# CT QC Under the ACR QC Manual

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# What? There's a Manual??

- YES!!
  - Almost

- Doesn't have a pretty cover yet

- Should be out by RSNA
  - Really...seriously...I mean it this time

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# Learning Objectives

- Review current recommendations for CT quality control.

- Describe the draft QC program of the ACR CT QC Manual

- Discuss the status of the ACR CT QC Manual

## Similar to other programs

- "Effective one year from the publication of this manual (MO/DAY/YR), all facilities applying for accreditation must maintain a documented QC program and **must** comply with the minimum frequencies of testing outlined in this manual."

- Some forms provided

- Most physics documentation is up to the physicist

## Contents

- Follows the format of other manuals
  - Radiologist Section
  - Technologist Section
  - Physicist Section

- QA Committee is recommended
  - One or more radiologists
  - A qualified medical physicist
  - A supervisory CT technologist
  - Other radiology department personnel who care for patients undergoing CT, including a nurse, desk attendant, medical secretary, or others
  - Personnel outside the radiology department, which includes medical and paramedical staff, such as referring physicians

## Scope

- Test procedures in this document are considered the minimum set of acceptable tests

- Additional tests may be required if the system is used routinely for advanced clinical CT procedures

- Description of advanced CT QC tests is beyond the scope of this manual. The qualified medical physicist is responsible for determining and setting up the methods and frequencies for these tests

## Action Limits

- The qualified medical physicist should review action criteria annually
  - Ensure that they are adequately sensitive to detect CT equipment problems
  - May be tighter than what's in the manual

- Should be based on the performance of an individual scanner

- Should be reevaluated whenever there are hardware changes or major service activities.

## Radiologist Responsibilities

- **Relative to the optimization of patient dose in CT:**
  - Convene a team to design and review all new or modified CT protocol settings to ensure that both image quality and radiation dose are appropriate
  - Develop internal radiation dose thresholds
  - Implement steps to ensure patient safety and reduce future risk if an estimated dose value is above the applicable threshold for any routine clinical exam
  - Institute a review process, which occurs at least annually, for all protocols to ensure no unintended changes have been applied that may degrade image quality or unreasonably increase dose.
  - Establish a policy stating that the CT dose estimate interface option is not to be disabled and that the dose information is displayed during the exam prescription phase

## Radiologist Responsibilities

- **Should develop appropriate elements of good practice in CT QC**
  - Provide technologists access to adequate training and continuing education in CT that includes a focus on patient safety
  - Provide an orientation program for technologists based on a carefully established procedures manual
  - Arrange staffing and scheduling so that adequate time is available to carry out the QC tests and record and interpret the results
  - Follow the facility procedures for corrective action when asked to interpret images of poor quality (all rads)

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## The staff's commitment to high quality will often mirror that of the radiologist-in-charge



PROFESSIONALISM
That's not my job.

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## Radiologist and RT

- With respect to the technologist, the radiologist has three important QC roles:
  - Reviews, with the technologist, image quality problems identified during interpretation of clinical images
  - Decides whether patient studies can continue or must be postponed pending corrective action when image quality or radiation dose issues arise
  - Participates in the initial assessment of image quality at implementation of the QC program and regularly monitors QC results in the intervals between the annual QC data reviews

## MP and RT

- With respect to the technologist, the qualified medical physicist has three important QC functions:
  - Responsible for ensuring the correct implementation and execution of the technologist's QC procedures
  - Should help design the QC scan protocol technique to be used on each CT scanner
  - Resource to answer questions concerning image quality and patient dose to help identify and correct image quality problems or radiation dose issues

## Technologist Section

| Procedure | Minimum Frequency | Approximate Time in Minutes |
|---|---|---|
| Water CT Number and Standard Deviation | Daily | 5 |
| Artifact Evaluation | Daily | 5 (or less) |
| Visual Checklist | Monthly | 5 |
| Wet Laser Printer Quality Control | Weekly | 10 |
| (if film is used for primary interpretation) | | |
| Dry Laser Printer Quality Control | Monthly | 10 |
| (if film is used for primary interpretation) | | |
| Display Monitor Quality Control | Monthly | 5 |

## What Phantom?

- A water-filled, cylindrical phantom, which is typically provided by the scanner manufacturer at installation, should be used for the QC program

- The ACR CT phantom may be used as an alternative to the water phantom

## Alternative Protocols

- It is acceptable to use proprietary scanner QC procedures in lieu of some tests
  - "Automatic QC procedures may be used in place of these tests if the QMP has critically reviewed them and approved this substitution (in writing)."

- If you use the manufacturer's test for water CT number and standard deviation, you must do a visual artifact evaluation.

## Failure Modes

- What errors does daily QC reveal?

- Display devices

## Recommended QC

- Alignment light
- Water CT number and standard deviation
- Artifact analysis
- Visual checklist
- (Printer QC)
- May be necessary to add tests for a specific scanner if indicated clinically

IF YOU CAN DREAM IT, YOU MUST DO IT

## Personnel

- Best to identify a single individual
  - Greater consistency
  - Improved sensitivity to problems
- QC must be completed, regardless of individual
- Appropriate training must be provided

## QC Notebook

- QC policies and procedures
- Data forms for each test
- Area for comments and communications
- Service engineer should also utilize the notebook
- Data reviewed at least annually by physicist
- Supervising physician should also review

## Alignment Light Accuracy

- Position phantom
  - If manufacturer's (MFG), use manufacturer's holder
  - If ACR, place on table or use optional stand
  - Use alignment lights
- Scan phantom
  - MFG: Use manufacturer protocol
  - ACR: Adult head technique
  - Thin slice: ~1 mm

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## Alignment Light Accuracy

- Action limits
  - MFG
    - Use manufacturer limits
  - ACR
    - ± 2 mm
- Correction within 30 days
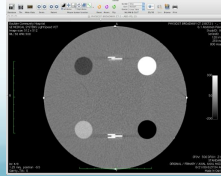


## CT Number Accuracy and Noise

- Warm up scanner per manufacturer recommendations
- Perform air calibrations per manufacturer recommendations
- Position phantom
  - If manufacturer's (MFG), use manufacturer's holder
  - If ACR, place on table or use optional stand
  - Use alignment lights

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## CT Number Accuracy and Noise

- Scan phantom
  - MFG: Use manufacturer protocol
  - ACR: Adult head technique
  - Recommend both helical and axial
  - Consider alternating modes each day
- Place ROI on image
  - 400 mm$^2$
  - Same location each time
  - Same slice if multi-slice
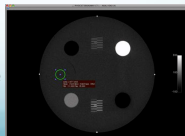
## CT Number Accuracy and Noise

- Action limits
  - MFG
    - Use manufacturer limits
  - ACR
    - Water value: 0 ± 5 HU
    - Noise: Limits must be established by the medical physicist based on the scan protocol used
- Schedule service if either value exceeds action limits 3 days in a row or 3 times in one week

## Artifact Analysis

- Position phantom
- Scan parameters (assume approx. 16 cm water)
  - Axial
    - 120 kVp
    - 350 mAs
    - Maximum number of slices possible
      - Want to check every data channel
      - 320 slices?
  - Helical
    - 120 kVp
    - 350 mAs
    - About 2.5 mm images

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## Artifact Analysis

- Visual analysis
  - Window width ≈ 100
  - Window level ≈ 0
  - Rings, streaks, lines
  - Record all findings
- Very effective to rapidly scan through the images, as the eye is sensitive to change

## Artifact Analysis

- Corrective action
  - While still sub-clinical
  - Re-run air calibrations
    - Often cover just a sub-set of scan conditions
    - May need to run several times
  - If still present
    - Determine if scanner can be used
      - Radiologist, medical physicist
      - Limited use?
    - Schedule service
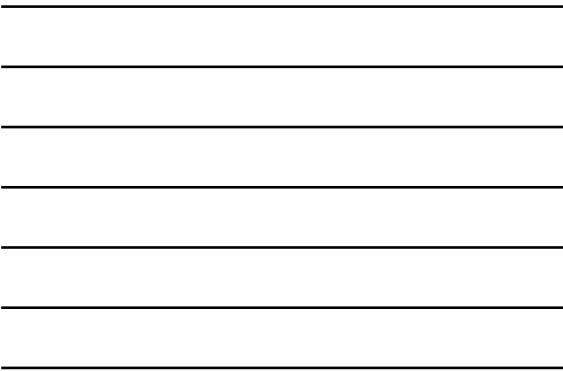
## Artifacts
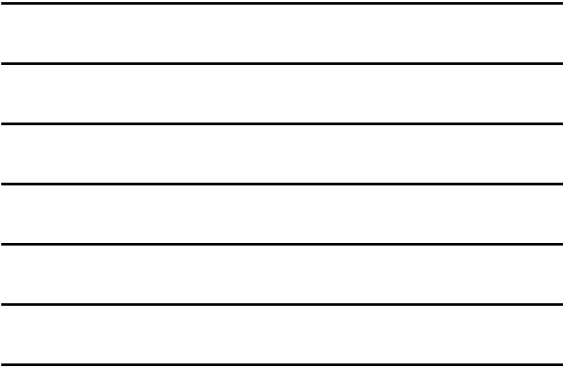


## Artifacts

# Artifacts

- It is recommended to use larger uniform phantom on a weekly or monthly basis to identify artifacts outside of the water QC phantom region
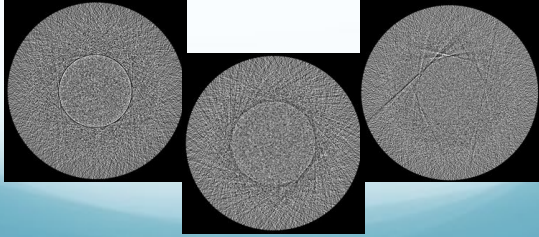






| A. DATA FORM FOR DAILY CT EQUIPMENT QUALITY CONTROL | | | | | | |
|---|---|---|---|---|---|---|
| CT Facility Name: | | | | | | |
| CT Scanner Identifier: | | | | | | |
| Date | Water HU | Limit | Water SD | Limit | Axial Artifacts | Notes |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| | Axial | Y/N | | Y/N | Y/N | |
| | Helical | Y/N | | Y/N | Y/N | |
| Reviewed by: | | | | | | |
| Qualified Medical Physicist | | | Date of Review | | | |

## Laser Printer QC

- Very few wet lasers left in the field
- Dry lasers generally have self-calibration feature
- Is QC necessary?

YES!

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## Laser Printer QC

- Case study
  - Kodak 8700 laser printer
  - Self-calibration performed on schedule
  - QC not performed
  - Got complaints regarding image quality
  - Sensitometric curve significantly different from same model
  - Internal densitometer had drifted and needed replacement
- Require **monthly** QC if used for primary interpretation

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## Laser Printer QC

- Visual analysis
  - 5%, 95% patches visible
- Quantitative analysis
  - Measure 0%, 10%, 40%, 90% squares
  - Plot values
  - Action limits of ± 0.15 from operating level

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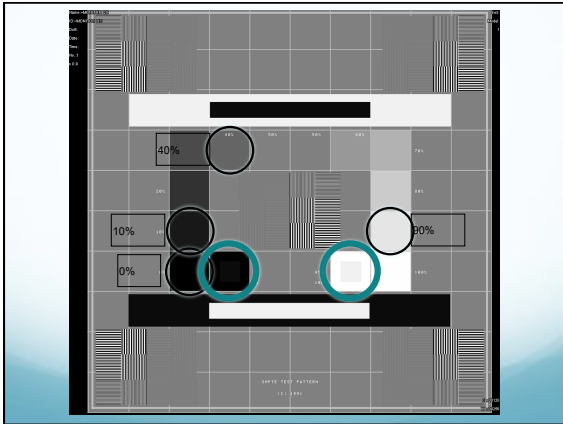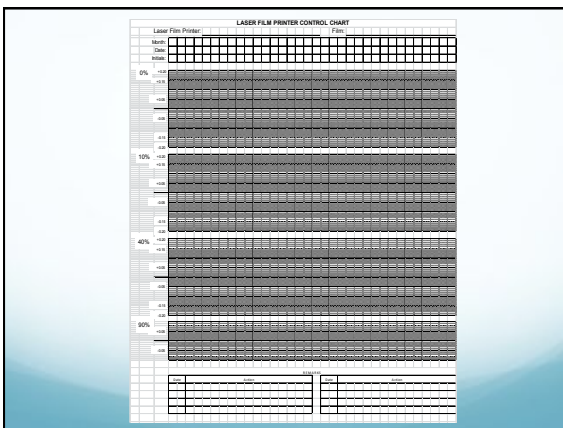
# Acquisition Display Monitors

- Applies ONLY to the acquisition station (the scanner)
  - Interpretation workstations will – hopefully – be covered by a separate manual
- Display SMPTE or equivalent pattern
- Examine the pattern to confirm that the gray level display on the imaging console is subjectively correct
  - The 5% patch can be distinguished in the 0/5% patch
  - The 95% patch can be distinguished in the 95/100% patch
  - All the gray level steps around the ring of gray levels are distinct from adjacent steps
  - Do not adjust the display window width/level in an effort to correct the problem

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## Visual Checklist

- Table height indicator functioning
- Table position indicator functioning
- Angulation indicator functioning
- Laser localization light functioning
- High-voltage cable/other cables safely attached (and not frayed)
- Acceptable smoothness of table motion
- X-ray on indicator functioning
- Exposure switch functioning
- Display window width/level
- Panel switches/lights/meters working
- X-ray on indicator functioning
- Door interlocks functioning
- Warning labels present
- Intercom system functioning
- Postings present
- Service records present

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**CT QUALITY CONTROL VISUAL CHECKLIST**

Facility: _____ Room #: _____ Unit: _____

**GANTRY**
- Table height indicator
- Table position indicator
- Angulation indicator
- Laser localization light
- High voltage cable/other cables
- Smoothness of table motion
- X-ray on indicator

**CONTROL CONSOLE**
- Exposure switch
- Display Window Width/Level
- Panel switches/lights/meters
- X-ray on indicator
- Door interlocks
- Warning labels
- Intercom system

**OTHER**
- Postings
- Service records

PASS = P
FAIL = F
DOES NOT APPLY = NA

Month:
Date:
Initials:

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## Follow Up

- Quality control must be active, not passive
- Data must be analyzed immediately
- All results must be logged or plotted
- Corrective action must be taken promptly

## Oversight

- The QMP must review the QC data at least annually
  - Be visible
  - Be accessible

- Data should be presented to the service engineer

- Radiologists must be involved
  - Reporting artifacts

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## Medical Physicist Section

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## Phantoms

- Manufacturer
  - Designed specifically for unit
  - Automated testing
  - May not allow all "physics" measurements
- ACR CT Accreditation
  - Good general, all purpose phantom
  - Direct comparison to ACR standards
- Phantom Lab
  - "Gold standard"
  - Many advanced measurement capabilities

## Alternative Approaches

- Manufacturers may provide phantoms and software to automate performance of many of the tests

- Use of such programs is acceptable during the annual performance evaluations

- At acceptance of the scanner, tests listed below should be performed independently of the software

- If it is to be used for the annual performance evaluation, the software must also be run at acceptance testing so that the results and conclusions can be verified.

- If the automated software was not tested by the QMP at acceptance testing, then it must be tested during the next annual QMP survey.

## Control Limits

- **Suggested acceptable** limit criteria provided for some tests

- Guidelines in the case that no other acceptable limit criteria exist

- QMP may elect to use manufacturer-provided testing conditions and criteria

## Tests and Evaluations

- Review of Clinical Protocols

- Scout Prescription and Alignment Light Accuracy

- Image Thickness – Axial Mode

- Table Travel Accuracy

- Radiation Beam Width

- Low-Contrast Performance

- Spatial Resolution

- CT Number Accuracy

- Artifact Evaluation

- Dosimetry

- CT Scanner Display Calibration

## Protocol Review

- Review at least six (6) clinical protocols, including
  - Pediatric Head (1 y.o.)
  - Pediatric Abdomen (50 kb, 20 kg; 5 y.o.)
  - Adult Head
  - Adult Abdomen
  - High Resolution Chest
  - Brain Perfusion (if performed at facility)
- Pay specific attention to

- kVp
- mAs
- Rotation time
- Detector configuration
- Reconstructed image thickness
- Pitch
- Reconstruction algorithm
- Dose reduction methods

## Protocol Review

- Firm rules for clinical imaging are difficult to establish. The ACR has set several practice standards:
  - Reconstructed scan width for standard Adult Head and standard Adult Abdomen should ≤5 mm.
  - Pitch for Pediatric Abdomen should not be less than 1.
    - Sometimes a pitch slightly lower than 1 is more does efficient.

## Protocol Review

- Several other rules of thumb should be kept in mind:
  - On a multi-slice scanner, the largest number of images for the chosen reconstructed scan width should be used, as this improves dose efficiency. For example, 5 mm x 4 slices is up to 30% more dose efficient than 5 mm x 2 slices in axial mode with no image quality penalty.
    - The facility may wish to be able to reconstruct to thinner in addition to the standard scan. N×T should allow for this.
  - Lower kVp settings should be used for pediatric scans and scans in which contrast media is used.

## Protocol Review

- High Resolution Chest (HRC) protocol should incorporate a very sharp reconstruction algorithm (GE recommends the BONE algorithm).
- HRC should be axial, thin slices separated by 10-20 mm. If HRC image are extracted from a helical chest scan, it must be verified that the chest scan is used appropriately for diagnosis.

## Protocol Review

- Doses should be as low as reasonably achievable. For the Adult Head protocols and the Adult and Pediatric Abdomen protocols, the CTDIvol must not exceed ACR Pass/Fail levels and should not exceed ACR reference levels.
- The ACR standards must be met when available.
- Protocols should be designed to optimize dose and image quality

## Scout Prescription Accuracy

- Required Test Equipment
  - Phantom incorporating radiopaque fiducial markers or an image center indication (ACR CTAP Phantom Module 1)

## Scout Prescription Accuracy

- Test Procedure Steps
  - Scan the entire phantom in scout mode.
  - Magnify the image, if possible, and position a single cut at the location of the radiopaque fiducial markers.
  - Perform an axial scan using a reconstructed scan width less than 2 mm, or as thin as the scanner can produce in axial mode.

## Scout Prescription Accuracy

- Data Evaluation
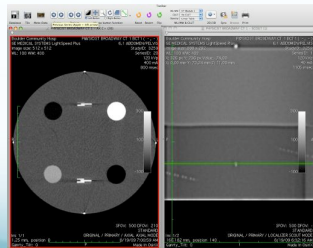


±2 mm

## Alignment Light Accuracy

- Most important when biopsies are performed

- Required Test Equipment
  - Phantom incorporating externally visible radiopaque fiducial markers or an image center indication (ACR CTAP Phantom Module 1)

## Alignment Light Accuracy

- Test Procedure Steps
  - Using the alignment lights, carefully position the phantom to the radiopaque markers in all three orthogonal planes.
  - Zero the table location indication.
  - Scan the phantom in axial mode, using a reconstructed scan width less than 2 mm at the zero position. Use technique to allow accurate visualization of the fiducial markers; for most phantoms, the Adult Abdomen technique works well.
  - Useful to scan also at ±0.5, ±1.0

## Alignment Light Accuracy

- Data evaluation
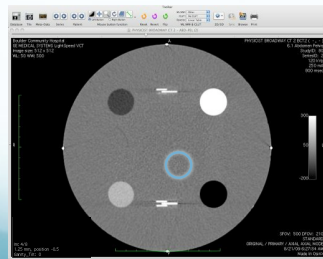


±1 mm if biopsies
±2 mm otherwise

## Image Thickness

- Detected / Reconstructed image width
  - Rarely an issue
- Radiation beam width
  - Often an issue

## Image Thickness

- Required Test Equipment
  - Phantom with internal targets allowing determination of reconstructed image thickness (Module 1 of the ACR CTAP Accreditation Phantom)

## Image Thickness

- Test Procedure Steps
  - Align the phantom to the reconstructed image thickness determination targets in the phantom.
  - Using zero table increment and techniques adequate to allow unambiguous visualization of the targets (for most phantoms, 120 kVp, 200 mAs is adequate), scan the phantom in axial mode using each reconstructed image thickness used clinically
    - Use as many different data channel (detector) configurations as possible.

## Reconstructed Scan Width

- Data Interpretation and Analysis
  - View the axial images collected above
  - Determine the reconstructed image thickness of each nominal thickness tested
  - For the ACR CTAP Phantom, each line represents ½ mm thickness
    - Count each line that is at least 50% of the brightness of the brightest line

## Reconstructed Scan Width
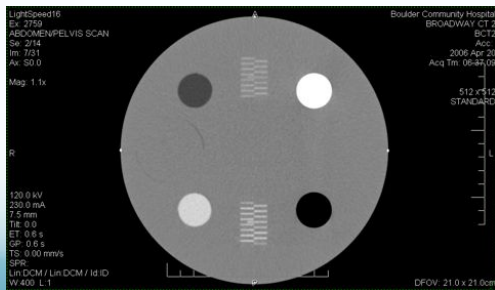


## Reconstructed Scan Width

- Count if half the brightness of the brightest



±1.5 mm
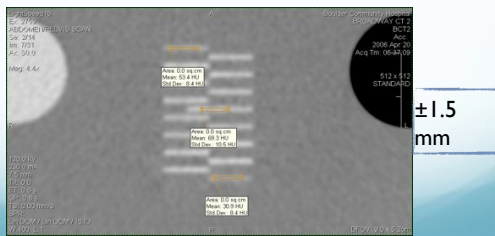
## Radiation Beam Width

- Required Test Equipment
  - External radiation detector (CR plate, self-developing film)
  - Flat radiation attenuator (1/16" lead); OR
  - Electronic test tool

## Radiation Beam Width

- Test Procedure Steps
  - Place the radiation attenuator on the table, unless contra-indicated by the test device being used.
  - Place the external radiation detector on the flat attenuator.
  - Adjust the table height so that the external radiation detector is at the isocenter.
  - Scan using each unique N×T product available, adjusting table position as appropriate for the beam width being used.

## Radiation Beam Width
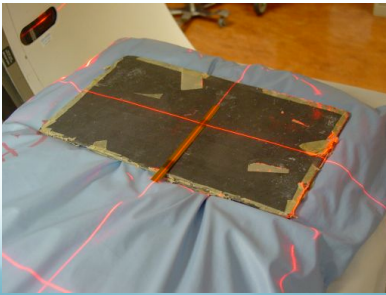


## Radiation Beam Width



GE LightSpeed Plus (4 slice)

±3 mm or 30% of N×T

| 1.25 | 5 | 10 | 15 | 20 |

| 4.7 | 8.2 | 12.2 | 16.6 | 21.1 |
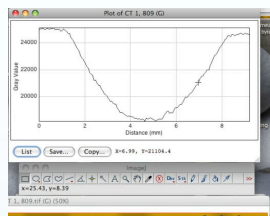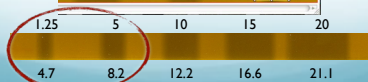
## Radiation Beam Width

- Data Interpretation and Analysis
  - Using a method appropriate for the external radiation detector used, determine the actual radiation beam width for each unique N×T product. For film and CR-based measurements, determination should be made at the full width at half maximum (FWHM).

## Radiation Beam Width

- Precautions and Caveats
  - Many manufacturers have standards that are in excess of the criteria stated below.
    - It has been the experience of the ACR CTAP Physics Subcommittee that most scanners can be calibrated to meet these tighter standards.
  - The above notwithstanding, scanners may exhibit over-beaming that can impact these tolerances.

## Radiation Beam Width

- Scanner-specific caveats
  - Toshiba
    - Thin beams (4 x 0.5) may be 2x wider than nominal. 1 x 1 mm is ok on Aquilion 64.
  - GE
    - 5 mm beam width often measures ~8.3 mm
    - 1.25 mm beam width often ~3-4 mm, but often is corrected when air cal. selects it.

# Table Travel Accuracy

- Required Test Equipment
  - Phantom with two sets of external fiducial markers of known separation (ACR CTAP Phantom Modules 1 and 4)
  - If possible, additional weight on the table to simulate the weight of a typical patient.

# Table Travel Accuracy

- Test Procedure Steps
  - Using the alignment light, carefully position the phantom to the first set fiducial markers in the axial plane.
  - Zero the table position indication.
  - Move the table to the second set of external fiducial markers.
  - Record the table position.
  - Translate the table to full extension and return to the first set of fiducial markers.
  - Record the table position.

# Table Travel Accuracy

- Data Interpretation and Analysis
  - Using the number recorded in Step 4, Compare the distance between the fiducial markers as determined by the table travel to the known distance.
  - Compare the number recorded in Step 6 to the zero position.

## Table Travel Accuracy

- Precautions and Caveats
  - Some scanners have specific limitations on the extent of table travel under which the performance specifications are valid. Scanner-specific limitations must be noted.

## Low Contrast Detection

- Required Test Equipment
  - Phantom incorporating low contrast targets of known contrast (Module 2 of the ACR CTAP phantom)

## Low Contrast Detection

- Test Procedure Steps
  - Align the phantom.
  - Perform clinical scans covering the low contrast section.
    - Any Auto mA feature must be disabled
    - Use an mAs value appropriate for an average sized patient.
  - The scans performed should include at least
    - Adult Head (average)
    - Pediatric Head (1 year old)
    - Adult Abdomen (average)
    - Pediatric Abdomen (50 lb, 20 kg; 5 y.o.)

## Low Contrast Detection

- Data Interpretation and Analysis
  - Visual Analysis
    - View each series and determine the slice providing the visually best low contrast performance.
    - Adjust the window width and window level to optimize visibility of the low contrast targets. On the ACR CTAP phantom, this is about WW=100, WL=100.
    - Record the size and contrast of the smallest visualized target.

## Low Contrast Detection

- Data Interpretation and Analysis
  - Numeric Analysis
    - Select the slice most central to the module containing the low contrast targets.
    - Place a Region of Interest (ROI) over the largest representative target and record the mean HU value.
    - Place an ROI adjacent to the target and record both the mean HU and the HU standard deviation.
    - Calculate the Contrast-Noise Ratio as

$$CNR = \frac{\left(\text{target mean HU - background mean HU}\right)}{\text{background HU std dev}}$$

## Low Contrast Detection

- Noise limited
- Specific realization of the noise may hide a target
- For ACR
  - OK to select any slice in Module 2 for low contrast performance evaluation
  - If all 4 lower rods visible, count larger
  - Use best slice

## Low Contrast Detection

- CNR measurements $CNR = \left( S_{25\,mm} - S_{bkgd} \right) / SD_{bkgd}$
  - Extremely sensitive to reconstruction algorithm
  - The specific algorithm used must be recorded for each clinical protocol
- Auto mA features must be disabled
  - Failure to do this leads to a low mA value
  - Poorer performance than should be
- Note that iterative reconstruction might make CNR undefined!

The Use of a Simple Contrast to Noise Ratio (CNR) Metric to Predict Low Contrast Resolution Performance in CT

Med. Phys. Volume 36, Issue 6, pp. 2451-2451 (June 2009)



CNR = 0.25

CNR = 1.07
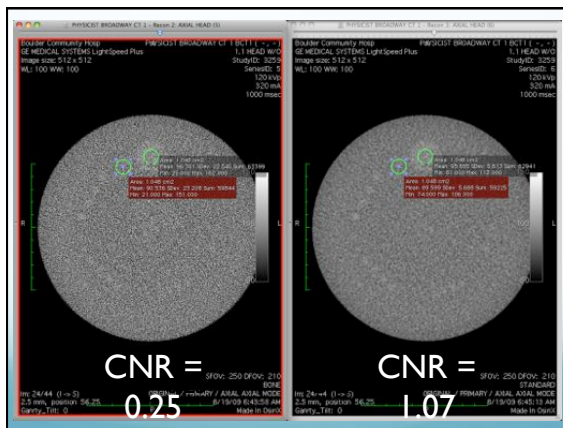
## Low Contrast Detection

- Assuming typical reconstruction algorithms, CNR should meet the following criteria

| Protocol | Minimum CNR |
| --- | --- |
| Adult Head | 1.0 |
| Adult Abdomen | 1.0 |
| Pediatric Head | 1.0 |
| Pediatric Abdomen | 0.5 |

## High Contrast Resolution

- Line pair pattern
- MTF
  - Point response
  - Via line pair standard deviation per *Droege and Morin. A practical method to measure the MTF of CT scanners. Med. Phys. (1982) vol. 9 (5) pp. 758-60*
- Required Test Equipment
  - Phantom incorporating high contrast targets of known resolution (Module 4 of the ACR CTAP phantom)

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## High Contrast Resolution

- Test Procedure Steps
  - Align the phantom
  - Perform clinical scans
    - Auto mA feature must be disabled
    - Use an mAs for average sized patient.
    - The scans performed should include scans appropriate to the facilities clinical scanning. These may include
      - Adult Head (average)
      - Pediatric Head (1 y.o.)
      - **Adult Abdomen (average)**
      - Pediatric Abdomen (50 lb, 20 kg; 5 y.o.)
      - **High Resolution Chest**

---

## High Contrast Resolution
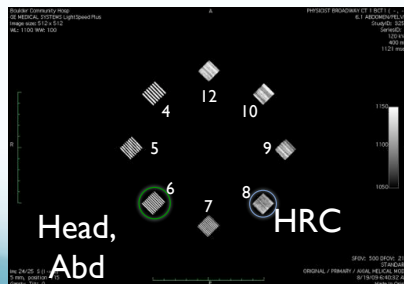
## High Contrast Resolution
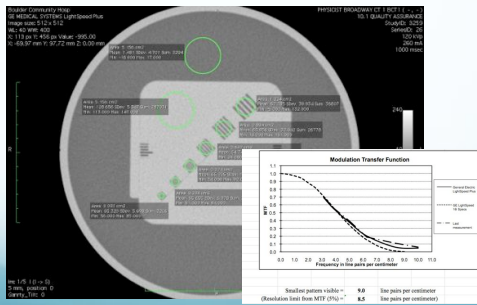


## CT Number Accuracy

- Why is this important?
  - Diagnosis
  - Treatment planning

## CT Number Accuracy

- Required Test Equipment
  - Phantom incorporating targets providing at least three different, known CT number values including water (or water equivalent material) and air. (ACR CTAP Phantom Module 1)

## CT Number Accuracy

- Test Procedure Steps
  - Align the phantom
  - Perform clinical scans covering the CT number accuracy section
    - Disable any Auto mA features
    - Use an mAs value appropriate for an average sized patient

## CT Number Accuracy

- The scans performed should include at least
  - Adult Head (average)
  - Pediatric Head (1 y.o.)
  - Adult Abdomen (average)
  - Pediatric Abdomen (50 lb, 20 kg; 5 y.o.)
- Perform scans of the CT number accuracy section of the phantom with each kVp setting available on the scanner. (Adult abd technique works usually)

## CT Number Accuracy

- Data Interpretation and Analysis
  - Select the image most central to the module containing the CT number accuracy targets.
  - Adjust the window width and window level to optimize visibility of the targets. On the ACR CTAP phantom, this is about WW=400, WL=0.

## CT Number Accuracy

- In the image from the 120 kVp scan, place a circular ROI, approximately 80% of the size of the target, in each target.
- Record the measured CT number mean for each target.
- For the images from each kVp scan, place a circular ROI, approximately 80% of the size of the water target, in the water target.
- Record the measured water CT number mean in each image.

## CT Number Accuracy

- All available kVp stations must be calibrated and tested.
- The CT number accuracy targets in most phantoms are calibrated only for 120 (or 130) kVp.
- CT numbers other than water will vary with kVp
  - May be useful information for scanners used for RT
- For ACR Phantom, use 200 mm$^2$ ROI

## CT Number Accuracy



| Material | CT # Range |
|---|---|
| Water | -5 to +5 HU |
| Air | -970 to -1005 HU |
| Teflon (bone) | 850 to 970 HU |
| Polyethylene | -107 to -84 HU |
| Acrylic | 110 to 135 HU |

## CT Number Uniformity

- Required Test Equipment
  - Phantom incorporating a uniform region, preferably water or water-equivalent

## CT Number Uniformity

- Test Procedure Steps
  - Align the phantom.
  - Perform clinical scans covering the CT number uniformity section.
    - Disable any Auto mA features
    - Use an mAs value appropriate for an average sized patient.
  - The scans performed should include at least
    - Adult Head (average)
    - Pediatric Head (1 y.o.)
    - Adult Abdomen (average)
    - Pediatric Abdomen (50 lb, 20 kg; 5 y.o.)
  - Perform scans of the CT number uniformity section of the phantom with each kVp setting available on the scanner. (Adult abd tech works usually)

## CT Number Uniformity

- Data Interpretation and Analysis
  - Select the image most central to the CT number uniformity module.
  - In each image, place a circular ROI, approximately 400 mm$^2$ (ACR phantom), at the center of the phantom.
  - Place similar ROIs at 12:00, 3:00, 6:00 and 9:00, one ROI diameter in from the periphery.
  - Record the measured CT number mean and standard deviation.

## CT Number Uniformity



$$\left| ROI_{center} - ROI_n \right| \le 5$$

## Artifact Evaluation

- Required Test Equipment
  - Phantom incorporating uniform section of adequate length for all data channels to be simultaneously used. (ACR CTAP Phantom Module 3)

## Artifact Evaluation

- Test Procedure Steps
  - Align the phantom.
  - Perform clinical scans covering the uniformity section.
    - Disable any Auto mA features
    - Use an mAs value appropriate for an average sized patient.
    - The scans performed should include at least
      - Adult Head (average)
      - Pediatric Head (1 y.o.)
      - Adult Abdomen (average)
      - Pediatric Abdomen (50 lb, 20 kg; 5 y.o.)

## Artifact Evaluation

- Test Procedure Steps (continued)
  - One scan in axial mode using approximately Adult Head techniques but with thin (approximately 1 mm) images using the maximum number of data channels available on the scanner
  - Repeat 4 for all kVp stations
  - (Repeat 4 for all bow tie filters)
  - It is recommended to use larger uniform phantom on a weekly or monthly basis to identify artifacts outside of the water QC phantom region

## Artifact Evaluation



Radiology 2005; 236:756 –761
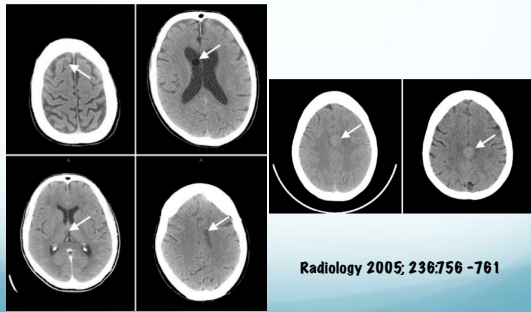
## Artifact Evaluation
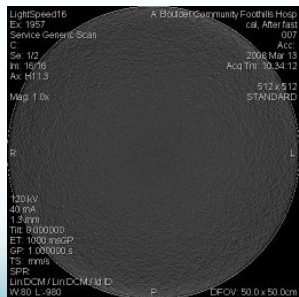
## Dosimetry

- Not just for patient dose estimates
- Generator calibration
- Tube condition
- Dose characterization

## Dosimetry

- CTDIvol for at least four clinical protocols
  - Compare to reference levels  [Less than ref. level]
  - Verify scanner CTDIvol  [±20%]

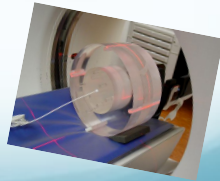- For large values of N × T, approaching or greater than the length of the ionization chamber, significant portions of the scatter tails may not be measured. Therefore, it may be necessary to mathematically correct for them to more closely estimate actual CTDI$_{vol}$.

Geleijns et al. Computed tomography dose assessment for a 160-mm wide, 320 detector row, cone beam CT scanner. *Physics in Medicine and Biology.* 2009;54(10):3141-59.
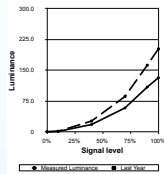
## CT Scanner Display Calibration

- Required Test Equipment
  - SMPTE Test Pattern (see Figure 1 in *Radiologic Technologist's Section, Section II K*) or Equivalent
  - Calibrated photometer with adequate precision, accuracy, and calibration to effectively measure to 0.1 cd/m$^2$ significance

## CT Scanner Display Calibration

- Test Procedure Steps
  - Display the test pattern on the imaging console.
    - Set the display window width/level to the manufacturer-specified values for the pattern (default).
      - Do not set the window width/level by eye; doing so invalidates this procedure.
  - Examine the pattern to confirm that the gray level display on the imaging console is subjectively correct.
    - Review the line pair patterns in the center and at each of the corners.
    - Review each black-white transition.
    - Look for any evidence of "scalloping" (loss of bit depth) or geometric distortion.

## CT Scanner Display Calibration

- Test Procedure Steps (continued)
  - Use the photometer to measure the maximum and minimum monitor brightness (0% and 100% steps)
  - Measure additional steps within the pattern to establish a response curve (10%, 40%, 70%, 90%)
  - Measure the brightness near the center of the monitor and near all four corners (or all four sides, depending on the test pattern used)



## CT Scanner Display Calibration

- Data Interpretation and Analysis
  - Visual Analysis
    - Examine the pattern to confirm that the gray level display on the imaging console is subjectively correct
      - The 5% patch can be distinguished in the 0/5% patch
      - The 95% patch can be distinguished in the 95/100% patch
      - All the gray level steps around the ring of gray levels are distinct from adjacent steps
      - Do not adjust the display window width/level in an effort to correct the problem
    - Ensure that the finest line pair pattern can be visualized in the center and at each of the four corners

## CT Scanner Display Calibration

- Data Interpretation and Analysis (continued)
  - Visual Analysis (continued)
    - Ensure that the finest line pair pattern can be visualized in the center and at each of the four corners
    - There must not be visible bleed-through in either direction of all black-white transitions
      - All high-contrast borders must be straight, not jagged
    - There must not be scalloping of the gray scale
    - There must not be geometric distortion in the image

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## CT Scanner Display Calibration

- Data Interpretation and Analysis
  - Visual Analysis (continued)

    

    - Ensure that the finest line pair pattern can be visualized in the center and at each of the four corners

    - There must not be visible bleed-through in either direction of all black-white transitions
      - All high-contrast borders must be straight, not jagged

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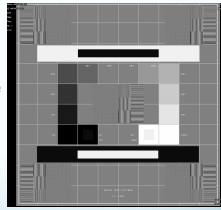
## CT Scanner Display Calibration

- Data Interpretation and Analysis
  - Photometric Analysis
    - The minimum brightness must be ≤1.2 cd/m$^2$
    - The maximum brightness must be ≥90 cd/m$^2$
    - The measured response curve should be compared visually to the prior year's result, verifying no significant change to the curve
    - Calculate the nonuniformity of the display brightness using the equation
    - % difference = 200 × (Lmax – Lmin) / (Lmax + Lmin)
      - CRT: Nonuniformity ≤ 30%
      - LCD: Nonuniformity ≤ 15%

## CT Scanner Display Calibration

- Corrective Action
  - Most often the problem is caused by incorrect adjustment of the monitor's brightness and contrast
    - Excessive ambient lighting can aggravate this problem
    - Occasionally, components of the display may need recalibration, repair, or replacement.
  - Perform the manufacturer's recommended procedure for monitor contrast and brightness adjustment
  - LCD brightness fades over time
    - Eventually, monitors need to be replaced

## Next Steps

- Remember I said "ALMOST"?
- "Final" manual must to go to MITA for review
- "Will" be published by RSNA
- "Should" be published prior to that

## Reporting

- Must use ACR summary form
- Report contents are at the discretion of the physicist
  - Include relevant data
  - Include comments
  - May include more than is required by this manual

**Medical Physicist CT Survey Report**

This report summarizes the results of tests performed in accordance with the American College of Radiology CT Accreditation Program QC Manual.

Facility Name_____    Unit ID_____
Address 1_____    Manufacturer_____
Address 2_____    Model_____
City, State, ZIP_____    Serial Number_____
                                          Date of Manufacture_____

CTAP #_____

                                          Survey Date_____
Medical Physicist    _____    Report Date_____

Signature    _____

| Medical Physicist Tests | Pass/Fail | Technologist QC Evaluation | Pass/Fail/NA |
|---|---|---|---|
| Review of CT Protocols | | Water CT Number and SD (Daily) | |
| Scout Prescription Accuracy | | Artifact Evaluation (Daily) | |
| Alignment Light Accuracy | | Wet Laser QC (Weekly) | |
| Table Travel Accuracy | | Visual Checklist (Monthly) | |
| Image Thickness | | Dry Laser QC (Monthly) | |
| Radiation Beam Width | | Acquisition Display QC (Monthly) | |
| Low Contrast Performance | | | |
| Spatial Resolution | | | |
| CT Number Accuracy | | | |
| Artifact Evaluation | | | |
| Dosimetry | | | |
| Acquisition Display Calibration | | | |

# Summary

- The new ACR CT QC Manual has been described

- Tests presented capture failure modes or areas in which the scanner should be characterized

- Not intended to be comprehensive
  - Acceptance testing
  - Problem scanner
  - Troubleshooting

- Should be published at latest by RSNA

- State and local regulations must be followed