAs:
- User defined image quality
- Based on reference image and associated surview
- Protocol specific

Works for different patients

Determination of Average Effective mAs

Dose Right Index (DRI)
- Index correlates to image quality
- DRI ≠ noise level
- DRI + 1 = increase mAs by 12%
- DRI – 1 = decrease mAs by 12%

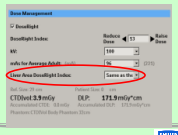


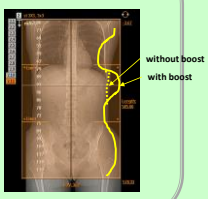
Works within the same patient

Determination of Average Effective mAs

Liver boost

- Set this index to 1 to 3 to boost image quality at liver region
- Liver is detected on the surview





Modulation of Tube Current

- Angular tube current modulation is calculated in real time.
- Determined according to the measured attenuation from the previous 180 or 360 degree projection.

Determination of Patient Size

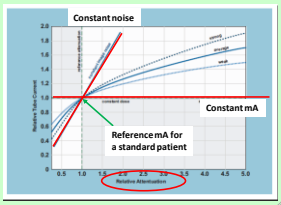
- Siemens – attenuation based
- Determine average attenuation for the anatomical region from a single topogram

Determination of Average Tube Current

- Similar to Philips DOM
- But uses patient's attenuation instead of diameter.

Quality Reference mAs (QRM):

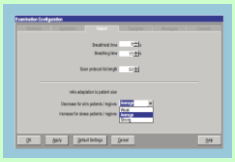
- User defined desired level of image quality
- Equal to the effective mAs that produces the desired image quality on a **standard-sized patient**
- Protocol specific



Determination of Average Tube Current

Modulation Strength Setting:

- No protocol specific index that is similar to Noise Index or Dose Right Index.
- Each scanner is globally configurable to a modulation strength (strong, average, or weak) for slim patients/thin regions and obese patients/ thick regions.



Less freedom, less headache

Modulation of Tube Current

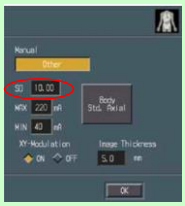
- Angular tube current modulation is calculated in real time.
- Determined according to the measured attenuation from the previous conjugate (180) projection.

Determination of Patient Size

- Canon – attenuation based
- Determine water-equivalent thickness for the anatomical region from either a single or both scanograms
- Single scanogram = longitudinal modulation
  Both scanograms = volume modulation

Determination of Average Tube Current

- Do not use reference patient size or reference phantom size
- Similar to GE AutomA
- Determine the average tube current based on user specified noise level, slice thickness, gantry rotation time, and helical pitch factor



Determination of Average Tube Current

Global Image Quality Setting:

- Similar to Siemens' Modulation Strength Setting
- But it is protocol specific
- Pre-determined desired level of noise

User's choice: a global noise level or noise levels for individual protocols

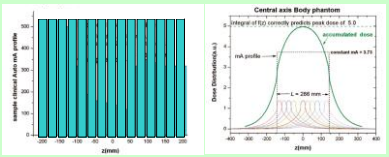
Modulation of Tube Current

- The mA table is pre-determined prior to the acquisition.

Erin Angel, Canon

Assumptions of CTDIvol

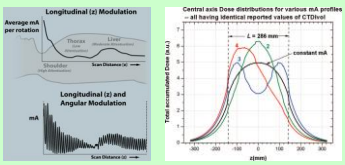
- Tube current is constant in z-axis
- The dose distribution peaks at the center – "bell shape"



Dixon and Boone, Med Phys 2013

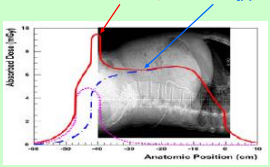
Actual Dose Profile with ATCM

- Actual dose distribution varies significantly in z-axis



Dixon and Boone, Med Phys 2013

Reported CTDIvol with ATCM and Multiple Series



Xinhua Li et. al, Med Phys 2019

- Average dose measured over 100 mm segment

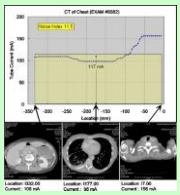
$$\frac{\overline{D_L}}{D_{100}(0)} \approx 0.68$$

- Average dose measured over the entire scan length (L)

$$\frac{\overline{D_L}}{D_L(0)} \approx 0.9$$

Reported CTDIvol with ATCM

- IEC 60601-2-44 recommends
  - To calculate scanner reported CTDIvol using an **imaginary** constant tube current
  - This constant tube current is equal to the "average tube current" over the scan range



Paul Lin et. al, Med Phys 2010

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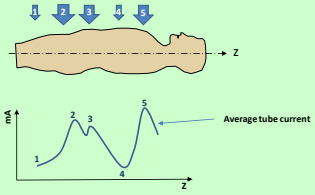
CT Patient Dose Monitoring Course (SAM): III. ATCM and Multiple Series

Feet to Head, Longitudinal ATCM



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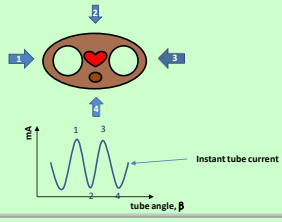
Angular ATCM



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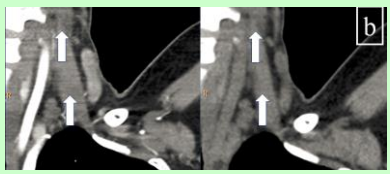
Minimizing streaks in neck CT by increasing mA in x-y plane through shoulder

Robyn Augustyn, BSRT(CT), Phoenix Children Hospital



Longitudinal ATCM Volume ATCM

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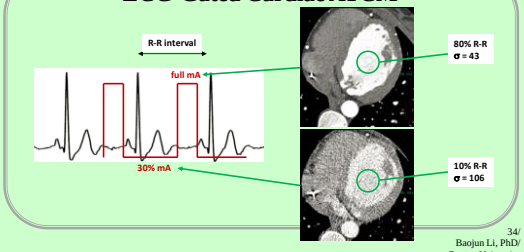
ECG-Gated Cardiac ATCM



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