ACR CT Accreditation Program
Image Quality Phantom and Dose Measurements

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Goal of accreditation

Increase quality

Timeline

- Program approved by ACR Council in 1997
- Robert Zeman, M.D. - Chairperson
- July 1998 first meeting
- Lots of work!!!
- Program Piloted summer 2001
- Program active March 2002, over 100 applications requested in 1st month
- Required for reimbursement by some insurers in 2004

Physics Subcommittee

- Cynthia McCollough, Ph.D., Chair
- Tom Payne, Ph.D.
- Mike McNitt-Gray, Ph.D.
- Tom Ruckdeschel, M.S.
- Jim Brink, M.D.
- ACR: Pam Wilcox, Penny Butler, Krista Bush, Chris Riha

ACR CT Accreditation Program

- Evaluation of the following primary determinants of clinical image quality
  - qualifications of personnel
  - clinical images and exam protocols
  - equipment performance
  - effectiveness of quality control measures
  - reference doses for three specific exams

Process Overview

- Entry application
  - Credentials of Physicians, Technologists, Physicists
  - Site and scanner demographics
- Full Application
  - Safety, QA, archive, reporting policies and procedures
  - Names, credentials and CME info for all Physicians, Technologists, Physicists
  - Clinical images
  - Phantom images

Physicist Qualifications

- Appropriate board certification or specific evidence of appropriate training
- ACR CME (CAMPEP, MEP) requirements
  - 150 hours every three years (not CT specific)
  - Minimum of 60 hours must be category 1
  - Category 2 can include teaching, literature review, manuscript preparation or review, computer instruction, etc.

SECTION J • PERSONNEL • MEDICAL PHYSICIST

Please print or type. Complete one copy of Section J for each physicist who provides physicist services at this facility. If you have multiple physicists, photocopy this form and complete a separate copy for each individual.

1. **Name** _____ Last name _____ First name _____ MI _____ Degree

2. **Indicate the category of board certification that currently applies to you:** *check all that apply*

A ____ ABR Diagnostic Radiological Medical Nuclear physics
B ____ ABR Diagnostic Radiological Physics
C ____ ABR Radiological Physics
D ____ ABR Roentgen Ray and Gamma Ray Physics
E ____ ABR X-ray and Radium Physics
F ____ ABMP Diagnostic Imaging Physics
G ____ ABMP Medical Health Physics
H ____ American Board of Health Physics *(please specify_____)*
I ____ Other board certification in physics *(please specify _____)*
J ____ Not board certified in physics

CONTINUING EXPERIENCE

3. **What is the total number of CT units for which you personally provided medical physicist services within the last year?**

☐ 1 0-1 ☐ 3 6-10 ☐ 6 21-50 ☐ 7 75-100
☐ 2 2-5 ☐ 4 11-20 ☐ 5 51-75 ☐ 8 over 100

CONTINUING EDUCATION

4. **Have you earned CME over a 36-month period in accordance with the ACR Standard on Continuing Medical Education?**

☐ 1 No ☐ 2 Yes

Physicist Qualifications (cont.)

- Physicist may have assistance in data collection
  - Properly trained individuals approved by the CMP
  - CMP is responsible for all data
  - Must be present during initial and annual surveys
  - Must review, interpret and approve all data
  - Must provide a signed report of conclusions

Physicist Responsibilities

- Physicist should be available for dosimetry consultations in a reasonable time
- Must establish and supervise QC program
  - What tests, done by whom, how often
  - Designate an on-site RT responsible for conducting routine QC
- Initial acceptance testing and annual survey
  - Tests should be consistent with ACR Standard for CT Performance Evaluation

Annual Performance Evaluation

- Alignment light accuracy
- Alignment of table to gantry
- Table/gantry tilt
- Slice localization from localization image (SPR)
- Table incrementation accuracy
- Slice thickness
- Image quality
  - High contrast (spatial) resolution
  - Low contrast resolution
  - Image uniformity
  - Noise
  - Artifact evaluation
- CT number accuracy and constancy

Annual Performance Evaluation

- Display devices
  - Video display
  - Hard-copy display
- Dosimetry
  - Computed Tomography dosimetry index (CTDI)
  - Patient radiation dose for representative examinations
- Safety evaluation
  - Visual inspection
  - Audible/visual signals
  - Posting requirements
  - Scattered radiation measurements
- Other tests as required by state and/or local regulations

Equipment and Exam Standards

- Must meet all state and or federal requirements
- Must meet applicable ACR standards
  - Neuro CT for children and adults
  - Thoracic CT for children and adults
  - CT of the abdomen and pelvis
  - ….

Clinical Images

- Three cases from each CT scanner
  - head / neck, chest and abdomen
  - attestation allowed for head- or body-only scanners
- One case must be a "specialty" exam
- One case must be pediatric for sites that scan kids
- Exam choices detailed in application instructions
- Images submitted on film with 1 page summary sheet of exam parameters and patient info

Phantom Images and Dose

- One set of phantom images (2 films) per CT
- Completed data sheets, including dosimetry
- Calculations of CTDIvol, DLP and E using the site's measured CTDIw and the reported scan acquisition parameters (pitch)
  - Routine head (cerebrum)
  - Adult abdomen
  - Pediatric abdomen (5 y.o)

Accreditation Cycle

- Peer review report sent to each facility to aid in "raising the bar" for CT imaging
- Accreditation is for a 3 year period
- Random site visits and film checks can occur
- For scanners added between accreditation cycles, site must submit clinical and phantom images, and dose info

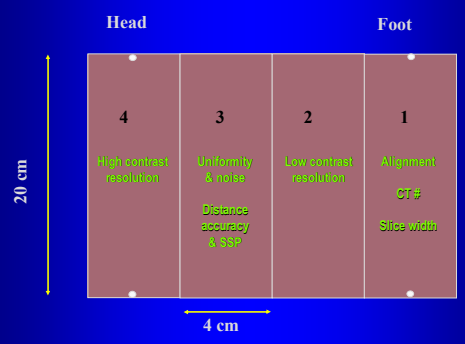
The Scan-a-thon

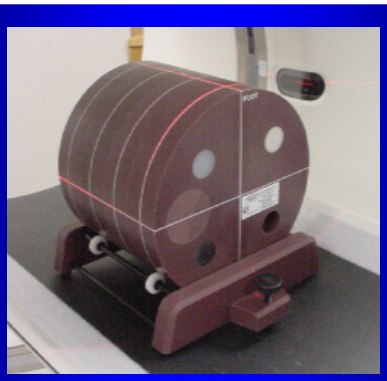
Consensus

- Single phantom design must be used
- No existing phantom had all desirable test objects
- Solid one-piece construction, 20-cm diameter
- Test objects must be simple to evaluate
- Objects and tests must be extendable to spiral
- Dosimetry will be $CTDI_{100}$-based in PMMA
- Assessment of phantom images will be film-based

The ACR CT phantom was designed to examine a broad range of scanner parameters

- Positioning Accuracy
- CT # Accuracy
- Slice Width Accuracy
- Low Contrast Resolution
- High Contrast (Spatial) Resolution
- Image Uniformity and Noise
- Image Artifacts
- Distance Measurement Accuracy
- Section Sensitivity Profiles





Instruction Manual

- Detailed step by step scan and analysis instructions
- Tells which set of scan parameters to use to acquire which phantom images
- Data sheet provides cells for measured and calculated data
- W/L and location on film grid given for all images to be filmed
- Dose measurement and calculation methods

Calibrations and water phantom

- Scanner should already meet all site QC criteria
- Perform scanner warm-up and daily calibrations
- Check water phantom for
  - Artifacts
  - CT number of water
  - Uniformity and noise
- Check SMPTE pattern on laser imager

Site Scanning Data Form

- Site or manufacturer-recommended protocols
  - **Adult Head**: Routine head (brain) CT for evaluation of patient with headaches to exclude neoplasms
  - **High Resolution Chest**: CT exam of the chest for evaluation of diffuse lung disease
  - **Adult Abdomen:** Routine oncologic CT survey of the abdomen for detection of possible liver metastases
  - **Pediatric Abdomen**: CT examination of pediatric (approx. 5 years old) abdomen for the evaluation of blunt trauma injuries

Table 1: Typical Image Acquisition Technical Parameters

	Adult Head (cerebrum portion)	High Resolution Chest	Adult Abdomen	Pediatric Abdomen (5 y.o.)
kVp				
mA				
Time per rotation (s)				
Scan FOV (cm or name)				
Display FOV (cm)				
Reconstruction Algorithm				
Axial (A) or Helical (H)				
Z-axis collimation (T, in mm) [1]				
# data channels *used* [1] (N)				
A: Table Increment (mm) or H: Table Speed (mm/rot) (I) [1]				
Pitch[2]				
Reconstructed Scan Width (mm)				
Reconstructed Scan Interval (mm)				
Dose Reduction Technique(s)[3]				

z-axis collimation (T) = the width of the tomographic section along the z-axis imaged by one data channel. In multi-detector row (multi-slice) CT scanners, several detector elements may be grouped together to form one data channel.

number of data channels (N)= the number of tomographic sections imaged in a single axial scan.

maximum number of data channels (Nmax) = the maximum number of tomographic sections for a single axial scan.

increment (I) = the table increment per axial scan or the table increment per rotation of the x-ray tube in a helical scan.

mA= the actual tube current used (averaged over one rotation)

exposure time = the time required for one complete rotation of the x-ray source.

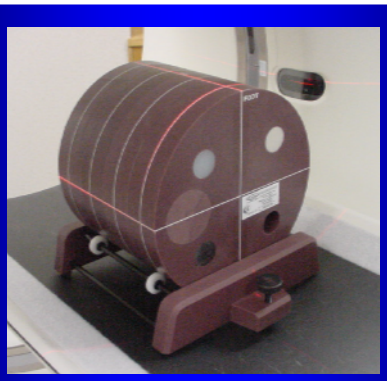
- Some scanners do not display
  - collimation width T
  - number of rows used N
  - IEC pitch
- Table feed per rotation (I) usually given
- Conversion table for GE on ACR website
- Other FAQ info also on ACR site

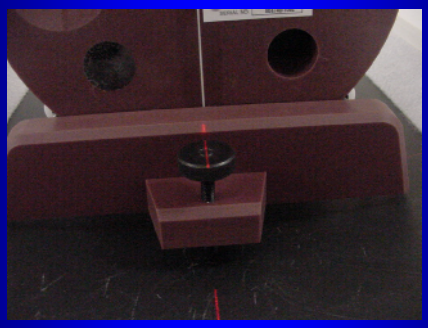
ACR CT Accreditation Tests performed using site's clinical protocol (Table 1)

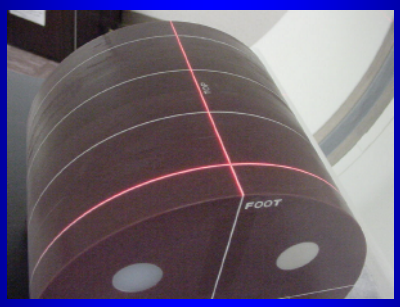
- Alignment light accuracy
- Table incrementation accuracy
- Slice thickness accuracy
- CT number accuracy
- Image Quality
  - low contrast resolution
  - image uniformity
  - image noise
  - artifact evaluation
  - high contrast resolution
- CTDI measurements
- Patient exam dose estimates

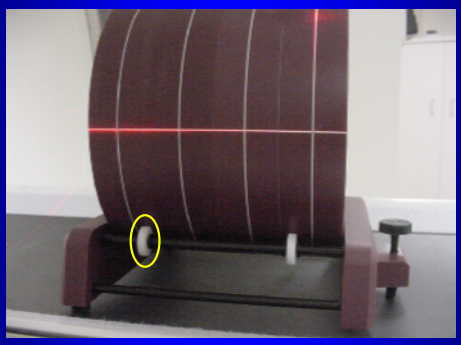
Phantom and Scanner Alignment

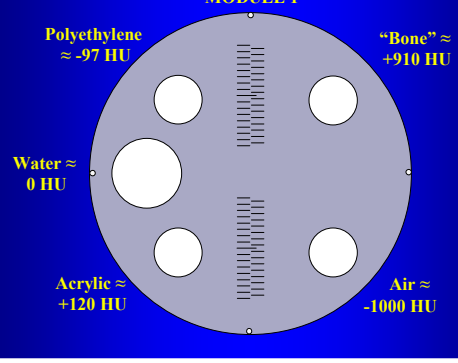
- Align Module 1 to lasers
- Scan with Hi Res Chest protocol
- Prescribe a scan at center of Module 4 (120 mm superior)
- Scan with Hi Res Chest protocol







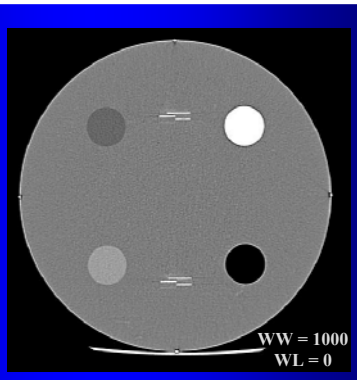




High-resolution chest technique

Must see all four BBs (in Modules 1 & 4)

Longer wire must have same number of lines above and below (±1)



Section 4 – Phantom and Scanner Alignment High Resolution Chest technique

Parameter	Measured	Film Page: Box
Internal or External used (circle one)		
Module 1 BB alignment (axial image)	Pass or Fail	1:2
Module 4 BB alignment (axial image)	Pass or Fail	1:3

If FAIL, do not pass "go", do not collect accreditation

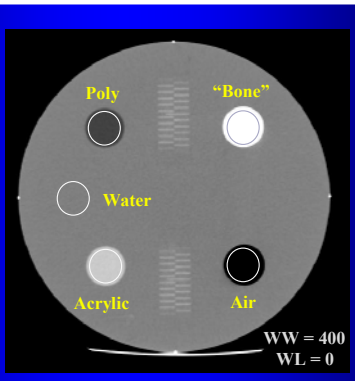
CT Number Accuracy and Slice Thickness

- Align Module 1 to lasers
- Scan with Adult Abdomen protocol
- Record slice thickness and all CT numbers
  - Water, air, polyethylene, bone and acrylic
- Scan varying slice thickness (≈ 3, 5, 7 mm & Hi Res)
  - Measure water CT number and slice thickness
- Scan varying kVp (scan with all available)
  - Measure water CT number and slice thickness

Adult abdomen technique

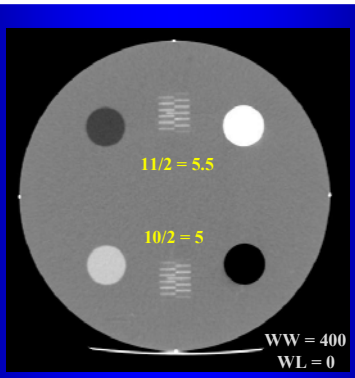
CT number measured in 5 materials

CT number of water measured at several scan widths and kVps



Adult abdomen technique

Scan width measured at several scan widths



Section 5 – Module 1: CT Number Calibration and Slice Thickness **Adult Abdomen technique**

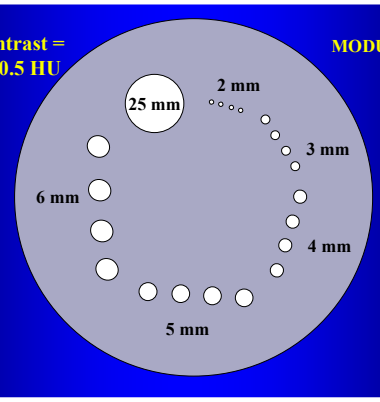
Parameter	Measured			Film Page: Box
Location of center of Module 1	_____mm			
CT number calibration and scan width accuracy for adult abdomen slice width				
Polyethylene	Mean CT # = _____HU	Top	Bottom	1:4
Water	Mean CT # = _____HU	_____mm	_____mm	
Acrylic	Mean CT # = _____HU			
Bone	Mean CT # = _____HU			
Air	Mean CT # = _____HU			
Dependency of CT Number of water on scan width and kVp, and scan width accuracy				
	CT number of water	Top	Bottom	
Hi Res Chest = _____mm	Mean CT # = _____HU	_____mm	_____mm	1:5
≈ 3 mm = _____mm	Mean CT # = _____HU	_____mm	_____mm	1:6
≈ 5 mm = _____mm	Mean CT # = _____HU	_____mm	_____mm	1:7
≈ 7 mm = _____mm	Mean CT # = _____HU	_____mm	_____mm	1:8
kVp	CT number of water			
_____ kVp	Mean CT # = _____HU			1:9
_____ kVp	Mean CT # = _____HU			1:10
_____ kVp	Mean CT # = _____HU			1:11
_____ kVp	Mean CT # = _____HU			1:12

Low Contrast Resolution

- Scan Module 2
  - Adult Abdomen protocol
  - Adult Head protocol
- Record the diameter (mm) of the smallest set of LCR rods seen

Low contrast =
6 HU ± 0.5 HU

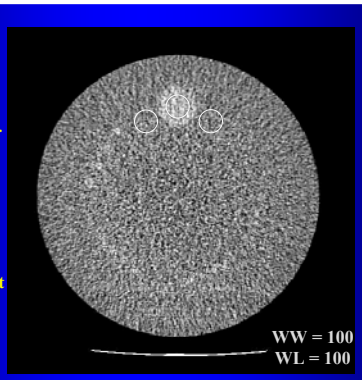
MODULE 2



Adult abdomen and head techniques

Record diameter of the smallest set of rods for which all 4 rods can be seen

ROI check of absolute contrast using large rod

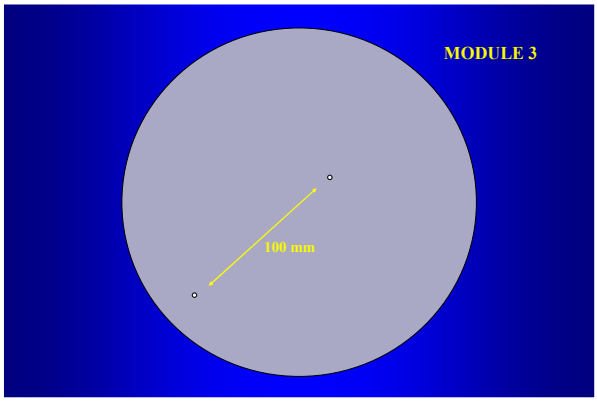


Section 6 – Module 2: Low Contrast Resolution

Parameter	Measured (or calculated)	Film Page: Box
Adult Abdomen Technique		2:2
Diameter of smallest cylinders for which all 4 cylinders can be visualized	_____mm	
Mean CT # over 25-mm-diameter cylinder (a)	_____HU	
Mean CT # next to 25-mm-diameter cylinder (b)	_____HU	
Measured contrast (a – b)	_____HU	
Adult Head Technique		2:3
Diameter of smallest cylinders for which all 4 cylinders can be visualized	_____mm	
Mean CT # over 25-mm-diameter cylinder (c)	_____HU	
Mean CT # next to 25-mm-diameter cylinder (d)	_____HU	
Measured contrast (c – d)	_____HU	

Image Uniformity and Noise

- Scan Module 3
  - Adult Abdomen protocol
- Record mean CT number & SD at center
- Record mean CT number at 3, 6, 9, 12 o'clock
- Examine for artifacts

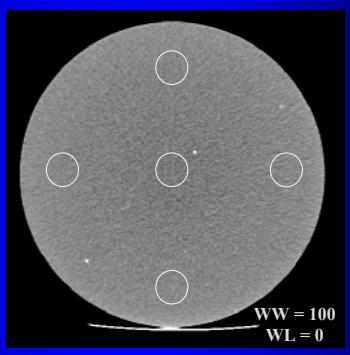


Adult abdomen and head techniques

Measure uniformity and noise

Assess for artifacts

Measure distance accuracy (optional)



Section 7 – Module 3: Uniformity and Noise

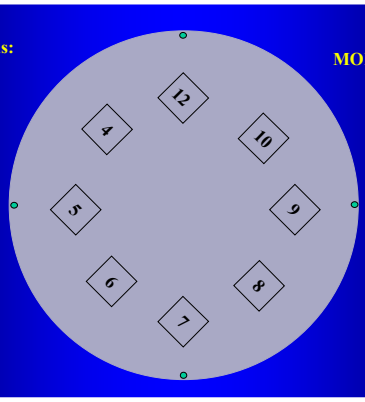
Parameter	Measured	Calculated	Film Page: Box
Adult Abdomen Technique			2:4
Center std. deviation	Standard deviation = _____HU		
Center mean	Mean CT # = _____HU		
3 o'clock mean	Mean CT # = _____HU	|Center – 3:00| = ____HU	
6 o'clock mean	Mean CT # = _____HU	|Center – 6:00| = ____HU	
9 o'clock mean	Mean CT # = _____HU	|Center – 9:00| = ____HU	
12 o'clock mean	Mean CT # = _____HU	|Center – 12:00| = ____HU	
Artifacts	Ring Y/N Streak Y/N	Other _____	

High Contrast Resolution

- Scan Module 4
  - Adult abdomen protocol
  - Hi Resolution Chest protocol
- Record limiting resolution (lp/cm)

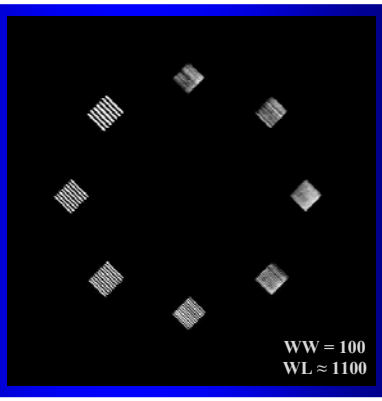
Bar patterns:
lp/cm

MODULE 4

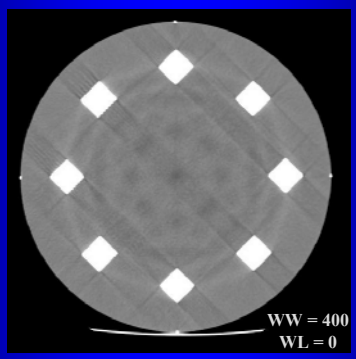


Adult abdomen, adult head and high-resolution chest techniques

Record the *first* highest frequency bar pattern for which the bars and spaces merge



Wrong window and level



Section 8 – Module 4: High Contrast (Spatial) Resolution

Highest epatial frequency for which bars and spaces can be resolved	[redacted]	Film Page: Box
Adult Abdomen Technique	_____lp/cm	2:5
High Resolution Chest Technique	_____lp/cm	2:6

CT Dosimetry

"What's the dose? "

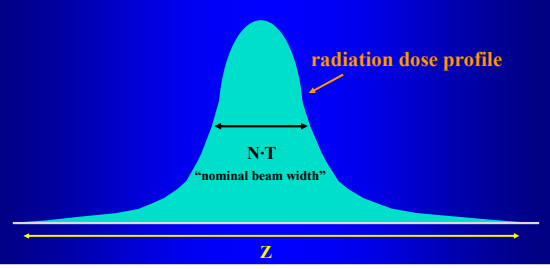
is not a simple question

What dose do you want to know?

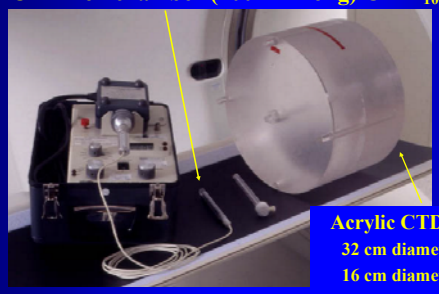
- Skin dose
- Midline dose
- Fetal dose
- Average dose
- Total dose
- Dose equivalent
- Effective dose equivalent
- Equivalent dose
- Effective dose

- CTDI
- $CTDI_{FDA}$
- $CTDI_{100}$
- $CTDI_{w}$
- $CTDI_{vol}$
- MSAD
- BERT

Computed Tomography Dose Index (CTDI)
is the integral under the *radiation dose profile*
from a single *axial* scan



CTDI ion chamber (100 mm long) $CTDI_{100}$

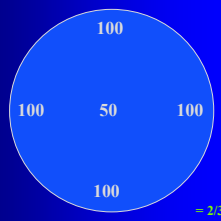


Acrylic CTDI phantoms

- 32 cm diameter (body)
- 16 cm diameter (head)
- Holes for measurements throughout FOV

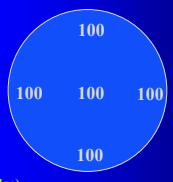
Typical FOV dose distributions (%)

Body
32 cm



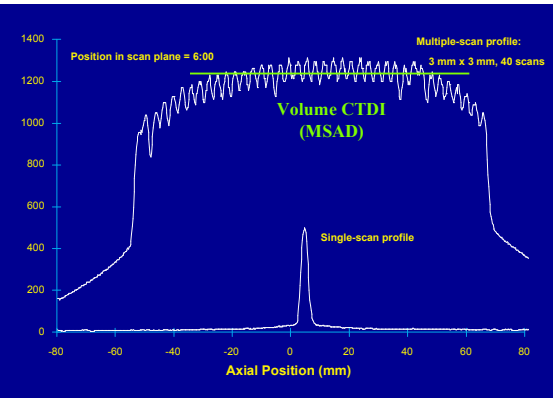
CTDIw = 83

Head
16 cm



CTDIw = 100

$CTDIw = 2/3\ CTDI_{100}\ (edge) + 1/3\ CTDI_{100}\ (center)$

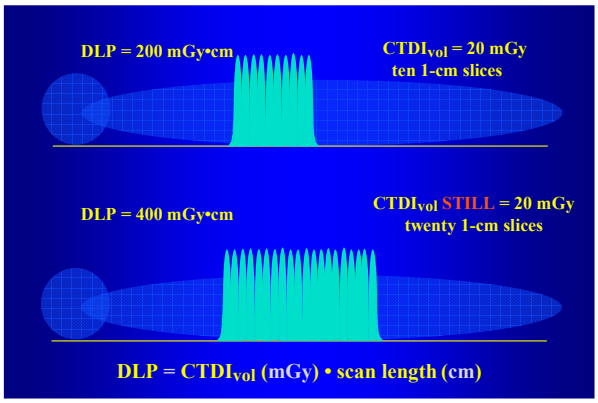


PITCH = $\frac{\text{table index per rotation (I)}}{\textit{total}\ \text{nominal scan width (NT)}}$

$$CTDI_{vol} = \frac{1}{pitch} \cdot CTDI_w$$

estimate of average dose in the scan volume (x, y, z)

measurements from one axial scan



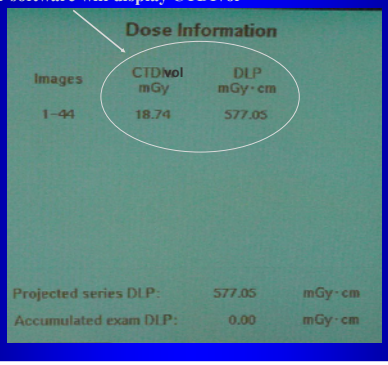
Typical Dose Values

(shown on operator console)

Exam	Detector Config.	Pitch	mAs	Z extent (cm)	CTDIvol (mGy)	DLP (mGy•cm)
head	4 x 2.5	axial	230	15	33.5	503
chest	4 x 5	0.75	100	40	12.0	480
abdomen	4 x 5	0.75	150	20	19.1	382
abd & pelvis	4 x 5	0.75	150	40	19.1	764

Dose indicators are now displayed prospectively on the CT Console

Newer software will display CTDIvol



Reference doses

- Concept has been shown to lower average dose in other modalities and/or other countries
- Represent the upper third or quartile of doses sampled from actual clinical practice data
- *Do not represent ideal or suggested doses*
- Identify when dose is unusually high

European Guidelines

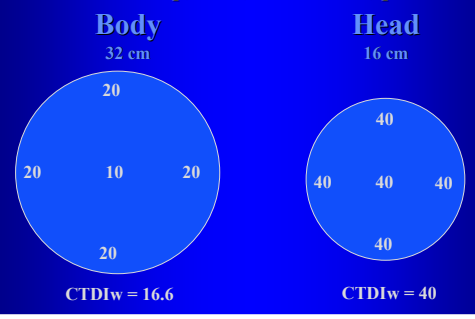
Exam	CTDIw	DLP	Effective Dose
Head	60	1050	2.4
Chest	30	650	11.1
Abd	35	800	12.0
Pelvis	35	600	11.4
Chest/Abd/Pel		2050	34.5

From European Commission EUR 16262
European Guidelines on Quality Criteria for Computed Tomography

- ACR CT Dose Reference Values
  - Adult Head 60 mGy
  - Adult Abdomen 35 mGy
  - Pediatric (5yr old) Abdomen 25 mGy
- Currently no pass/fail criteria
  - ACR will require documentation detailing either site's justification or corrective action
  - At renewal (3 yrs), reference doses will become pass/fail
- *Analysis of ACR data will determine future reference dose values (will use CTDIvol)*

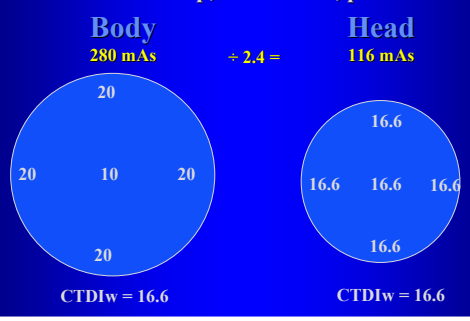
Phantom size affects CTDI values

Same kVp, mAs, collimation, pitch



Phantom size affects CTDI values

Same kVp, collimation, pitch



- ACR CT Dose Reference Values
  - Adult Abdomen 35 mGy
  - Pediatric (5yr old) Abdomen 25 mGy
- Use of smaller phantom *requires* factor of 2.4 reduction in dose to get *same* CTDIw
- Decrease in reference value (25/35) suggests another factor of 1.4 reduction in dose with respect to site's adult protocol
- Total dose reduction for 5 y.o. abdomen should be about a factor of to 3 - 4

Preliminary dose statistics

- Adult head
  - 76 mGy ± 30 (35 - 180 +) 60% sites > reference
  - *U.S. average 1990 and 2000 approx. 50 mGy*
- 5 y.o. abdomen
  - 21 mGy ± 10 (5 to 52) 24 % sites > reference
- Adult abdomen
  - 21 mGy ± 7 (9 to 40) 10 % sites > reference
  - *Same CTDIw implies average mAs reduction of 2.4 occurring for pediatric exams submitted for accreditation*

When someone asks …
"What is the dose"
they typically mean
"What is the risk of biologic injury"

- Biological injury includes
  - deterministic effects (skin burns, cataract formation)
  - stochastic effects (cancer induction, genetic effects)
- Risk estimates are derived from
  - atomic bomb survivor data, other exposed groups
- Risk estimates are dependent on
  - organ dose and type, age, gender, reproductive status
  - organ doses depend on patient size

What's my dose (risk)?

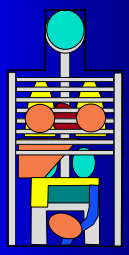
Radiation detriment better expressed by

Effective Dose

a *single dose parameter* which reflects the risk of a *non-uniform exposure* in terms of a whole-body exposure

ICRP 60 Weighting Values

Gonads	0.20
RBM, colon, lung, stomach	0.12
Bladder, breast, liver	0.05
Esophagus, thyroid	0.05
Skin, bone surface	0.01
Remainder	0.05
	Σ 1.00



Data In: Equipment exposure measurements and exam technique factors → CTDI(air, isocenter)

↓

Multiply by: Conversion coefficients (exposure to dose) — NRPB, GSF

↓

Data Out: Organ Doses

↓

Weighted sum: ICRP 60: Effective Dose (E) — Several implementations

Typical effective dose values

Head CT	1 - 2 mSv
Chest CT	5 - 7 mSv
Abdomen CT	5 - 7 mSv
Pelvis CT	3 - 4 mSv
Abd & pelvis CT	8 - 11 mSv

Average U.S. background radiation
≈ 3.6 mSv

Caveats

- Effective dose *estimates*
  - facilitate exam optimization
  - allow risk comparisons between different exams
  - provide risk information for IRB protocol review
  - are based on healthy worker adult populations
  - should be used as a broad measure of risk
    (i.e. one or two significant digits are sufficient)
  - DO NOT APPLY TO ANY INDIVIDUAL PATIENT

Effective Dose: Variability in estimation methods

- GSF and NRPB conversion coefficient data sets
- Several SW packages available to perform computations
  - *WinDose (IMP), CT-Expo (Nagel),* CTDosimetry (ImPACT), P-Dose (CyberQual), CT-Dose (LeHeron), DoseMacro (Mayo)
- For thorax $E \approx 0.017 \cdot DLP$
  - European Guidelines on Quality Criteria for CT
  - DLP takes into account much of scanner influence
  - Appears to give reasonable estimate of E (± 30%)

Dose Information for Accreditation

- Submit calculations of CTDIvol, DLP and Effective Dose using the site's measured CTDIw and the reported scan acquisition parameters (pitch)
  - Routine head (cerebrum)
  - Adult abdomen
  - Pediatric abdomen (5 y.o)
- CDTI phantom acquisition must be filmed

CTDI Measurements

- Adult Head
  - 16 cm CTDI phantom
  - Phantom in head holder
- Pediatric abdomen (5 y.o.)
  - 16 cm CTDI phantom
  - Phantom on table
- Adult Body
  - 32 cm CTDI phantom
  - Phantom on table
- Measure at center and 12:00
- MUST use Axial scan mode

Radiation Dosimetry

Section 9 – Radiation Dosimetry (Adult Head) **Adult Head (Cerebellum) technique**

***** CTDI data must be acquired using a single axial (non-spiral) scan *****

Use: 16-cm-diameter PMMA CTDI phantom	Measured	Calculated[2]	Film Page: Box
kVp			
mA			
Exposure Time per rotation (s)			
Z-axis collimation (T) [1]	_____mm		
# data channels *used* (N) [1]			
Axial (A): Table increment (mm) [1] = (I) or Helical (H): Table Speed (mm/rotation) [1] = (I)			
Active Chamber Length	_____mm		
Chamber Correction Factor[3]			
Isocenter			
Measurement 1 (note units)			
Measurement 2 (note units)			
Measurement 3 (note units)			2:7
Average of above 3 measurements (note units)			
Head CTDI at isocenter in phantom (mGy)			
12 o'clock position			
Measurement 1 (note units)			
Measurement 2 (note units)			
Measurement 3 (note units)			
Average of above 3 measurements (note units)			
Head CTDI at 12 o'clock position in phantom (mGy)			
CTDIw (mGy)			
Clinical Exam Dose Estimates (using measured CTDIw and site's Adult Head protocol from Table 1)			
CTDIvol (mGy)	= CTDIw • N • T / I		
DLP (mGy-cm)	= CTDIvol • 17.5		
Effective Dose (mSv)	= DLP • 0.0023		

Dose Calculator Spreadsheet (Exposure) CTAP ID Number

Section 11 - Radiation Dosimetry (Adult Body)

CTDI Body Phantom (32-cm diameter PMMA Phantom)	Measured	Calculated	Film
kVp	120		
mA	240		
Exposure time per rotation (s)	0.8		
Z axis collimation T (mm)[1]	3.75		
# data channels used (N)[1]	4		
Axial (A): Table Increment (mm) = (I)[1] OR Helical (H): Table Speed (mm/rotation) = (I)	11.25		
Active Chamber length (mm)	100		
Chamber correction factor	0.97		

Center			
Measurement 1 (mR)	197		
Measurement 2 (mR)	199		
Measurement 3 (mR)	199		2:9
Average of above 3 measurements (mR)		198.3	
Body CTDI at isocenter in phantom (mGy)		11.2	
12 o'clock position			
Measurement 1 (mR)	401		
Measurement 2 (mR)	422		
Measurement 3 (mR)	401		
Average of above 3 measurements (mR)		408.0	
Body CTDI at 12 o'clock position in phantom (mGy)		23.0	
CTDIw (mGy)		19.0	

CTDIw (mGy)		19.0	
Clinical exam dose estimates (using measured CTDIw and site's Adult Abdomen Protocol from Table 1)			
CTDIvol (mGy)	=CTDIw*N*T/I	25.4	
DLP (mGy-cm)	=CTDIvol*25	634.2	
Eff Dose (mSv)	=DLP*0.015	9.5	

Volume CTDI = CTDIw / pitch
= 19.0 * (4 * 3.75) / 11.25 = 25.4

CTDIw (mGy)		19.0	
Clinical exam dose estimates (using measured CTDIw and site's Adult Abdomen Protocol from Table 1)			
CTDIvol (mGy)	=CTDIw*N*T/I	25.4	
DLP (mGy-cm)	=CTDIvol*25	634.2	
Eff Dose (mSv)	=DLP*0.015	9.5	

DLP = CTDIvol * total length of scan (given)

CTDIw (mGy)		19.0	
Clinical exam dose estimates (using measured CTDIw and site's Adult Abdomen Protocol from Table 1)			
CTDIvol (mGy)	=CTDIw*N*T/I	25.4	
DLP (mGy-cm)	=CTDIvol*25	634.2	
Eff Dose (mSv)	=DLP*0.015	9.5	

ESTIMATED Effective Dose = DLP * body part coefficient

Goal of accreditation

Increase quality

From head …

to toe …

We need to keep our eyes on quality!

For further information contact the ACR