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Assessment of Low-Contrast Resolution for the ACR CT Accreditation Program: What is the Impact of Iterative Reconstruction?

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Abstract

Objective—To compare contrast-to-noise ratio (CNR) thresholds with visual assessment of low-contrast resolution (LCR) in filtered-backprojection (FBP) and iteratively-reconstructed (IR) CT images.

Methods—ACR CT accreditation phantom LCR images were acquired at CTDIvol levels of 8, 12, and 16 mGy using two scanner models and reconstructed using one FBP and two IR kernels. Acquisitions were repeated 100 times. Three board-certified medical physicists blindly reviewed the LCR-section images. Pass-percentage rates (PPRs) using previous and current ACR CT accreditation criteria were compared.

Results—Observer PPRs for FBP images were <32%. For IR images, 5/18 settings/dose/model configurations had PPRs >32% (maximum 76.3%). For CNR evaluation of FBP images, PPRs for 15 configurations were >70%. For IR images, all PPRs were 96%.

Conclusions—The CNR threshold used by the ACR CT accreditation program yields higher PPRs than visual assessment of LCR, potentially resulting in lower quality images passing the ACR CNR criteria.

Keywords

Computed Tomography; Iterative Reconstruction; CT Accreditation; Low Contrast Resolution

Introduction

With the increasing processing power of modern computers, iterative reconstruction (IR) is now commercially available on many CT scanners. These reconstruction techniques can dramatically affect the appearance of CT images—generally resulting in reduced image noise although, in some cases, with a different noise texture relative to conventional filtered

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back projection (FBP) images¹. A reduction in image noise suggests the potential to acquire scans of acceptable noise levels using fewer photons. This capability can translate to reduced patient doses. This feature of IR is complicated, however, by the potential change in overall appearance of images processed with IR. One source of this change in appearance is the non-linear manner in which IR techniques affect the noise and spatial resolution of CT images²: IR allows substantial noise reduction while maintaining the high-contrast spatial resolution but degrading the low-contrast spatial resolution³⁻⁶. Therefore, the dose reduction potential is highly dependent on the contrast level involved in different diagnostic tasks⁷. For tasks requiring excellent low-contrast resolution, which is the primary image quality criterion associated with CT exams such as liver lesion detection and stroke imaging, it is critical to evaluate how much dose reduction can be facilitated by IR while still maintaining the required level of low-contrast resolution.

One example where a quantitative measure of low-contrast resolution is performed is with the American College of Radiology (ACR) CT accreditation program⁸. The program requires submission of images of low-contrast resolution (LCR) test objects, acquired using the clinical protocol for the relevant exams. Until recently, the ACR used medical physicist reviewers to subjectively assess the LCR based on the minimum objects size considered to be resolvable. This practice assured some minimal, albeit subjective, threshold for LCR that involved human observers and reasonably well represented clinical tasks such as detecting discrete low contrast lesions. The ACR has since replaced the visual assessment of LCR with a quantitative measure of contrast-to-noise ratio (CNR), thereby eliminating human subjectivity. The use of CNR measurements as a surrogate for human observer assessment of LCR is based on the assumption that the two measures are highly correlated. The purpose of this work was to test this assumption. Specifically, this study sought to determine whether similar pass rates would be achieved for the same image data sets using visual assessment of LCR and CNR measurements.

Materials and Methods

Data acquisition and image reconstruction

Image data were acquired using two scanner models from two different manufacturers, including a Lightspeed VCT (GE Healthcare, Waukesha, WI) and a Definition Flash (Siemens Healthcare) (Table 1). The Flash, which was equipped with Stellar detectors, was used in single-source mode. Three different reconstruction algorithms were employed for each acquisition, two of which were iterative reconstruction techniques. For the Lightspeed VCT, reconstructions were completed using the FBP algorithm “standard” as well as Adaptive Statistical Iterative Reconstructions (ASIR) at settings of 50 and 100. For the Definition Flash scanner, reconstructions were completed using the FBP kernel “B40” and the Sinogram Affirmed Iterative Reconstructions (SAFIRE) I40_3 and I40_5. Images were acquired of the low-contrast resolution section of the ACR CT accreditation phantom (model 464, Gammex, Inc., Fig. 1) at three different dose levels, including 8, 12, and 16 mGy (as indicated by the CTDI_{vol} value displayed on the scanner). Image acquisition and reconstruction were repeated 100 times for each combination of dose level and

reconstruction technique, yielding a total of 1800 images. All images were reconstructed using a nominal image thickness of 5 mm.

Human observer study

Visual analysis consisted of an independent randomized blind review by each of three ABR-certified medical physicists. A confidence scale was used to assign a reader score to the four 6-mm rods on each image: (1) definitely not visible; (2) not visible, a few rods barely visible; (3) some, but not all, rods visible; (4) all rods slightly visible; (5) all rods reasonably visible; and (6) all rods definitely visible. The visual image assessments were completed in a darkened room using a single calibrated monitor. Images were presented in 18 sets of 100 randomized images using an automated software tool for recording each score. The viewing screen was briefly blanked between each image and sessions were limited to 2 hours to prevent reviewer fatigue. A training session with all three reviewers was completed prior to the individual assessments to improve consistency in reader scores.

CNR evaluation

Numerical determination of CNR was performed on each image. The CNR was calculated as

$$\text{CNR} = \frac{|A - B|}{\text{SD}_B},$$

where “A” is the mean CT number within the 25-mm rod, “B” is the mean CT number of an equal-size region of interest (ROI) in an adjacent background-only area equidistant from isocenter, and “SD_B” is the standard deviation of CT numbers of the background-only region B. This definition is identical to that used by the ACR CT accreditation program for CNR measurement⁸. CNR was measured on each of the 1800 images.

Data and statistical analysis

Based on the past ACR CT accreditation criteria, a “pass” status was assigned to images that scored a 4 or above by at least two of the three physicists. A pass-percentage rate (PPR) was determined by calculating the percent of all images in a given 100-image set that achieved a “pass” status based on the human observer visual assessment scores. Because of variations in image quality due to photon statistics, all 100 images were used to determine PPR. Wilson 95% confidence limits were computed for PPRs.

For the analysis of the data using CNR measurements, a PPR was determined by calculating the percent of all images in a given 100-image set that had measured CNR values greater than or equal to 1.0, as specified by the current ACR requirements for an adult abdomen scan.

All statistical analyses were conducted using The SAS System (v. 9.3; Cary, NC).

Results

The human observer LCR assessment showed a general increase in mean reader score (improved LCR) with increasing dose (Fig. 2). An increase in the measured CNR value with increasing dose was also noted. For vendor 1 (Fig. 3), PPRs for human observer assessment of LCR for the FBP images were 0.7% (CI: 0.18, 2.41), 8.3% (CI: 2.27, 12.92), and 31.7% (CI: 25.81, 38.17) for dose levels of 8, 12, and 16 mGy, respectively. The corresponding PPRs using the ACR CNR criteria were 3% (CI: 0.010, 0.0845), 69% (CI: 0.594, 0.772), and 98% (CI: 0.930, 0.994). The human observer PPRs improved slightly with the IR images and increasing dose, while the PPRs determined by CNR increased dramatically with the IR images, with little dependence on dose over the range investigated (Fig. 3). For the ASIR_50 images, the human observer PPRs at 8, 12, and 16 mGy were 5.3% (CI: 3.18, 8.82), 16.7% (CI: 12.19, 22.51), and 46.7% (CI: 33.86, 53.60), respectively. The corresponding PPRs for the CNR method were 96% (CI: 0.902, 0.984), 100% (CI: 0.963, 1.000), and 100% (CI: 0.963, 1.000). For the ASIR_100 images, the observer PPRs were 8.3% (CI: 5.27, 12.92), 25.3% (CI: 19.27, 32.53), and 51.5% (CI: 45.08, 57.88) at 8, 12, and 16 mGy, respectively. Using the CNR criteria, the PPRs for the ASIR_100 images were all 100% (CI: 0.963, 1.000) at all dose levels investigated.

For Vendor 2 (Fig. 4), the human observer PPRs for the FBP images were 2.7% (CI: 1.18, 5.93), 8.4% (CI: 5.64, 12.31), and 21.0% (CI: 16.17, 26.81), for dose levels of 8, 12, and 16 mGy, respectively. The corresponding PPRs for the FBP images using the ACR CNR criteria were 27% (CI: 0.193, 0.364), 98% (CI: 0.930, 0.994), and 100% (CI: 0.963, 1.000). For I40_3, The observer PPRs at 8 mGy, 12 mGy, and 16 mGy were 7.7% (CI: 4.85, 11.90), 28.1% (CI: 22.16, 34.90) and 56.7% (CI: 49.45, 63.61), respectively. The corresponding PPRs using the CNR criteria were all 100% (CI: 0.963, 1.000) at all dose levels. The human observer PPRs for the I40_5 images were 17.7% (CI: 13.10, 23.39), 46.8% (CI: 39.93, 53.83), and 76.3% (CI: 69.85, 81.79) at 8, 12, and 16 mGy, respectively. The CNR-based PPRs were 100% (CI: 0.963, 1.000) at all dose levels for the I40_5 images.

Discussion

Although an increase in CNR with IR has been previously shown³, the dramatic discrepancy between the PPRs between the human observer and the CNR methods suggests that the two methods do not provide an equivalent assessment of LCR; each can result in different success or failure rates for the LCR test used as part of achieving ACR CT accreditation. This has implications for more than simply achieving accreditation. Clinical image quality is assumed to be acceptable for exams used in the accreditation process if a site has successfully obtained ACR accreditation. The previous LCR accreditation criteria (ability to visualize all four of the 6mm rods) established a minimum image quality for LCR when assessed by human observers that appears to no longer be met with use of IR and decreased dose levels (relative to 16 mGy and FBP). This implies that the LCR previously required to obtain ACR CT accreditation need not be achieved using the current CNR-based method criteria.

It is important to note that visual assessment of LCR by human observers is somewhat subjective, while CNR measurements are not reader dependent. However, because the task requires seeing all four low-contrast rods, there is an objective standard on which readers make their decisions. Additionally, the blinded review of 100 images yielded a PPR of approximately 32% for the visual assessment method. This low pass rate is not experienced in the ACR accreditation program because sites are told the review criteria in advance, and hence can select in an unblended fashion an image for submission that meets the published criteria.

The CNR-based assessment of LCR had a much higher PPR, for both reconstruction methods and all doses. This suggests that, compared to the assessment of human observers, quantitative assessment of only CNR leads to images with reduced LCR being deemed acceptable. This is particularly true for IR images, where the CNR pass rate was essentially 100% at all dose levels for both vendors, even though in many cases the human observer scores indicated poor LCR. Consequently, the current CNR measurement method and passing criteria represent a lowering of the ACR standard. This was most prevalent when IR was used. These results suggest that an alternative method for assessing LCR are warranted for IR images ⁹.

One option for objective assessment of LCR with IR images would be to use model observers ⁹ or detectability ¹⁰ approaches. Regardless, until a resolution to the disassociation of the CNR measurement to human observer assessments of LCR is implemented, the LCR performance of images that pass the ACR LCR test can be dramatically degraded relative to what was previously required. CT facilities must be aware that passing the LCR requirement of the ACR CT program does not ensure that LCR is comparable to the previous standards used by the accreditation program, especially when IR is used.

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Figure 1.
The low contrast resolution section of the ACR CT accreditation phantom.

Figure 2.

The distribution of mean human observer scores for image acquisitions from a) Vendor 1 and b) Vendor 2; and the distribution of CNR measurements for c) Vendor 1 and d) Vendor 2. The dashed line represents the “pass” level for each method.

Figure 3.

Vendor 1 pass-percentage results as determined by 2 of 3 human observers assigning a passing score, and as determined by the ACR criteria of CNR ≥ 1.0 . Error bars indicate the Wilcoxon 95% confidence intervals. Images acquired at a CTDIvol of a) 8 mGy, b) 12 mGy, and c) 16 mGy.

Figure 4.

Vendor 2 pass-percentage results as determined by 2 of 3 human observers assigning a passing score, and as determined by the ACR criteria of CNR ≥ 1.0 . Error bars indicate the Wilcoxon 95% confidence intervals. Images acquired at a CTDIvol of a) 8 mGy, b) 12 mGy, and c) 16 mGy.

Table 1

Reconstruction settings and dose levels used in this study. 100 images were acquired using each combination of IR setting and dose level for each scanner.

	LightSpeed VCT (GE)	Definition Flash (Siemens)
FBP reconstruction	STD	B40
IR-Type	ASIR	SAFIRE
IR Settings	ASIR_50 and ASIR_100	I40_3 and I40_5
Detector configuration	64×0.625 mm	128×0.6 mm *
Helical pitch	0.983	1.0
Dose levels *	8, 12 and 16 mGy	
Tube potential	120 kVp	
Image thickness	5 mm	

* CTDIvol, as displayed on scanner console.