Evaluation of image quality in digital radiography based on marginal detectability

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INTRODUCTION

Although diagnostic quality of an image can be subjective, it may be described in terms of image noise and feature contrast (CNR). A common FOM for IQ optimization is CNR^2/D [1], where D is the detector dose, which balances image quality and safety.

But, consider an emphasis on lowering patient dose while still requiring acceptable diagnostic quality. In this case, there is a baseline CNR (CNR_B) and a reference detector dose (D_B). If the dose is lowered so that $D_{B'} < D_B$ and $CNR_{B'} < CNR_B$, will the ability to make a clinical diagnosis based on a feature be lost?

The CNR of some features will be high enough CNR to always be visible, and some will be low enough to never be visible. It is reasonable, then, to focus on features at the borderline of visibility ("marginal features") and how the detectability of just those features is affected by lowering the detector dose.

AIM

This research will assess the significance of the change in marginal feature visibility due to a drop in detector dose by using the method described by Chao [2] where the distribution of background values sampled for an ROI size provides the variance in the background at that size. This variance provides an uncertainty on the CNR, which can then be used to determine the significance of a change in CNR.

METHOD

- The experiment used a Siemens x-ray room retrofitted with two detector models ("1A" and "1B") from vendor 1 and a portable x-ray unit with a digital detector from vendor 2.
- Image quality phantoms were constructed using an image quality object and variable thicknesses of Lucite.
  - The image quality object was an aluminum contrast-recovery plate with milled low-contrast targets in a 10x10 matrix of different diameters (columns) and hole depths (rows). The Lucite thicknesses were 2", 3", 5", and 8". The image quality phantoms were placed directly on the detector/grid, with the Lucite distal to the detector.
- Two images were produced for each phantom build using a kVp between 55 and 110 (tied to Lucite thickness [3]) and a mAs producing an EI of approximately 220 or 140.

ANALYSIS

To determine marginal features, the images were put in a pseudo-random order and then scored by a group of seven physicists and technologists for the last resolvable feature in each column. Given the array of features $f_{i,j}$ where there are iso-contrast rows $j \in \{1,2,...10\}$ and iso-diameter columns $i \in \{1,2,...10\}$, the marginal features for each feature size *j* were identified as the feature one step before and one step after the mean score of the readers (e.g., for a score of '7.4" the marginal features would be in rows $j = 7$ and $j = 8$).

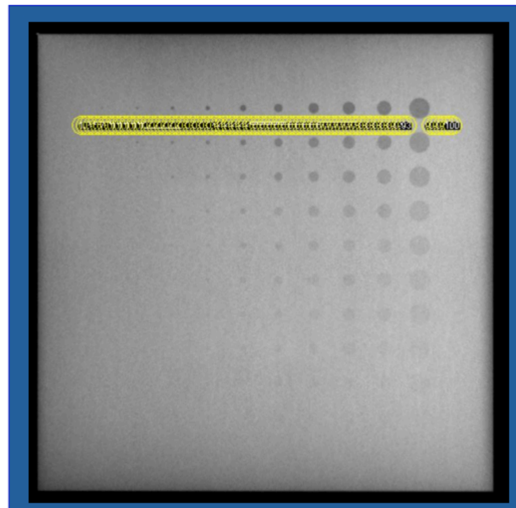
To measure the $CNR_{i,j} \pm \sigma_i$ for each feature $f_{i,j}$ of the low contrast phantom:

- First, the background pixel intensity was sampled in the space below each row of isocontrast elements (between $f_{i,1}$ and $f_{i,2}$, between $f_{i,2}$ and $f_{i,3}$, ...) with ROIs of the same area as the largest feature (size 1). 100 ROIs were measured and fitted with a polynomial of 4th or 5th power depending on whether the distribution appeared even or odd. See Figures 1 and 2 for examples of sampling and background fit.

- Next, the background was sampled at 100 locations (evenly distributed along the coordinates covered by the polynomial fit) using ROI sizes corresponding to all feature sizes. The measured values were reduced by the fitted background value at each ROI coordinate and the residual represented the background variability at the spatial frequencies of interest. A histogram of the residuals was generated for each ROI size, which was well-fitted by a Gaussian in all cases ($R^2 > .90$). The σ from the Gaussian fit for each ROI size was used to determine the uncertainty on the CNR calculation. See Figures 3 and 4 for the sampling and the fit.

- Then, the CNR of each low-contrast feature $f_{i,j}$ was calculated by placing an ROI of slightly smaller size than the target area over the feature to measure the signal. The feature background was measured with an annular ring ROI, of similar size to the signal ROI, that surrounded the feature. See Figures 5 and 6 for the signal and background feature ROIs. The noise used in calculating the CNR was determined from the averaged ROI standard deviation of background samples for that size. The uncertainty on the CNR came from the σ determined in the previous step. The difference in CNR for each high and low EI image pair for corresponding features: $\Delta CNR_{i,j}$ was then calculated. The uncertainty on this value was the sum in quadrature of the individual uncertainties.

- The significance of the change in CNR when going from high to low EI was determined using the chi-squared statistic and a p-value of .05. The significance was determined separately for $\Delta CNR_{i,j}$ of all marginal features and also for $\Delta CNR_{i,j}$ of only the 5 largest marginal features ($i \in \{1,2,..5\}$). The smallest features were only 1-2 pixels in diameter and the certainty of the measurement matrix aligning with the feature arrangement within 2 pixels was low.



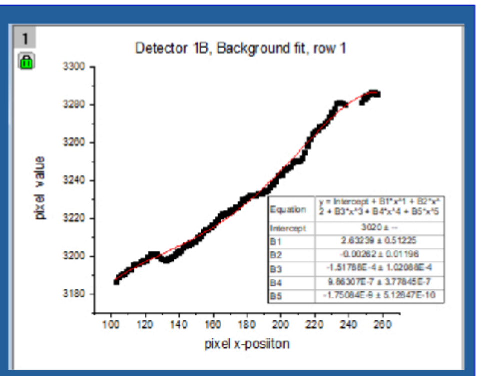
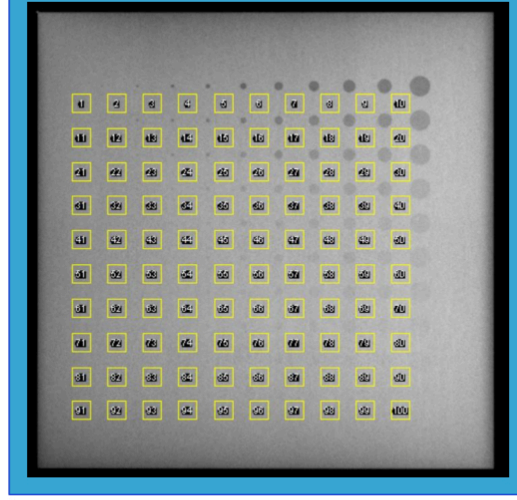


Figure 1 (left): background ROI for row 1
Figure 2 (top): fit for row 1 background



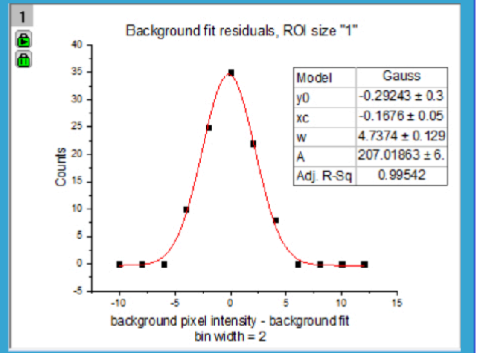
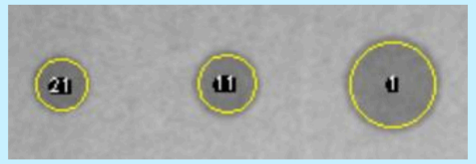


Figure 3 (left): background ROI for size 1
Figure 4 (top): fit for size 1 residual distribution



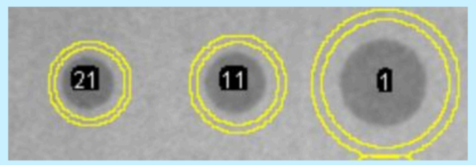


Figure 5 (left): Signal ROI for row 1, columns 1 - 5
Figure 6 (right): Local background ROI for row 1, columns 1 - 5

Lucite:	2"	3"	5"	8"
Detector 1A	.008	.000	.091	.720
Detector 1B	.342	.119	.027	.197
Detector 2	.384	.798	.000	.789

Table 1: P-values for detectors 1A, 1B, and 2

A p-value < 0.05 indicates a significant change in image quality when lowering the dose

RESULTS

For phantom 2" & 3": The results for 1B and 2 show no significant change in the image quality while 1A had a significant change in image quality.
For phantom 5": Detector 1B seemed to have an artifact in the low dose image, reducing the CNR for one feature in a way that greatly increased the chi-square.
For phantom 8": the variability in the background was greater than the difference in CNR, so the change was not significant for any detector.

CONCLUSIONS

Based on both reader scoring and CNR measurements of phantoms, patient doses can be lowered by 35% for detectors 1B and 2 without a statistically significant difference in lesion perceptibility of the marginally visible feature. This is consistent with the clinical experience of our technologists, who have lowered technique to EI 140 for detector 1B, and our radiologists who have been satisfied with the results.

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