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Deep Residual Neural Network-based Standard CT Estimation from Ultra-Low Dose CT Imaging for COVID-19 Patients

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***Abstract*– Chest computed tomography (CT) imaging was widely used for diagnosis and staging of severe acute respiratory syndrome coronavirus (SARS-CoV-2). CT can be utilized for initial diagnosis, severity scoring, serial monitoring, and patient status follow-up. For serial monitoring and follow-up, patients need to be scanned multiple times. The tendency in CT imaging is to minimize patient radiation dose. However, CT imaging is still considered as a high radiation dose modality. In this work, we proposed a deep residual neural network-based high quality (full dose) generation from ultra low-dose CT images to decrease the radiation dose for COVID-19 patients. In this multicenter study, we enrolled 1140 subjects with 313 PCR positive COVID-19 patients. The ultra low-dose CT images were analytically simulated, and then a deep residual neural network employed to estimate/generate full-dose images from the corresponding ultra-low-dose images. Various quantitative parameters, including the root mean square error (RMSE), structural similarity index (SSIM), and qualitative visual scoring were implemented to evaluate image quality of the generated CT images. The mean $CTDI_{vol}$ for full-dose images were 6.5 Gy (4.16-10.5 mGy), while, the simulated low-dose images were intended for a mean $CTDI_{vol}$ of 0.72 mGy (0.66-1.02 mGy). Regarding the external validation set (test set), the RMSE declined from 0.16±0.06 to 0.08±0.02 in low-dose and predicted standard-dose CT images, while the SSIM metric increased from 0.89±0.07 to 0.97±0.01, respectively. The highest visual scores (out of 5) were achieved by full-dose images (4.72±0.57) and predicted full-dose images (4.42±0.08). Conversely, ultra-low-dose images received the lowest score (2.78±0.9). In can be concluded that the proposed deep residual network improved image quality of ultra low-dose CT images, thus recovering their diagnostic value.**

***Index Terms*— CT, Low Dose, Deep Learning, COVID-19**

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I. INTRODUCTION

CHEST computed tomography (CT) imaging has been widely used after the emergence of the coronavirus, known as severe acute respiratory syndrome coronavirus (SARS-CoV-2), for different diagnostic and prognostic purposes. Different studies have been conducted for early COVID-19 detection and also patients' management [1], wherein CT imaging could be utilized for initial diagnosis, severity scoring, serial monitoring, and patient status follow-up. For serial monitoring and follow-up, patients need to be scanned multiple times over the course of treatment. Different hardware and software advances have been made to decrease the radiation doses in CT imaging, however, CT is still considered as a high radiation dose modality [2].

Deep learning algorithms have been recently applied to medical images to cope with different challenges such as image reconstruction [3, 4], image quality improvement [5, 6], image segmentation[7], and quantitative analysis [8, 9]. Reducing the acquisition dose would result in increased noise levels in the resulting CT images, wherein the conventional noise suppression approaches would result in significant loss of signal and quantitative bias [10]. In this study, we proposed a deep residual neural network to estimate the high quality (full-dose) from ultra low dose CT images in an attempt to decrease the radiation dose while maintaining the diagnostic value of CT image for COVID-19 patients. The detailed description of the current study has been published in [6].

II. MATERIALS AND METHODS

Data acquisition

In this multicentre study, we enrolled 1140 subjects with 313 PCR positive COVID-19 patients. All chest images were collected from 12 medical image centres, which were reconstructed by filtered back projection (FBP) algorithm.

Low dose CT simulation

We simulated ultra-low-dose CT images in multiple steps which include, generating projection data from linear attenuation coefficient map (estimated from the Hounsfield Units (HU) of CT images), generating low-dose transmission data using the low-dose scan incident flux and full dose transmission data. In the next step, we added Poisson and Gaussian noise to the transmission data. In the final step, HU CT images were reconstructed from the low-dose sinograms using the filtered back-projection (FBP) algorithm. The CT images were simulated assuming a tube current between 20-45 mA and energy of 90 kVp.

Deep residual neural Network

For this study, we implemented a 20-convolutional-layer deep residual neural network, where every two layers were connected by residual connections. Different low, medium, and high-level features were extracted using dilation factors of 0, 2, and 4 in the different layers.

Implementation details

In this study, we randomly split the data set into 800, 170, and 170 pairs for training, test, and external validation sets.

Quantitative image analysis

Different quantitative parameters including the root mean square error (RMSE) and structural similarity index (SSIM) were measured for quantitative image analysis considering the full-dose CT scans as ground-truth.

Clinical evaluation

All CT images were qualitatively/quantitatively assessed by a radiologist with 10 years of experience. Each image was scored ranging from 1 to 5, wherein 5 indicates, 4 good, 3 adequate, 2 poor, and 1 uninterpretable.

III. RESULTS

The mean $CTDI_{vol}$ for the full-dose images was 6.5 Gy (4.16-10.5 mGy), however, simulated low-dose images resulted in a mean $CTDI_{vol}$ of 0.72 mGy (0.66-1.02 mGy).

Quantitative parameters of RMSE and SSIM calculated for the ultra-low-dose and predicted full-dose CT images by the deep learning algorithms considering the full-dose CT images as the reference are presented in Fig. 1. In the external validation set (test set), the RMSE declined from 0.16±0.06 (in the low-dose CT images) to 0.08±0.02 for the predicted full-dose images, while the SSIM increased from 0.89±0.07 (in the low-dose) to 0.97±0.01 (in the predicted full-dose CTs).

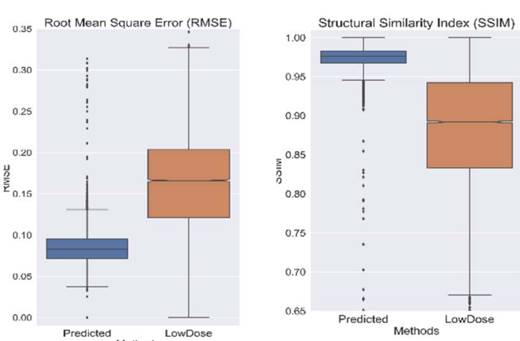

Fig. 1. SSIM and RMSE metrics calculated of the low-dose and predicted high-dose CT images.

Fig. 2 represents the overall image quality assessment carried out by the visual inspection (scoring) of the full-dose, ultra-low-dose, and predicted full-dose CT images. The highest scores were achieved by full-dose images (4.72±0.57) and predicted full-dose images (4.42±0.08), while the ultra-low-dose images received the lowest mean score of 2.78±0.9.

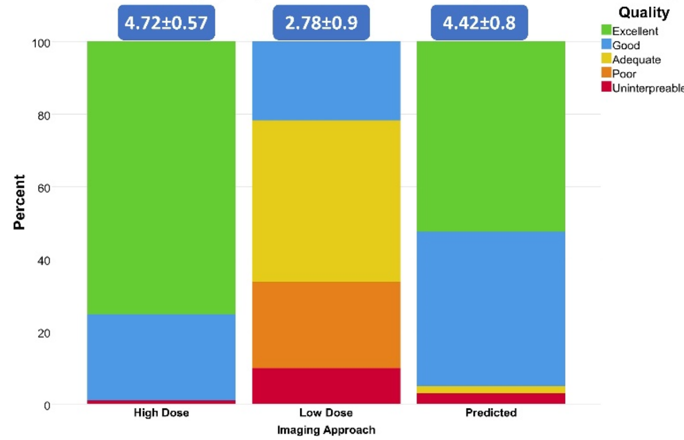

Fig. 2. Overall image quality assessment by visual scoring (excellent:5, good:4, adequate, 3, poor: 2 and uninterpreatable:1)

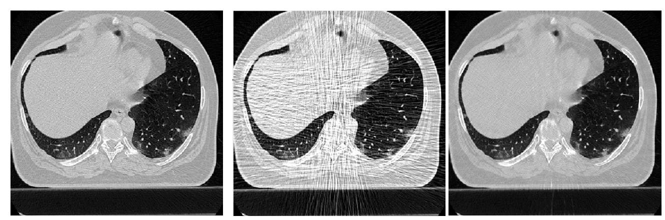

Fig. 3. Representative transverse views of the full-dose, low-dose and predicted full-dose CT images from left to right, respectively.

Fig. 3. depicts the representative transverse views of the full-dose, low-dose, and predicted full-dose CT images. The predicted CT image presents significant improvement in terms of recovery of the underlying signals and patterns particularly within the lung region and Covid-19 infection.

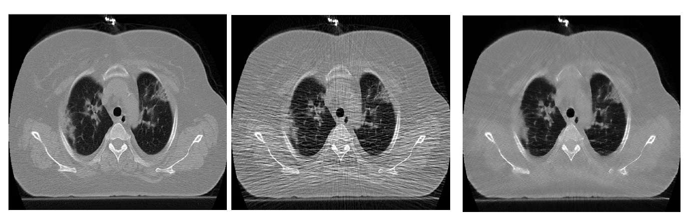

Fig. 4. Transvers views of full-dose, low-dose and predicted full-dose CT images for an outlier case from left to right, respectively.

Fig. 4 shows an example of an outlier wherein the deep neural network failed to properly recover the lesion types, however, the overall quality was improved.

IV. DISCUSSION AND CONCLUSION

In the current study, low-dose CT imaging with 89% of the full-dose scan was simulated for the Covid-19 patients. Deep residual network improved the image quality of the simulated ultra-low-dose images and enhanced the clinical diagnostic accuracy. We also reported the outliers where the developed model failed to recover the correct lesion patterns and/or led to noticeable image artifacts particularly within the lung region. According to the results of this study, the dose imposed to patients during the chest CT can be reduced up to 89%, while the diagnostic value and information can be remained comparable with the full-dose images by utilizing deep neural networks. This was proved by the quantitative evaluation as well as subjective image quality scoring by the radiologist. The deep learning model was able to establish a reasonable compromise between the reduced radiation dose and the CT image quality for the Covid-19 patients. We also reported the outliers in which the deep learning model failed to recover the lesion types in a few cases which should be considered in future studies.

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