Published in final edited form as:

Proc SPIE Int Soc Opt Eng. 2016 February ; 9783: . doi:10.1117/12.2217009.

Evaluation of a projection-domain lung nodule insertion technique in thoracic CT

Chi Ma, Baiyu Chen, Chi Wan Koo, Edwin A Takahashi, Joel G Fletcher, Cynthia H McCollough, David L Levin, Ronald S Kuzo, Lyndsay D Viers, Stephanie A Vincent Sheldon, Shuai Leng, and Lifeng Yu

Department of Radiology, Mayo Clinic, Rochester, MN

Abstract

Task-based assessment of computed tomography (CT) image quality requires a large number of cases with ground truth. Inserting lesions into existing cases to simulate positive cases is a promising alternative approach. The aim of this study was to evaluate a recently-developed raw-data based lesion insertion technique in thoracic CT. Lung lesions were segmented from patient CT images, forward projected, and reinserted into the same patient CT projection data. In total, 32 nodules of various attenuations were segmented from 21 CT cases. Two experienced radiologists and 2 residents blinded to the process independently evaluated these inserted nodules in two sub-studies. First, the 32 inserted and the 32 original nodules were presented in a randomized order and each received a rating score from 1 to 10 (1=absolutely artificial to 10=absolutely realistic). Second, the inserted and the corresponding original lesions were presented side-by-side to each reader, who identified the inserted lesion and provided a confidence score (1=no confidence to 5=completely certain). For the randomized evaluation, discrimination of real versus artificial nodules was poor with areas under the receiver operative characteristic curves being 0.69 (95% CI: 0.58–0.78), 0.57 (95% CI: 0.46–0.68), and 0.62 (95% CI: 0.54–0.69) for the 2 radiologists, 2 residents, and all 4 readers, respectively. For the side-by-side evaluation, although all 4 readers correctly identified inserted lesions in 103/128 pairs, the confidence score was moderate (2.6). Our projection-domain based lung nodule insertion technique provides a robust method to artificially generate clinical cases that prove to be difficult to differentiate from real cases.

Keywords

Image quality assessment; radiation dose reduction; lesion simulation; lesion insertion; thoracic CT; lung nodules; observer study

1. Purpose

A large number of cases with positive findings is needed to establish the task-based assessment of image quality in computed tomography (CT) [1]. These cases can be collected prospectively through carefully designed clinical trials or retrospectively by querying a large amount of archived clinical exams. For example, in a recent multi-center study to evaluate the dose reduction potential of an iterative reconstruction (IR) in a lung-nodule detection task, over 100 patients with known or suspected lung tumors were prospectively collected, which yielded 221 nodules for the study [2]. This case collection process can be very time

and resource intensive. In addition, it can be challenging to establish the diagnostic truth. As an alternative, one can artificially generate a large number of patient cases with positive findings by inserting lesions into existing negative patient cases. This approach is efficient and the truth of lesion characteristics can be readily established.

Most of the existing lesion insertion techniques were performed in image domain after image reconstruction [3–6]. As a result the appearance of lesions cannot accurately reflect the impact of CT acquisition and reconstruction process, making the assessment results of clinical CT image quality questionable. We recently developed a raw-data based lesion insertion technique that allows segmented lesions from real patients to be reinserted back into the patient projection data prior to image reconstruction, which can maintain the process of the original CT acquisition and reconstruction in the simulation and may have a great potential to provide simulated lesions with realistic appearance [7].

There has been growing interest in optimizing radiation dose in lung cancer screening CT using various novel reconstruction and data acquisition techniques. The lesion insertion tool in projection data domain may provide a powerful tool for designing efficient observer studies for this purpose. The aim of the current study was to validate the lesion insertion technique by evaluating how realistic the inserted lesions appear in thoracic CT in a radiologist observer study.

2. Methods

2.1. Projection domain lesion insertion

The projection domain lesion insertion technique is briefly described below [7]. Raw data acquired from patients on a commercial CT scanner (Somatom Definition Flash, Siemens Healthcare, Forchheim, Germany) was decoded with the aid of the vendor. Two types of information were obtained: 1) projection data, which record the attenuation information about the patient along each projection view; 2) CT acquisition parameters, including the tube potential, tube current, projection angle, gantry geometry, and table position. Next, the scanning acquisition parameters, together with a lung nodule previously segmented from multiple thin slice images of a patient exam and a desired location for lesion insertion, were sent to a forward projection program to compute lesion projections. The forward projection program mathematically simulated the CT acquisition process; as a result, the lesion projections were similar to what would be acquired by physically scanning the lesion. The lesion projections were added into the original patient projections and then reconstructed on the scanner to generate images with inserted lesions.

2.2. Patient and lesion selection

Twenty-one thoracic CT exams were retrospectively included in the evaluation. These exams were performed on a Somatom Definition Flash clinical CT scanners (Siemens Healthcare) using a routine chest protocol (128x0.6 mm, 120 kV, 0.28 second rotation time, and a quality reference mAs of 140). Images were reconstructed with 1.5 mm image slice thickness and 1 mm increment using a B46f kernel. In total, 32 nodules of various attenuations were segmented from these 21 cases. The nodules were selected to represent different

characteristics of lesions including size, contrast, shape and pathology. The 32 nodules were then reinserted into the same patient's scan, but at different anatomical locations. The new location of each inserted nodule was selected by an experienced thoracic radiologist with 11 years of experiences to simulate the corresponding anatomical background of each nodule. Figure 1 shows examples of inserted lung nodules of different sizes, attenuation and shapes. The final database consists of a total of 64 lesions including 32 inserted simulated lesions and 32 original real lesions.

2.3. Observer study

Two experienced thoracic radiologists with 20 and 21 years of experiences and two radiology residents with 2 and 4 years of experiences performed an observer study with this database. The observer study was divided into two sub-studies: a randomized scoring study and a two-alternative-forced-choice (2AFC) study.

2.3.1 Randomized scoring study—The 32 inserted and the 32 original nodules were mixed together and presented in a randomized order. The readers who were blinded to whether the nodules were artificial or real, reviewed the cases independently and provided a rating score from 1 to 10 (1=absolutely artificial to 10=absolutely realistic) for realism of each lesion. The study was conducted on a dual monitor workstation (Advantage Workstation, GE Healthcare, Waukesha, WI) with only one active monitor.

2.3.2 Two-alternative-forced-choice (2AFC) study—The 2AFC test was conducted as an established controlled measure of observers' ability to distinguish between two features [8]. The inserted and the corresponding original lesions were presented side-by-side on the dual-monitor workstation with both monitors active, the readers identified the inserted lesion and provided a confidence score (1=no confidence to 5=completely certain). For each reader, the 2AFC study was conducted after the randomized scoring study.

During both studies, readers were allowed to scroll back and forth through image slices, and to adjust the window/level from the default lung window setting (window center = -600 HU, window width = 1500 HU) in order to assimilate clinical practice.

3. Results

For the randomized scoring study, receiver operative characteristic (ROC) curves[9] were plotted along with the 95% confidence interval, for two radiology residents, two radiologists, and all four readers in Figure 2. Discrimination of real versus inserted nodules was poor with areas under the ROC curves (AUC) being 0.69 (95% CI: 0.58–0.78), 0.57 (95% CI: 0.46–0.68), and 0.62 (95% CI: 0.54–0.69) for the 2 radiologists, 2 residents, and all 4 readers, respectively. Figure 3 shows example cases with real and inserted lesions receiving similar scores for each reader.

In the 2AFC study, the 2 radiologists correctly identified inserted lesions in 55/64 pairs, the confidence score was moderate (2.4 out of 5). Among those correctly identified nodules (55), only 16 of them had a confidence score greater than 3. Similarly, the 2 residents were correct in 48/64 pairs with a confidence score of 2.7 out of 5. Among those correctly

identified nodules (48), only 17 of them had a confidence score greater than 3. Figure 4 shows example cases with confidence score 2 and at least one reader incorrectly classified the lesion pair.

4. Discussion and Conclusions

We performed an observer study to assess the realism of lung nodules simulated using a newly developed projection domain lesion insertion technique. Our results showed that the artificially generated lung nodules were difficult to be differentiated from real nodules by radiologists, indicating that the projection domain lesion insertion technique can be used to create patient cases with realistically appearing nodules.

To the best of our knowledge, the evaluated lesion insertion tool was the first to insert segmented patient lesions into *real* patient raw data to simulate positive cases. The validation of inserted lung nodules performed in this study may facilitate efficient and quantitative virtual clinical trials to optimize image quality and radiation dose in thoracic CT and lung-cancer screening CT.

Acknowledgments

This project was supported by NIH Grant Number U01 EB017185 from the National Institute of Biomedical Imaging and Bioengineering.

References

1. Fletcher JG, Yu L, Li Z, et al. Observer Performance in the Detection and Classification of Malignant Hepatic Nodules and Masses with CT Image-Space Denoising and Iterative Reconstruction. *Radiology*. 2015; 276(2):465–78. [PubMed: 26020436]
2. Nagatani Y, Takahashi M, Murata K, et al. Lung nodule detection performance in five observers on computed tomography (CT) with adaptive iterative dose reduction using three-dimensional processing (AIDR 3D) in a Japanese multicenter study: Comparison between ultra-low-dose CT and low-dose CT by receiver-operating characteristic analysis. *European journal of radiology*. 2015; 84(7):1401–12. [PubMed: 25892051]
3. Madsen MT, Berbaum KS, Ellingson AN, et al. A new software tool for removing, storing, and adding abnormalities to medical images for perception research studies. *Academic radiology*. 2006; 13(3):305–12. [PubMed: 16488842]
4. Li X, Samei E, Delong DM, et al. Three-dimensional simulation of lung nodules for paediatric multidetector array CT. *The British journal of radiology*. 2009; 82(977):401–11. [PubMed: 19153182]
5. Hoe CL, Samei E, Frush DP, et al. Simulation of liver lesions for pediatric CT. *Radiology*. 2006; 238(2):699–705. [PubMed: 16371579]
6. Solomon J, Samei E. A generic framework to simulate realistic lung, liver and renal pathologies in CT imaging. *Physics in medicine and biology*. 2014; 59(21):6637–57. [PubMed: 25325156]
7. Chen B, Ma C, Yu Z, et al. Lesion Insertion in Projection Domain for Computed Tomography Image Quality Assessment. *Proceedings of SPIE--the International Society for Optical Engineering*. 2015:9412.
8. Lapid E, Ulrich R, Rammsayer T. On estimating the difference limen in duration discrimination tasks: a comparison of the 2AFC and the reminder task. *Perception & psychophysics*. 2008; 70(2): 291–305. [PubMed: 18372750]
9. Metz CE. ROC methodology in radiologic imaging. *Investigative radiology*. 1986; 21(9):720–33. [PubMed: 3095258]

Figure 1.

Examples of inserted lung nodules with different sizes, attenuation and shapes. From a to c, solid, part-solid, and ground glass nodules. The display window width is 1500 HU and the window level is -600 HU.

Figure 2. Fitted ROC curve (blue) and 95% confidence interval for (a) two radiology residents, (b) two radiologists, and (c) all four readers.

Figure 3.
Example cases that radiologists cannot differentiate real and inserted nodules in random scoring study.

Figure 4.
Examples of real and inserted lesions with confidence score 2 and at least one reader incorrectly classified the lesion pair in 2AFC study.