The Effect of Patient Organ Dose Reduction on Diagnostic Accuracy of a CT Clinical Task

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Purpose

**Background and Purpose:**

Abdominal pain is the most common reason for Emergency Room visits, with up to 8 million visits per year in the US for this complaint. Right lower quadrant (RLQ) pain accounts for a large percentage of these cases. Differential diagnosis for RLQ pain includes many etiologies, among which appendicitis is the most common condition (14%) requiring surgery in patients with abdominal pain (reference 1).

CT has emerged as the modality of choice for evaluation of patients with RLQ pain, with sensitivity and specificity for diagnosing appendicitis of 90%-100% (reference 2). Because it has become commonly used, radiation exposure from CT examinations has emerged as an issue of concern, especially as this condition is more common among a younger population.

Simple image quality metrics such as noise or CNR have been used to assess the performance of CT scanners. However, these metrics obtained in phantoms are too simple to represent the actual diagnostic outcome from CT images, considering the variety of the nature of the clinical tasks.

On the other hand, metrics such as CTDI or DLP have been used to describe radiation dose from CT. However, they only quantify the output of CT scanners and do not represent the radiation dose actually delivered to patients. Organ dose is a preferred dose metric, which takes size and anatomical characteristics into account for individual patients.

The purpose of this study is to investigate the tradeoffs between diagnostic performance and individual patient dose in CT exams performed for ruling out appendicitis.
Methods and Materials

Case collection:

The study was IRB approved for data collection. Raw data files for more than 100 patient cases were collected (raw projection data) from Siemens Sensation 64 CT scanners. Either IV contrast or IV and Oral contrast administered. The imaging protocol is as follows:

- 120kVp
- 250 Effective mAs (CareDose4D On)
- 24 x 1.2 mm collimation
- Pitch 1
- 5mm reconstruction thickness

Medical records were reviewed to establish the clinical diagnosis. A review committee consisting of two experienced senior radiologists selected 20 patient cases for a pilot study with 10 positive cases and 10 negative cases, confirmed by review of patient’s charts. These cases include:

- Obvious positive cases
- Subtle positive cases
- Obvious negative cases
- Subtle negative case

Simulating lower dose images:

A Raw data based algorithm was developed to simulate lower dose images by taking into account:

- Scanner photon flux at different mAs levels
- Scanner electronic noise
- Scanner geometry and bowtie filtration

This method was validated using phantom images. This tool was used to add noise to all 20 patient cases simulating specific lower mAs levels:

- 100% (original images)
- 70% 
- 50%
- 30%
- 20%

These simulated raw data files were used to reconstruct images in both axial and coronal views at 5 mm intervals (as in clinical practice). Figure 1 to 5 shows an example of axial images of a patient at 100%, 70%, 50%, 30%, and 20% dose levels, respectively.
**Observer study:**

6 observers who are attending radiologists with different levels of experience participated in the study. These include:

- 2 non-abdominal trained, occasional CT readers who primarily read non-CT images
- 2 non-abdominal trained, routine CT readers who primarily read non-abdominal CT images
- 2 abdominal trained, routine CT readers who primarily read abdominal CT images

Each observer participated in 5 reading sessions with 20 image sets in each session (totaling 100 image sets per reader). There was at least a 2 weeks wash out interval between sessions for each clinical reader. To further minimize the bias, the order of the patient cases and the order of the dose level to be presented to the observer were randomized, so that the lower dose images appear more often in the earlier sessions (but some appear in later sessions), and higher dose images appear more often in the later sessions (but some also appear in earlier sessions).

In order to obtain the diagnostic accuracy, every observer was required to rate their confidence in a diagnosis of appendicitis based on a 5 point scale:

- Definitely positive for appendicitis (5)
- Probably positive for appendicitis (4)
- Indeterminate (3)
- Probably negative for appendicitis (2)
- Definitely negative for appendicitis (1)

Observer ratings were then compared to diagnostic truth established by medical records review for ROC analysis.

**Organ Dose Estimation:**

Organ dose was estimated using a previously developed method based on Monte Carlo simulated data, incorporating the accurate model of the CT scanner, as well as the size for each patient. The liver was contoured for each of the 20 patients for organ dose estimations. Tube current modulation schema for each patient was extracted from the raw projection data and used as input for Monte Carlo simulations. Using this method, the dose to liver was obtained for the original 100% dose level for each patient. Since organ dose is proportional to mAs, the organ dose at 70%, 50%, 30%, and 20% were obtained by scaling by the factor of mAs.
The patients were stratified into 5 different groups based on the liver dose, with 20 cases within each group. These liver dose ranges are: 13.48-22.04mGy, 9.63-13.33mGy, 6.37-9.52mGy, 3.99-6.33mGy, and 2.04-3.85mGy.

**Receiver Operating Characteristic (ROC) study:**

ROC methodology is a tool to evaluate observer performance in terms of their abilities to use image data to classify patients as "positive" or "negative" for a particular disease. ROC curve is a plot of sensitivity (true positive fraction) versus 1-specificity (true negative fraction) as the threshold of decision making gradually changes. It starts at (0,0) and ends at (1,1).

Area Under the ROC Curve (AUC) is a metric to evaluate the overall performance by taking variations of threshold into account. For example, an ideal performance has an AUC of 1 (ROC curve is all 1); and random guess has an AUC of 0.5 (ROC curve is unity line).
Images for this section:

Fig. 1: 100% dose level for an example patient case.

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Fig. 2: 70% dose level for an example patient case.

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**Fig. 3:** 50% dose level for an example patient case.

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Fig. 4: 30% dose level for an example patient case.

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Fig. 5: 20% dose level for an example patient case.
Results

**ROC analysis by pooling reading results from all 6 observers:**

The ROC curves and AUC values at all 5 liver dose groups by pooling the reading results for all 6 observers are shown in Fig. 6 on page 12 and Fig. 7 on page 12.

**ROC analysis by separating observers into subgroups:**

Individual ROC analysis was performed for each of the subgroup of the 6 observers. These includes:

- 2 primarily non-CT image readers
- 2 primarily non-abdominal CT readers
- 2 primarily abdominal CT readers

The ROC curves and AUC values at all 5 liver dose groups for the 2 non-CT image readers are shown in Fig. 8 on page 16 and Fig. 9 on page 15.

The ROC curves and AUC values at all 5 liver dose groups for the 2 non-abdominal CT readers are shown in Fig. 10 on page 13 and Fig. 11 on page 15.

The ROC curves and AUC values at all 5 liver dose groups for the 2 abdominal CT readers are shown in Fig. 12 on page 14 and Fig. 13 on page 17.
Fig. 6: ROC curves at 5 liver dose ranges for all 6 observers.

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Fig. 7: AUC values at 5 liver dose ranges for all 6 observers.

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Fig. 10: ROC curves at 5 liver dose ranges for 2 non-abdominal CT readers.

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**Fig. 12:** ROC curves at 5 liver dose ranges for 2 abdominal CT readers.

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**Fig. 11:** AUC values at 5 liver dose ranges for 2 non-abdominal CT readers.

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**Fig. 9:** AUC values at 5 liver dose ranges for 2 non-CT image readers.

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**Fig. 8:** ROC curves at 5 liver dose ranges for 2 non-CT image readers.

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**Fig. 13:** AUC values at 5 liver dose ranges for 2 abdominal CT readers.

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Conclusion

1. For primarily CT readers (including both abdominal and non-abdominal CT readers), the diagnostic performance is nearly perfect when liver organ dose > 6mGy.
2. For primarily abdominal trained CT readers, the diagnostic difference is not substantially compromised even at 2-4mGy liver dose range.
3. Non-CT image readers have inconsistent performance across dose ranges (e.g., the performance is the highest at 2-4mGy dose range), possibly due to the fact that they spent more time interpreting images on earlier sessions, which have a higher number of simulated low dose images.
References


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