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Evaluation of Adult Lung CT Image for Ultra-Low-Dose CT Using Deep Learning Based Reconstruction*

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Abstract

Although CT has an advantage in describing the three-dimensional anatomical structure of the human body, it also has a disadvantage in that high doses are exposed to the patient. Recently, a deep learning-based image reconstruction method has been used to reduce patient dose. The purpose of this study is to analyze the dose reduction and image quality improvement of deep learning-based reconstruction (DLR) on the adult's chest CT examination. Adult lung phantom was used for image acquisition and analysis. Lung phantom was scanned at ultra-low-dose (ULD), low-dose (LD), and standard dose (SD) modes, and images were reconstructed using FBP (Filtered back projection), IR (Iterative reconstruction), DLR (Deep learning reconstruction) algorithms. Image quality variations with respect to varying imaging doses were evaluated using noise and SNR. At ULD mode, the noise of the DLR image was reduced by 62.42% compared to the FBP image, and at SD mode, the SNR of the DLR image was increased by 159.60% compared to the SNR of the FBP image. Based on this study, it is anticipated that the DLR will not only substantially reduce the chest CT dose but also drastic improvement of the image quality.

Keywords : Deep learning reconstruction(DLR), Ultra-low-dose (ULD), Computed tomography(CT)

Major Classification Code: Artificial Intelligence

1. Introduction

Computed tomography (CT) is an imaging method that collects attenuation data transmitted through a patient, reconstructs the data using mathematical techniques in a computer system, creating a cross-sectional image of the human subject. CT has the advantage of obtaining three-dimensional images and the exam time being fast but has the disadvantage of higher radiation exposure levels than compared to normal X-rays (Brenner & Hall, 2007). In the case of chest CT, for example, a dose of approximately 10 mSv per person is used for a single examination, which is

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substantially larger than that of 0.1 mSv of chest X-ray (Kim, Cho, & Park, 2010). The medical field is the area that delivers the highest exposure to artificial radiation, and among them, the exposure dose of CT is the most problematic. According to the Korea Centers for Disease Control and Prevention, the number of CT patients steadily increased from 2016 to 2019. Although it was only 3.2% of the total medical radiation examination rate as of 2019, the CT exposure dose accounted for 38.7% of the total medical radiation exposure dose. Therefore, studies to improve image quality while reducing the exposure dose of patients are actively investigated.

During the CT scan, it mainly uses filter back projection (FBP), a method of transmitting subjects from various directions, correcting filters, and iterative reconstruction (IR), a method of repeatedly correcting projection values measured through subjects from several directions to obtain mean attenuation coefficient values. For dose reduction purposes, IR is superior to FBP, and image quality can be further improved. Considering the high exposure dose of CT, an image reconstruction technique using deep learning reconstruction (DLR), which is an effective method for dose reduction compared to IR, has recently been introduced. In particular, the screening test for lung diseases by low-dose CT has attracted attention because images with high sensitivity to detect diseases can be obtained while reducing exposure doses. In particular, the low-dose CT screening test for lung disease has attracted attention because it is possible to obtain an image with high sensitivity for detecting diseases while reducing the exposure dose. In addition, a CT scan is non-invasive, has a short test time, and is excellent in terms of cost-effectiveness without using any special pretreatment or contrast agent for the diagnosis (Willemink & Noel, 2019).

Recently, it became feasible to obtain CT images at 20% lower doses and 3-4 times faster than before using a deep convolutional neural network (DCNN). This method can effectively remove noise by learning more than 100,000 high-definition images and images without noise removal. Therefore, the purpose of this study is to quantitatively evaluate the CT image quality of DLR compared to conventional FBP and IR.

2. Literature Review

The image reconstruction methods used to compare image quality in this study are FBP, IR, and DLR. (See Fig. 1)

FBP is a technique for reconstructing an object by removing low frequency and augmenting the high frequency by performing a convolution process to minimize the blur formed around the center of the data before performing the back projection of X-ray projection data. Such a relatively simple process provides a fast image reconstruction speed, the noise level of the image increases during low-dose imaging, which in turn limits the dose reduction. IR is a technique that performs an update process at each iteration until a satisfactory mathematical condition is met through an iterative process from measured projection data. Although the reconstruction time is longer, it is advantageous as a high-quality image can be reconstructed from low-dose imaging data. At the initial phase, FBP was used more dominantly; however, recently, the demand for dose reduction has been increasing. Therefore the IR technique is being used more frequently. DLR is an artificial neural network composed of one or several convolution layers and max-poling layers and is applied to image recognition, medical image analysis, and natural language processing applications. (Lee & Koo, 2017) Utilizing a vast amount of pre-scanned images, it reconstructs images using a neural network trained on the pairs of high-quality images and low-dose noisy images.

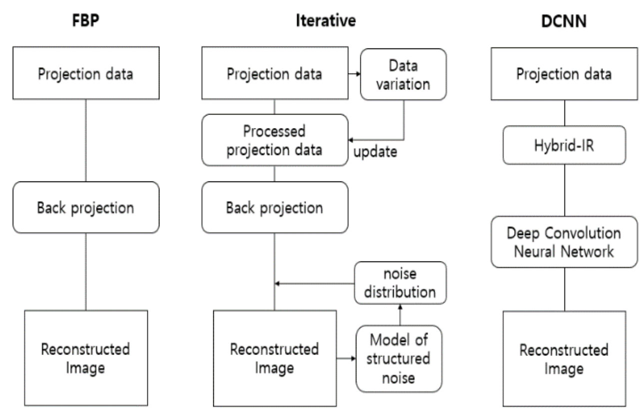

Figure 1: Flow chart of FBP, IR, DLR method

3. Methodology

3.1. Experimental Equipment and Phantom Information

This study used CT (Aquillion ONE GENESIS, Canon Medical Systems, Japan) that enables FBP, IR, and DLR reconstructions was used. A phantom of a human body model (Lungman, Kyoto Kagaku, Japan) was used for image quality evaluation. The phantom represents the anatomical structure of the thorax of the human body and includes soft tissues, spine, ribs, and blood vessels. As shown in Table 1, the phantom imaging conditions were set to 100 kV tube voltage, 1 mm slice thickness, and 512 x 512 image matrix. The dose conditions set for phantom imaging were Ultra low-dose (ULD), Low-dose (LD), and standard-dose used for clinical lung imaging at Wonju Severance Christian Hospital. (Standard dose, SD). The lung area was imaged with SD 2.7mGy when using FBP, and the LD set in the IR image was 0.6mGy. ULD CT images can be acquired using DLR, and the dose can be lowered up to 0.4 mGy. In this study, images were acquired with 0.4, 0.6, and 2.7 mGy based on CTDIvol, and the performance of FBP, IR, and DLR at each dose level was evaluated.

Table 1: CT scan parameters in this study

Parameters	description
Reconstruction methods	FBP, IR, DLR
kVp	100
CTDIvol (mGy)	0.4, 0.6, 2.7
Slice thickness (mm)	1
Image matrix	512 × 512

3.2. Quantification Matrix

The image quality of FBP, IR, and DLR reconstruction methods for dose was evaluated with noise and SNR. To quantify images acquired with FBP, IR, and DLR, ROI was set in lung tissue and soft tissue, respectively, to measure noise and SNR. Noise and SNR were measured using the average value and noise value of the ROI by setting Region-Of-Interest (ROI) at the same location in FBP, IR, and DLR images obtained from doses of ULD, LD, and SD. Figure 2 displays the ROI of the lungs and soft tissues.

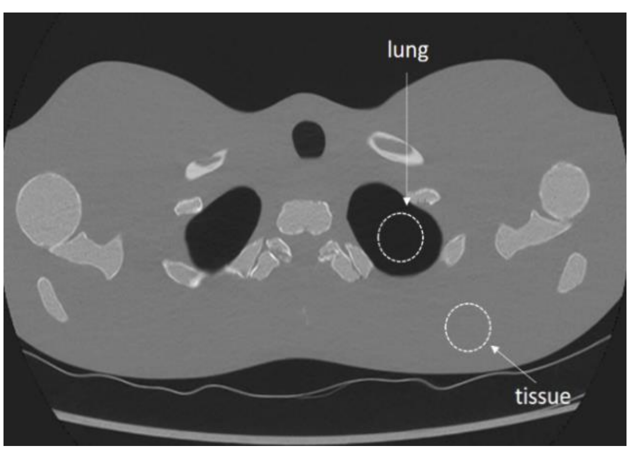

Figure 2: ROI in the lung phantom image

The noise was measured by setting an ROI in the lung tissue and then obtaining a standard deviation of the ROI. SNR was calculated using Equation (1) by obtaining the average value and standard deviation of pixels in the lung tissue ROI and the average value of pixels in the soft tissue ROI.

$$SNR = \frac{|S_{lung} - S_{tissue}|}{SD_{lung}} \quad (1)$$

where, S_{lung}, $S_{tissue,}$ and SD_{lung} refer to the average value of lung tissue ROI, the average value of soft tissue ROI and the standard deviation of lung tissue ROI, respectively.

4. Results

Figure 3 is an CT image obtained using FBP, IR, and DLR at the doses of ULD, LD, and SD of the lung phantom. As shown in Figure 3, FBP and IR images show more artifacts than DLR image at ULD. Conversely, even at ULD, the image quality of DLR is significantly improved. FBP image showed deterioration of image quality even at LD.

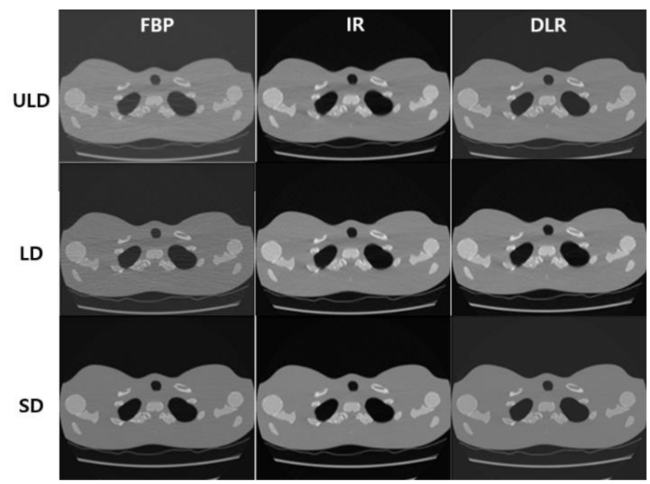

Figure 3: FBP, IR, DLR CT images at ULD, LD, and SD doses in the lung phantom.

4.1. Image noise comparison between different dose modes

Figure 4 represents the tendencies of image noises according to different dose modes for FBP, IR, and DLR, respectively. Based on the noise analysis, the noise values at the FBP mode measured from 0.4 mGy, 0.6 mGy, and 2.7 mGy were 210.62, 164.51, and 51.42, respectively. Moreover, the noise values at IR mode were 30.13, 28.95, and 16.94, and the noise values at DLR mode were obtained as 19.27, 18.96, and 11.72. The noise values were the highest at FBP mode while were lowest at DLR mode under the same dose condition. At ULD mode, the noise of the DLR image was reduced by 90.85% compared to the FBP image and 36.04% compared to the IR image.

Furthermore, the noise of the DLR at ULD mode is reduced by 62.42% compared to the FBP image at SD mode.

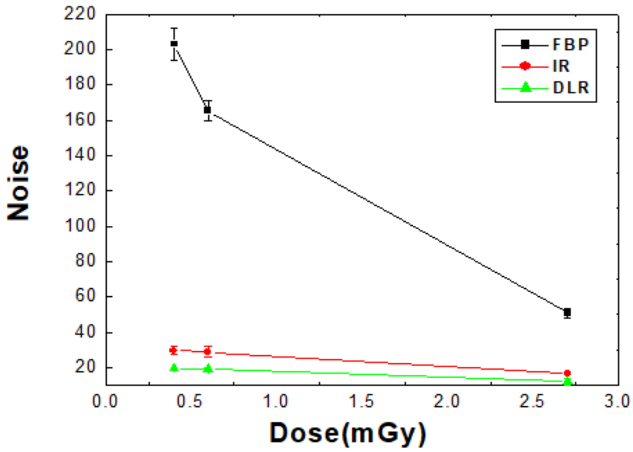

Figure 4: Noise for FBP, IR, DLR images per dose (mGy).

4.2. Analysis of the SNR values between different dose modes

Figure 5 shows the tendencies of the SNR values of each FBP, IR, and DLR image according to different dose modes. Based on the SNR assessments, the SNR values at the FBP mode from 0.4 mGy, 0.6 mGy, and 2.7 mGy were 4.72, 5.94, and 19.53, respectively. Also, the SNR values at IR mode were 31.91, 33.16, and 59.10, and the SNR values at DLR mode were obtained as 50.70, 51.35, and 85.63. Overall, the SNR values were the highest at DLR mode while were lowest at FBP mode under the same dose condition. At ULD mode, the SNR of the DLR image was increased by 974.15% compared to the FBP image and 58.88% compared to the IR image. Moreover, the SNR of the DLR at ULD mode is enhanced by 159.60% compared to the FBP image at SD mode.

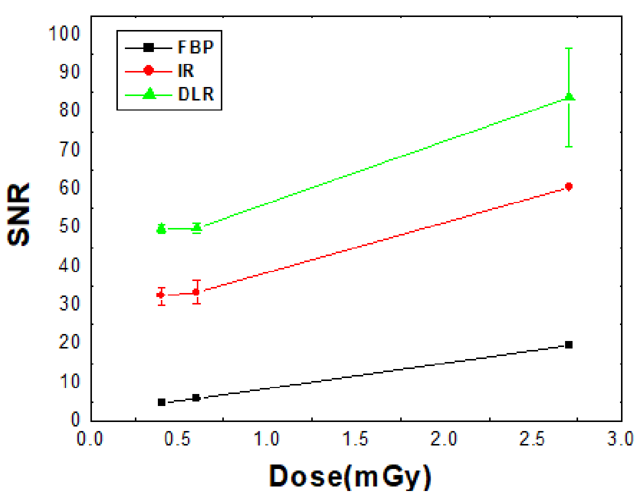

Figure 5: SNR for FBP, IR, DLR images in accordance with dose (mGy).

5. Discussion and Conclusions

The utilization of CT scans continues to increase, and therefore, the exposure dose of patients is continuously increasing. Various methods have been introduced to reduce the exposure dose. In this study, DLR was compared with other existing image reconstruction techniques. Images were acquired with doses of 0.4 mGy, 0.6 mGy, and 2.7 mGy at a tube voltage of 100 kVp, using FBP, IR, and DLR algorithms, respectively. In the previous work, the reference dose of CTDIvol for chest CT scan was set at 3.4 mGy, and the CTDIvol was reduced to 1.4 mGy in IR image (Lee & Goo, 2018). In this study, the image quality of DLR was compared with that of FBP and IR at the ULD of 0.4 mGy.

In CT, a tube voltage of 120 kVp is commonly used for imaging. However, in this study, a tube voltage of 100 kVp was used for all imaging due to the fact that the tube voltage of 100 kVp maintains the patient's exposure dose as low as possible without significantly affecting the image quality (Fanous, Kashani, Jimenez, Murphy, & Paul, 2012).

Based on the experiment of this study, it was confirmed that DLR in ULD can significantly reduce noise compared to FBP and IR. In particular, the noise of the DLR image in ULD showed 62.42% dose reduction effect compared to the noise of the FBP image in SD. Based on the SNR results, it was observed that DLR in ULD can increase SNR compared to FBP and IR. In addition, the SNR of the DLR image in ULD was increased by about 1.5 times than that of the FBP image in SD. Through the noise and SNR evaluation, it was also observed that DLR outperformed FBP at SD dose even at ULD dose.

It is to be noted that, although this study was limited to chest CT examinations, other studies have validated the superiority of DLR performance for examination of other site. In abdominal phantom CT images, DLR showed better noise characteristics than other methods (FBP, IR), especially at low dose. In other words, DLR demonstrated that the noise can be reduced in the low dose condition even in the abdomen (Higaki, Nakamura, Zhou, Yu, Nemoto, Tatsugami, & Awai, 2020). In addition, the improvement of DLR image quality in brain CT scan was also demonstrated. In that study, the performance of the DLR was compared to that of the IR based on the patient's brain study results, and as a result, the DLR improved the contrast-to-noise ratio(CNR) (Kim, Kang, Yoon, Chung, & Shin, 2021). In several studies, the application of DLR to CT imaging provided noise reduction at low doses. The performance of the DLR on the lung was confirmed in this work, and the superiority of the performance of the DLR on the head and abdomen was demonstrated in other studies. Therefore, it is thought that DLR can be applied to various parts of the human body and contribute to dose reduction and image quality improvement.

In this study, we investigated the performance of DLR in terms of dose reduction and image quality compared to conventional reconstruction methods such as FBP and IR during chest CT examination. According to the results of this study, DLR outperformed conventional FBP and IR at the same dose level. Considering the increasing utilization of CT scans and exposure dose, the DLR approach is anticipated to significantly reduce the chest CT dose while maintaining excellent performance in terms of image quality.

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