Physics Testing for ACR CT Accreditation: Tips and Suggestions From Physics Reviewers

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INTRODUCTION

The ACR CT accreditation program was initiated over 6 years ago and has seen an accelerated growth in the past few years. This exhibit is a compilation of the most common problems in the physics component of the ACR CT accreditation submissions, as recalled by the physics reviewers. Some of the problematic issues in completing the submission materials are related to newer CT scanner technologies, some are related to limitations of the available scanner settings, and others are oversights in completing the forms and measurements. The intent of this educational exhibit is not be a complete reference on ACR CT accreditation but to focus on the most common errors and to provide suggestions on how to proceed when questions in the process are encountered. Complete details on all of the required physics tests have been published by McCollough et. al.[1] and are also available on the ACR website[2].

General Overview the Accreditation Physics Requirements

The following materials need to be submitted for the physics component of the ACT CT accreditation program (the modules refer to the portion of the ACR CT phantom, as shown in Figure 1):

1. **Scanner data sheet**. Includes general information on the scanner type and capabilities.
2. **ACR Table 1.** A matrix of scan parameters for an adult head, high-resolution chest, adult abdomen and pediatric abdomen exam. (If site chooses to be accredited for a subset of exams, contact the ACR for information on which exams need to be submitted).
3. **Data sheet 1.** Includes phantom alignment, CT number calibration, image thickness accuracy, and dependency of CT number on scan width and kVp. Uses modules 1 and 4.
4. **Data sheet 2.** Includes low contrast resolution, uniformity and noise, and high contrast resolution. Uses modules 2, 3, and 4. The routine clinical scan mode should be used, whether axial (sequential) or helical (spiral).
5. **Dosimetry sheets.** Includes measured CTDI values and the calculation of estimated dose values for the adult head, pediatric body, and adult abdomen exams. Scans must be performed in axial (sequential) mode.
6. **Film 1.** Contains images associated with data sheet 1 and a SMPTE test pattern.
7. **Film 2.** Contains images associated with data sheet 2 and a SMPTE test pattern.

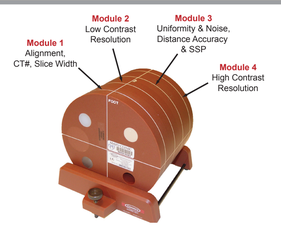


Figure 1. The ACR CT accreditation phantom, showing the location of the various modules and the associated tests.

COMMON ERRORS

Most of the reasons for failing the physics component of the ACR CT accreditation program are not related to scanner performance, but are caused by inadequate or erroneous information provided in the submission. The remainder of this exhibit will highlight the most common errors, explain the significance of the error, and describe the proper method to fulfill the requirements for a successful physics submission.

COMMON ERRORS *(continued)*

Common Error 1: Mistakes in determining the correct value for the z-axis collimation (T) and the number of data channels (N).

Significance: The z-axis collimation (T) and the number of data channels (N) is required for ACR Table 1 and can also influence the axial-equivalent scan parameters for Data Sheet 1 and Film 1. If incorrect values are used then measured values and images can be irrelevant to evaluating the system. Consequently, failure to accurately determine these parameters typically results in failing accreditation.

Solution: Determining the correct detector configuration is two-fold. The definitions of the terms must be understood and they must be determined directly from the scanner or, when possible, from the annotation on the images. The scanner user's manual may also be useful for determining which configurations are available. The meaning of the terms is illustrated in Figure 2.

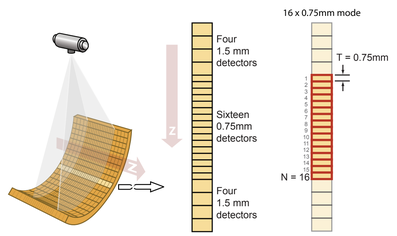


Figure 2. Consider a single row of detectors on a multi-slice scanner. This example shows a detector matrix of 24 elements in the z-direction. However, not obvious is that system has only 16 detector channels, which implies that not all 24 elements can be used simultaneously. If the inner 16 channels were used, the sixteen 0.75mm elements would be active. Therefore the z-axis collimation (also referred to as the "detector collimation") would be 0.75mm. The number of data channels, N, would be 16. These values are typically displayed on the scanner console in the form of "# of channels x z-collimation, as in "16 x 0.75mm" in the example above. Occasionally they can be deduced from the annotation on the images but this typically requires some prior knowledge of the available configurations. Do not confuse the z-axis collimation with the image thickness. *See additional examples in Common Errors 4.*

Common Error 2: Errors in listing and using the correct mA value.

Significance: The mA must be listed in ACR Table 1 and can affect many of the test results. The reviewer can sometimes adjust the dosimetry results if the correct value mA can be determined but this is not always possible. Using an mA value that is not consistent with the submitted clinical protocols can invalidate the tests and result in failure to achieve accreditation.

Solution: ACR Table 1 specifically ***requires*** the tube current (in mA), not the mAs or other related values. Note that for some scanners, the user interface does not directly provide the mA value; instead the mAs, effective mAs (Eff. mAs), mAs/slice or quality reference mAs (QRM) value is provided. If the scanner provides the mAs value, divide this by the rotation time (s) to yield the mA. If the scanner indicates the effective mAs (or quality reference mAs or mAs/slice), the mA is determined using the following equation.

$$\text{Eff. mAs} = \frac{\text{mAs}}{\text{Pitch}} \quad \Rightarrow \quad \text{mA} = \frac{\text{Eff. mAs} \times \text{Pitch}}{\text{s}}$$

If the protocol uses dose modulation then the mA value for a typical patient should be used. A technologist may be able to provide insight regarding typical mA values.

COMMON ERRORS *(continued)*

Common Error 3: Pitch is not calculated correctly.

Significance: The pitch value is required for ACR Table 1. If the other clinical parameters used for the tests that require helical acquisitions are correct, the stated pitch value should be correct. For some scanners, the pitch value is not explicitly given (another parameter such as table feed per rotation is given instead) and so pitch must be calculated. In other cases, the pitch is given, but N and T may be difficult to determine (see Common Error 1).

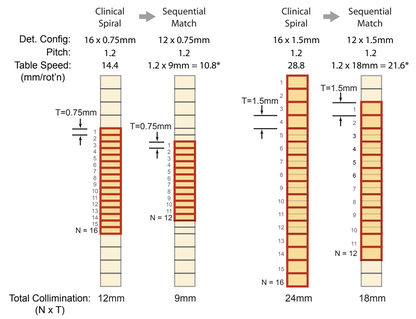
Solution: There is only one acceptable definition of pitch[3], as shown below. The physicist should use this formula and check all values (Pitch, I, N, and T) for consistency.

$$\text{Pitch} = \frac{\text{Table Speed (I, } \textit{in mm/rotation}\text{)}}{\text{Total Collimation (N x T, } \textit{in mm}\text{)}}$$

Common Error 4: The wrong axial-equivalent detector configuration is used for tests requiring axial scans, including dosimetry.

Significance: This is perhaps the biggest challenge for most submitters. To properly assess the doses, an axial scan MUST be used for CTDI measurements. However, the clinical protocol typically uses a spiral acquisition. Choosing the wrong axial-equivalent detector configuration can result in meaningless dosimetry calculations (e.g., measured output normalized to the wrong nominal beam width) and irrelevant performance tests (measurements don't reflect clinical performance of the scanner). Errors of this type cannot be corrected by the reviewer and result in the submission failing accreditation.

Solution: There may not be an axial detector configuration available to the user that is identical to the helical configuration. In this case, first determine the total collimation (N x T) for the helical acquisition and choose the closest matching axial total collimation that is available to the user (see Figure 3). This is best achieved by selecting an axial configuration that uses the same z-collimation (T) and choosing the next smallest allowed value of N (number of data channels). If a reasonable match cannot be determined, contact the ACR for guidance. Including an explanatory note to the reviewer in the margin of the form can also assist the reviewer in determining if the selection was reasonable. Note that if a different total collimation is used for the axial acquisition, then the Table Speed (I) in the dosimetry spreadsheets must be adjusted to match the clinical pitch.



* The table speed is calculated only for use in the dosimetry spreadsheets and will not match the clinical table speed. The purpose is to match the clinical pitch with the axial-equivalent configuration such that correct CTDIvol values are obtained. The new table speed is calculated by multiplying the axial-equivalent total collimation by the clinical pitch.

Figure 3. An illustration showing the process for selecting an axial-equivalent detector configuration. Two different scenarios are shown, both for a 16 channel system. Determination of the axial-equivalent configuration is best achieved at the scanner console where the available options will be listed. Note that some systems display the pitch value while others display the table speed, so familiarity with the equation shown in Common Errors 3 is essential. Note also that the pitch listed on earlier model multi-slice CT scanners may not be consistent with the IEC definition of pitch, in which case the pitch displayed on the console should not be used.

COMMON ERRORS *(continued)*

Common Error 5: The 6 mm rods are not visible on the low contrast resolution image.

Significance: Low contrast resolution is very important for clinical imaging. If all four 6 mm rods cannot be visualized, the site will fail accreditation.

Solution: Random noise patterns can obscure the test objects. If the 6 mm rods are just barely visible in an optimum viewing environment then repeating the test may yield a better result. Acquire the image several times and select the image with the best visualization for the submission. Also check that the clinical mAs was used—if the mAs is incorrectly lower than the clinical protocol the test results will be negatively affected. Lastly, make sure the film printer is optimally calibrated. A slightly miscalibrated printer may produce an acceptable SMPTE pattern but still impact the quality of the images. If visualizing the 6 mm rods is not possible the clinical protocol may need to be altered. Do not alter the protocol and use for accreditation unless the medical director of the practice has been able to confirm that it yields acceptable image quality.

Other Reviewer Concerns

☹ *The high resolution chest protocol is extremely dose inefficient.*

If the high resolution chest images are reconstructed from a helical acquisition (as an optional reconstruction from a standard chest scan), the dose can appear to be excessive. This is because the helical scan irradiated the entire scan range yet slices are typically only reconstructed every 10-20mm. Include a note to the reviewers in the margin of the form to indicate that the high resolution chest is reconstructed from a helical scan, of which all the data is used for other purposes. If the protocol is a dedicated solely to high resolution chest scans, then a helical acquisition should never be used.

☹ *Not all available kVp settings are tested.*

All available kVp settings must be included in the test data. This implies that all must be calibrated.

☹ *Artifacts are present in the uniformity image.*

The most common artifacts are cupping and ring artifacts. Subtle cupping and ring artifacts (especially near the periphery) may not be completely avoidable. Artifacts that are obvious or near the interior of the image warrant attention from service personnel.

☹ *The wrong window/level or reconstruction algorithm was used.*

These types of oversights should not occur but are quite frequent. Read the instructions and double-check your images before submitting. Several of the reviewer assessments are visual, therefore it is imperative that the correct window/level settings and algorithm are used.

CONCLUSIONS

The goal of the ACR CT accreditation program is to ensure consistent high quality CT imaging. The accreditation process should not be viewed as merely "jumping through hoops". Rather it should be viewed as an opportunity to determine any insufficiencies or opportunities for improvement, either in the scanner performance, the clinical protocols, or the physicist's understanding of the technology. In order to determine areas that may need attention, the physics tests need to be representative of the clinical practice and need to be performed using consistent testing methods. In an effort to promote clinically meaningful physics submissions and to reduce the possibility of oversights, the following checklists were created and will be available on the ACR website (www.acr.org). Remember that if you have any questions regarding the physics tests or submission process, you can contact the ACR by email (ctaccred@acr.org) or by phone (800.770.0145).

References

1. McCollough, CH, Bruesewitz, MR, McNitt-Gray, MF, Ruckdeschel, T, Payne, JT, Brink, JA, Zeman, RK, The phantom portion of the American College of Radiology (ACR) Computed Tomography (CT) accreditation program: Practical tips, artifact examples, and pitfalls to avoid, Med. Phys. 31 (9), September 2004.
2. American College of Radiology website, www.acr.org/accreditation/computed.aspx.
3. International Electrotechnical Commission, *Medical Electrical Equipment. Part 2-44: Particular Requirements for the Safety of X-ray Equipment for Computed Tomography*, IEC publication No. 60601-2-44, 2nd edition, Amendment 1.

ACR TABLE 1 CHECKLIST

- ❒ Techniques listed match those on the Clinical Test Image Data Sheet and the clinical protocols stored in the scanner and those descirbed in the practices' protocol book.
- ❒ mA value is listed—not mAs, mAs/slice, effective mAs, or quality reference mAs.
- ❒ If dose modulation is used, then the mA value for a typical patient should be used.
- ❒ Appropriate scan field of view is given (e.g., small FOV for pediatric abdomen).
- ❒ High-resolution chest protocol should use a very sharp algorithm (kernel).
- ❒ Correct detector configuration is given (N x T).
- ❒ Pitch is calculated correctly and is consistent with total collimation and table increment.
- ❒ Note if high-resolution chest protocol represents an additional reconstruction from a routine chest acquisition.

FILM SHEET 1 CHECKLIST

Box 1 (SMPTE) ❒ 95% square visible ❒ 5% square visible ❒ No bar pattern aliasing ❒ No artifacts	**Box 2 (Module 1, Alignment)** ❒ All 4 BBs visible (and not obscured by annotation) ❒ Image thickness < 2mm* ❒ Long wires centrally located (±1 wire) in both top AND bottom patterns. *If not possible, use thinnest available image thickness.	**Box 3 (Module 4, Alignment)** ❒ All 4 BBs visible (and not obscured by annotation) ❒ Image thickness < 2mm* *If not possible, use thinnest available image thickness.
Box 4 (Module 1, CT# calibration) ❒ Adult abdomen protocol used (axial equivalent if spiral/helical) ❒ ROIs centered over each cylinder ❒ Polyethylene CT# -107 to -87 HU ❒ Water CT# -7 to +7 HU ❒ Acrylic CT# +110 to +130 HU ❒ Bone CT# -850 to -970 HU ❒ Air CT# -1005 to -970 HU	**Box 5 (Module 1, H_2O & Slice width)** ❒ High-resolution chest image thickness (<2mm)* ❒ Water CT# -7 to +7 HU ❒ Measured image thickness is within 1.5mm of prescribed thickness *If not possible, use thinnest available image thickness.	**Box 6 (Module 1, H_2O & Slice width)** ❒ ≈3mm image thickness ❒ Water CT# -7 to +7 HU ❒ Measured image thickness is within 1.5mm of prescribed thickness
Box 7 (Module 1, H_2O & Slice width) ❒ ≈5mm image thickness ❒ Water CT# -7 to +7 HU ❒ Measured image thickness is within 1.5mm of prescribed thickness	**Box 8 (Module 1, H_2O & Slice width)** ❒ ≈7mm image thickness ❒ Water CT# -7 to +7 HU ❒ Measured image thickness is within 1.5mm of prescribed thickness	**Box 9 (Module 1, H_2O vs. kVp)** ❒ Lowest kVp used on scanner (see note at bottom of table) ❒ Water CT# -7 to +7 HU
Box 10 (Module 1, H_2O vs. kVp) ❒ Second lowest kVp used on scanner (see note at bottom of table) ❒ Water CT# -7 to +7 HU	**Box 11 (Module 1, H_2O vs. kVp)** ❒ Second highest kVp used on scanner (see note at bottom of table) ❒ Water CT# -7 to +7 HU	**Box 12 (Module 1, H_2O vs. kVp)** ❒ Highest kVp used on scanner (see note at bottom of table) ❒ Water CT# -7 to +7 HU

Boxes 9-12: If 4 different kVps are not available on the scanner then the box can be left blank (provide note to reviewer).

FILM SHEET 2 CHECKLIST

Box 1 (SMPTE) ❒ 95% square visible ❒ 5% square visible ❒ No bar pattern aliasing ❒ No artifacts	**Box 2 (Module 2, Low contrast res.)** ❒ Adult abdomen protocol used (with clinical scan type–helical or axial) ❒ Window/level = 100/100 ❒ 6mm rods visible	**Box 3 (Module 2, Low contrast res.)** ❒ Adult head protocol used (with clinical scan type–helical or axial) ❒ Window/level = 100/100 ❒ 6mm rods visible
Box 4 (Module 3, Uniformity & noise) ❒ Adult abdomen protocol used ❒ ROIs in correct locations ❒ Center-to-edge <7HU (<5 HU preferred) ❒ Central ROI CT# -7 to +7 HU ❒ No artifacts ❒ Window/level = 100/0	**Box 5 (Module 4, Spatial resolution)** ❒ Adult abdomen protocol used (especially algorithm/kernel) ❒ At least 5 lp/cm pattern resolved ❒ Window/level ≈ 100/1100	**Box 6 (Module 4, Spatial resolution)** ❒ High-resolution chest protocol used (especially algorithm/kernel) ❒ At least 6 lp/cm pattern resolved ❒ Window/level = 100/1100
Box 7 (CTDI phantom, Adult head) ❒ Adult head protocol used ❒ Axial scan with appropriate detector configuration (same or closest total collimation as clinical protocol) ❒ 16cm phantom in head holder ❒ Non-chamber holes filled ❒ Technique on film matches that on dosimetry spreadsheet, Table 1 of physics sheet, and clinical worksheet	**Box 8 (CTDI phantom, Ped abdomen)** ❒ Pediatric abdomen protocol used ❒ Axial scan with appropriate detector configuration (same or closest total collimation as clinical protocol) ❒ 16cm phantom on table top ❒ Non-chamber holes filled ❒ Technique on film matches that on dosimetry spreadsheet, Table 1 of physics sheet, and clinical worksheet	**Box 9 (CTDI phantom, Adult abdomen)** ❒ Adult abdomen protocol used ❒ Axial scan with appropriate detector configuration (same or closest total collimation as clinical protocol) ❒ 32cm phantom in head holder ❒ Non-chamber holes filled ❒ Technique on film matches that on dosimetry spreadsheet, Table 1 of physics sheet, and clinical worksheet
Box 10 (blank)	**Box 11 (blank)**	**Box 12 (blank)**

DOSIMETRY REMINDER

$CTDI_{vol}$ values exceeding ACR thresholds result in failure to achieve accreditation. The threshold values are as follows.

Exam	$CTDI_{vol}$ Threshold
Adult head	80 mGy
Pediatric abdomen	25 mGy
Adult abdomen	30 mGy

Failure to pass accreditation due to excessive dose is not common and is straightforward to remedy. The dose is linearly proportional to mAs. Therefore, if the dose is slightly above the limit, the mAs should be reduced proportionally. A slight reduction in mAs will likely have very little impact on image quality. However, changing the mAs on the clinical protocol implies that all tests that use the protocol will need to be repeated using the new technique and that the medical director approves the image quality at that dose.