CT Accreditation Program: Image Quality and Dose Measurements

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In 1997, the ACR approved the development of an Accreditation Program for CT. Since that time, many knowledgeable and dedicated individuals have volunteered countless hours towards the development of the CT Accreditation Program, including radiologists, medical physicists, and ACR staff members. The CT Accreditation committee is chaired by Robert Zeman, M.D. I was pleased to be asked to chair the Physics subcommittee, which includes fellow physicists Mike McNitt-Gray Ph.D., Tom Payne Ph.D., Tom Ruckdeschel M.S., and physics-savvy radiologist, James Brink, M.D. I am particularly pleased to report that the physics subcommittee members were involved in the full gamut of committee activities from the beginning, and have contributed significantly to the shaping of the program, especially with respect to dealing with the wide range of rapidly evolving equipment and dose awareness issues.

The ACR's CT Accreditation Program evaluates the following primary determinants of clinical image quality and, ultimately, the quality of patient care:

- qualifications of personnel
- equipment performance
- effectiveness of quality control measures
- clinical images and exam protocols.

For the program to achieve its full potential in reducing dose and increasing image quality, it is essential that medical physicists contribute to each of these areas. An affordable, high quality CT phantom was developed to permit a standardized and comprehensive evaluation of all QC parameters. It can be used by the medical physicist and onsite QC personnel in the pursuit of the goals of the accreditation program.

Process Overview

When a facility first applies to the ACR for accreditation, the application questionnaire requires information concerning the qualifications of the radiologists, radiologic technologists, and medical physicists (see Appendix A for the requirements of a Qualified Medical Physicist). Additional information common to the practice of CT, such as the number and types of CT scanners, is requested. After this information is reviewed and approved by the ACR, the facility is sent the *Full Application*, which details the requirements for the acquisition of clinical and phantom images and the submission of scan protocols, safety policies, and quality assurance program documentation. The facility receiving ACR CT Accreditation is awarded a three-year certificate recognizing its achievement. Clinical images from the basic clinical examinations, phantom images, and radiation dosage measurements are required of new scanners added between accreditation cycles.

The Role of the Physicist

The qualified medical physicist plays an essential role in the accreditation program, as he or she must perform initial performance testing upon installation of a CT system, supervise the ongoing equipment quality control program, be available for consultations relating to radiation dose to the patient or facility personnel, and work in close collaboration with the radiologist, technologist, and manufacturer to optimize imaging protocols. As the use of CT continues to grow, both in the number and type of examinations, as well as the complexity of the equipment, it is imperative that the medical physics community assists in the safe and efficient use of this powerful imaging tool.

Phantom Testing: Image Quality

The Physics Subcommittee met in March of 1999 for a "Scan-a-thon," where we discussed and scanned all then-current commercial (and several "home-made") CT image quality phantoms, in attempt to determine if any existing phantom met the needs of the program. We attempted to find a method by which different phantoms could be used to test similar image quality properties. After much data collection, review, analysis and discussion, the committee determined that it would be necessary, as with each of the other ACR Accreditation programs, to allow only one phantom design.

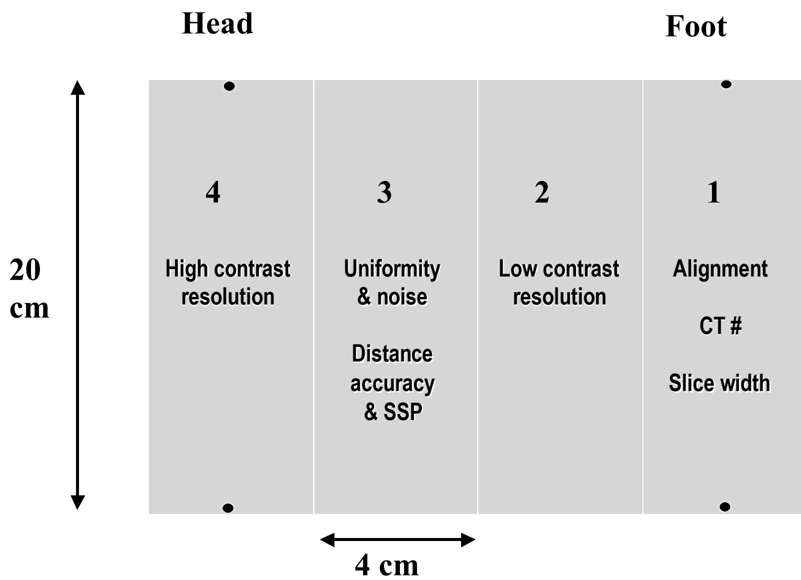
The committee worked to design a phantom that was easy to use, measured all the image quality parameters required by the ACR standards, was made from solid materials, and could be reproducibly and economically manufactured. The design specifications were sent to all known phantom manufacturers to obtain prototype phantoms and cost estimates. In the end, Gammex-RMI was awarded the contract to produce the ACR CT Accreditation phantom. The well-established CTDI head and body phantoms are used for the dose measurement portions of the accreditation application.

In order to assess the technical performance of each CT scanner, phantom images of the ACR CT Accreditation Phantom will be required using the facility's typical head and body exam protocols. The specific performance criteria evaluated using the phantom include:

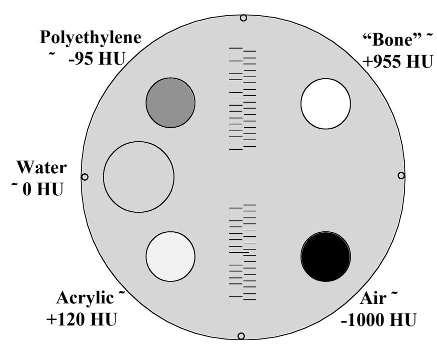
- Slice width and positioning
- CT number accuracy
- Low contrast resolution
- High contrast resolution
- Image uniformity

The Phantom

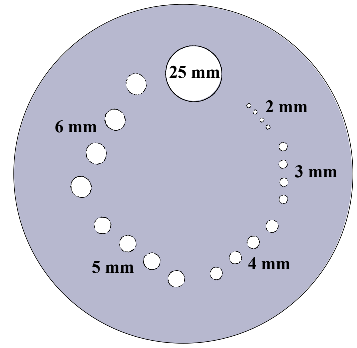
The ACR CT Accreditation Phantom is a solid phantom containing four modules, and is constructed primarily from a water-equivalent material. Each module is 4 cm in depth and 20 cm in diameter. There are external alignment markings scribed and painted white (to reflect alignment lights) on EACH module to allow centering of the phantom in the axial (z-axis, cranial/caudal), coronal (y-axis, anterior/posterior), and sagittal (x-axis, left/right) directions. There are also “HEAD”, “FOOT”, and “TOP” markings on the phantom to assist with alignment.



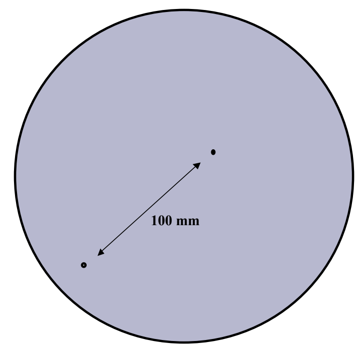
Module 1 is used to assess positioning and alignment, CT number accuracy, and slice thickness. The background material is water equivalent. For positioning, the module has 1-mm diameter steel BBs embedded at the longitudinal (z-axis) center of the module, with the outer surface of the BB at the phantom surface at 3, 6, 9, and 12 o’clock positions within the field of view (19.9cm center to center). To assess CT number accuracy, there are cylinders of different materials: bone-mimicking material (“Bone”), polyethylene, water equivalent material, acrylic, and air. Each cylinder, except the water cylinder, has a diameter of 25 mm and a depth of 4 cm. The water cylinder has a diameter of 50 mm and a depth of 4 cm. To assess slice thickness, two ramps are included which consist of a series of wires that are visible in 0.5-mm z-axis increments.



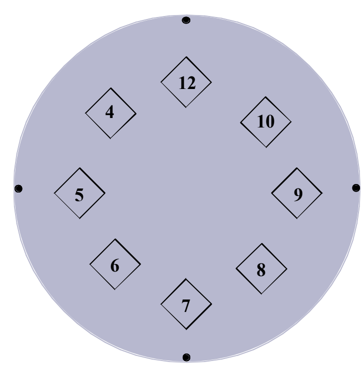
Module 2 is used to assess low contrast resolution. This module consists of a series of cylinders of different diameters, all at 0.6% (6 HU) difference from a background material having a mean CT number of approximately 90 HU. The cylinder-to-background contrast is energy-independent. There are four cylinders for each of the following diameters: 2 mm, 3 mm, 4 mm, 5 mm, and 6 mm. The space between each cylinder is equal to the diameter of the cylinder. A 25-mm cylinder is included to verify the cylinder-to-background contrast level.



Module 3 consists of a uniform, tissue-equivalent material to assess CT number uniformity. Two very small BBs (0.28 mm each) are included for optional use in assessing the accuracy of in-plane distance measurements. They may also be used to assess section sensitivity profiles.



Module 4 is used to assess high contrast (spatial) resolution. It contains eight bar resolution patterns: 4, 5, 6, 7, 8, 9, 10 and 12 lp/cm, each fitting into a 15-mm x 15-mm square region. The z-axis depth of each bar pattern is 3.8 cm, beginning at the Module 3 interface. The aluminum bar patterns provide very high object contrast relative to the background material. Module 4 also has four 1mm steel beads, as described for Module 1.



Phantom Testing: Dose

Dose measurements are required for each of a facility's CT scanner(s) and are to be made using the standard head and body CTDI phantoms and a pencil ionization chamber. The physicist instruction manual is very detailed with regard to how dose should be measured and provides instructional material to assist the facility physicist to perform estimates of patient dose parameters such as Effective Dose and Dose Length Product. See the Appendix B for CT Dose definitions.

Using the CTDI measurements, the physicist must calculate (with the aid of a provided Excel spreadsheet) several descriptors of dose for an adult head, pediatric abdomen (5 y.o.) and adult abdomen examination. The calculations use the technique factors provided by the site. Thus, a measure of each facility's dose for these three examinations will be submitted to the ACR.

Reference dose values are given in the program documentation and are to be used by the ACR and the site to identify situations where the level of patient dose is unusually high. If a dose for any of the three exams exceeds the respective reference value, the site will be required to submit documentation detailing their investigation, corrective action if necessary, or justification of the higher dose level. The current reference CTDIw values are as follows: Adult head, 60 mGy; Pediatric Abdomen (5 y.o.), 25 mGy; Adult Abdomen, 35 mGy.

Clinical Images

Clinical images from a basic, specialty and pediatric (if applicable) exam must be submitted from each scanner using the site's routine exam protocols. Specific instructions are included in the application packet as to what types of exams are required.

Summary

In summary, it has been an extraordinary experience to participate in the development of the ACR CT Accreditation program. I am confident that in spite of the growing pains involved in developing and going through such a comprehensive quality assessment (and quality improvement) program, the radiology community, and the patients that we serve, will benefit from the accreditation experience.

For further information, or to request an application packet, please contact the ACR CT Accreditation Program office in Reston, Virginia should be contacted for further information at 800-227-5463.

Appendix A: Medical Physicist Personnel Qualifications

A Qualified Medical Physicist is an individual who is competent to practice independently one or more of the subfields in medical physics. The American College of Radiology (ACR) considers that certification and continuing education in the appropriate subfield(s) demonstrate that an individual is competent to practice in one or more of the subfields in medical physics and to be a Qualified Medical Physicist. The ACR recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR).

The appropriate subfields of medical physics for CT Accreditation are Diagnostic Radiological Physics and Radiological Physics.

Continuing education for a qualified medical physicist should be in accordance with the ACR Standard for Continuing Education (CME).

The qualified medical physicist must be familiar with the principles of imaging physics and of radiation protection; the guidelines of the National Council on Radiation Protection and Measurements; laws and regulations pertaining to the performance of the equipment being tested; the function, clinical uses, and performance specifications of the imaging equipment; and calibration processes and limitations of the instruments used for performance testing.

The qualified medical physicist may be assisted by properly trained individuals in obtaining data. These individuals must be approved by the qualified medical physicist in the techniques of performing tests, the function and limitations of the imaging equipment and test instruments, the reason for the tests, and the importance of the test results. The qualified medical physicist is responsible for and must be present during initial and annual surveys and must review, interpret, and approve all data, as well as provide a signed report of conclusions. The qualified Medical Physicist should be available for consultation regarding patient dosimetry issues within a reasonable period of time.

Appendix B: CT Dose Definitions

CT Dose Index ($CTDI_{100}$)

$CTDI_{100}$ is acquired using a 100-mm long, 3-cc active volume CT "pencil" ionization chamber and two standard CTDI acrylic phantoms [head (16-cm diameter) and body (32-cm diameter)]. The $CTDI_{100}$ measures, over 100 mm, the radiation produced from one axial exposure. The measurement must be performed with a *stationary* patient table. It is calculated according to the formula:

$$\mathbf{CTDI_{100}\ (rad) = \frac{f\ (rad/R) \cdot C \cdot meter\ reading\ (R) \cdot 100\text{-}mm}{N \cdot T\ \ (mm)}}$$

where

C = the chamber calibration factor,

N = the number of tomographic sections imaged in a single axial scan. This is equal to the number of data channels used in a particular scan. The value of N may be less than or equal to the maximum number of data channels available on the system.

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. In single-detector row (single-slice) CT, the z-axis collimation (T) is the nominal scan width.

One must use the f-factor (f) appropriate to the task at hand to convert exposure (R) to absorbed dose (rad):

- 0.78 rad/R for comparison to FDA-required, manufacturer-reported data (Lucite)
- 0.94 or 0.98 rad/R for patient dose estimates (tissue or water)
- 0.87 rad/R for calculation of, or comparison to, $CTDI_W$ (air).

When an ion chamber measurement is given in air kerma (mGy), care must be taken to indicate which f-factor is used, if any, since the chamber reading and CTDI value are both given in units of mGy:

- 0.90 mGy/mGy for dose to Lucite
- 1.06 mGy/mGy for dose to tissue
- 1.00 mGy/mGy for dose to air.

Weighted CT Dose Index ($CTDI_W$)

$$\mathbf{CTDI_W = 1/3\ CTDI_{100,center} + 2/3\ CTDI_{100,edge}}$$

Per IEC 60601-2-44, $CTDI_W$ must use $CTDI_{100}$ as described above and an f-factor for air (0.87 rad/R or 1.0 mGy/mGy).

Volume $CTDI_W$ ($CTDI_{vol}$)

$$\mathbf{CTDI_{vol} = CTDI_W \cdot N \cdot T / I}$$

where

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

In helical CT, the term pitch (P) is defined as the ratio of the table increment per tube rotation to the nominal (total) width of the radiation beam. Hence,

$$\mathbf{Pitch = I / (N \cdot T)}$$

and

$CTDI_{vol} = CTDI_W$ /pitch.

$CTDI_{vol}$ is the parameter that best estimates the average dose at a point with the scan volume for a particular scan protocol.

Dose Length Product (DLP)

DLP = $CTDI_{vol}$ (mGy) • scan length (cm)

The dose-length product gives an indication of the energy imparted for a particular scan, as clearly the radiation risk for a 20 mm scan length differs from that of a 200 mm scan length, in spite of each having the identical $CTDI_{vol}$ value.

Effective Dose

Although more rigorous techniques exist for estimating effective dose (and the dose to particular organs), a reasonable *estimate* of effective dose can be obtained with use of the following:

Effective dose = k • DLP

where k (mSv • mGy^{-1} • cm^{-1}) is dependent upon body region and is given in the European Guidelines on Quality Criteria for Computed Tomography (EUR 16262 EN, May 1999)

Region of body	k (mSv • mGy^{-1} • cm^{-1})
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Additional references/resources:

AAPM Reports # 31, 39, 74

ImPact (UK CT expert group): Impactscan.org

Kalender, Schmidt, Zankl et al., "A PC program for estimating organ dose and effective dose values in computed tomography," Eur Radiol 9:555-562 (1999).

McCollough, Schueler, "Calculation of effective dose," Med Phys 27:838-844 (2000)

McNitt-Gray, "Radiation dose in CT," Radiographics 22:1541-1553 (2002)

Nagel, Radiation exposure in computed tomography, 2nd edition. Frankfurt: COCIR (2000) [cocir@zvei.org]

Rothenberg, Pentlow, "CT Dosimetry and radiation safety," Categorical Course in Diagnostic Radiology Physics: CT and US Cross-sectional Imaging. RSNA (2000)