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CT Image Quality Evaluation Using Deep Learning Image Reconstruction Algorithm

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Abstract: This this study analyzed retrospectively reconstructed images by applying the deep learning image reconstruction (DLIR) algorithm from dynamic liver CT scan images, to find the optimal DLIR algorithm that can improve image quality compared to ASIR-V while maintaining low radiation dose. Our hospital used the method of reconstructing images of 30 patients who have undergone dynamic liver CT scan retrospectively. The quality of the images of ASIR-V 30% were then compared to the quality of images reconstructed with DLIR-high and DLIR-medium techniques. The DLIR technique improved the signa-to-noise ratio (SNR) by increasing the image signal and reducing the noise compared to ASIR. In contrast-to-noise ratio (CNR) measurement results, the DLIR-high had the highest values, followed by DLIR-medium and ASIR, although their differences were not statistically significant. However, when comparing the value of CNR comprehensively, it showed statistically significant difference in order of ASIR > DLIR-medium > DLIR-high algorithms. Results showed that DLIR improved SNR and CNR by reducing the noise without image distortion. However, since the stronger DLIR intensity, the more the image blurring, it is significant to find the appropriate value of DLIR strength. In conclusion, DLIR showed results of improving SNR and CNR by reducing the noise without causing image distortion. However, since the stronger DLIR intensity, the more the image blurring is increased, it is significant to find the appropriate value for DLIR strength.

Keywords*: Deep learning image reconstruction, Adaptive statistical iterative reconstruction, Computed tomography, Signal-to-noise ratio, Contrast-to-noise ratio*

1. Introduction

Together with the development of medical technology, CT has been developed in order to scan the condition or function of human organs in high resolution image. Its fast scan time has made it the most excellent equipment in diagnostic tests for various diseases such as cerebrovascular disease (1). Particularly, in South Korea, the number of CT scans tends to increase every year as most disease codes with the use of a CT equipment are covered by insurance benefits. In addition, in the CT scan area, diverse efforts are being made to minimize radiation damage to comply with reasonably achievable low doses (2).

Diverse methods have been studied to reduce the radiation dose of patients in CT scan. First of all, a protocol with parameters optimized those fits characteristics of the patient and disease is needed. If one understands the characteristics of the patient and the test equipment exactly the radiation exposure dose could be reduced the most effectively. However, in the position of imagery interpretation, changing the protocol every time is not an easy decision because the diagnosable image quality should be maintained.

Traditionally, filtered back projection (FBP) has been developed as an interactive reconstruction (IR) algorithm and used as a way to improve image quality and reduce noise to substantially reduce radiation dose (3). Among the various IR algorithms, the ASIR method is one of the most notable artificial intelligence technologies. This method provides image quality similar to that of FBP method with reduced radiation dose by applying both FBP and the IR algorithm. However, in the ASIR method, the faults, meaning that the image quality is degraded due to artificial texture and high mixing ratio, the spatial resolution is reduced. To correct such weaknesses, ASIR-V of new iterative reconstruction method was developed, showing solid and improved noise reduction performance even when the dose was lower than existing ASIR (4).

Recently, to correct the problem of IR algorithm, DLIR algorithm, a deep neural network (DNN)-based engine (5), was proposed. Having characteristics of DNN trained with high quality FBP dataset, DLIR learns how to distinguish the signal and the noise and suppress the noise intelligently without affecting the anatomical or pathological structure (6). DLIR engine is based on the specific technology on the detailed design of specific CT system containing knowledge on the conditioning of collected imaging data (2). The more important feature is that as this knowledge is contained in DNN, it can learn through countless actual cases. Through these cases, DLIR engine optimizes gradually the coefficient of internal network when it finds

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out how to reach the optimized image by comparing with actual training datasets. When the DLIR engine is trained and completely tested, the inference network distributes new image reconstruction of DLIR in the clinical environment using the coefficient trained (7). Therefore, this study analyzed retrospectively reconstructed images by applying the DLIR algorithm from dynamic liver CT scan images, to find the optimal DLIR algorithm that can improve image quality compared to ASIR-V while maintaining low radiation dose.

2. Materials and Methods

A hospital used the method of reconstructing images of 30 patients who have undergone dynamic liver CT scan retrospectively and compared the quality of the image of ASIR-V 30% and images reconstructed with DLIR-high and DLIR-medium. CT scan was performed under manual mode and at 100 kV by injecting 100 ml of the contrast medium 'Omnipaque350' automatically at 3 ml/sec when HU value became 100 by establishing region of interest (ROI) within the descending aorta and applying bolus tracking.

For the evaluation method, after acquiring portal venous phase images by reconstructing with ASIR-V 30%, DLIR-high, and DLIR-medium techniques, SNR and CNR were compared by establishing ROI in the background (BG), psoas muscle, fat, aorta, liver and spleen using ImageJ (ver. 1.51j) program (Fig. 1).

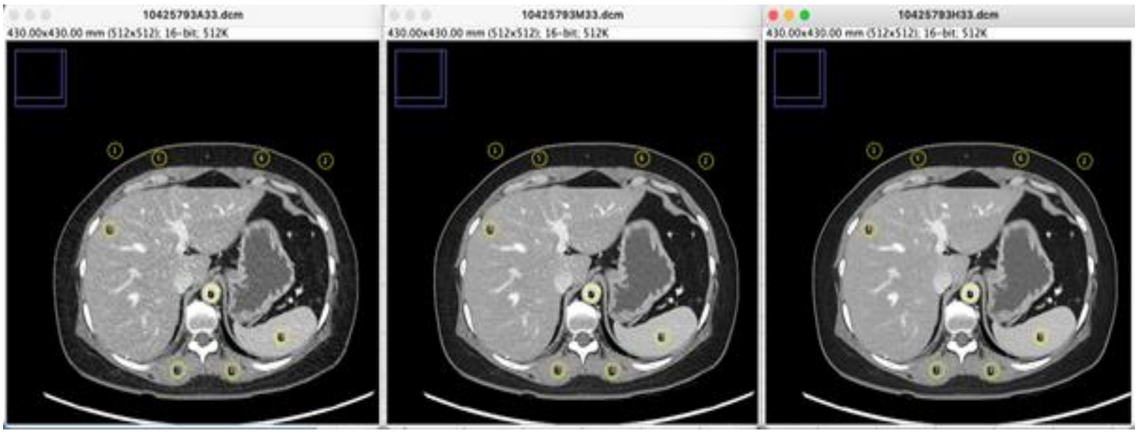

Fig. 1: ROI measurement of ImageJ program used for image evaluation

(a) ASIR-V 30%, (b) DLIR Medium, (c) DLIR High

For SNR and CNR, their calculation was made by correcting the formula used in the paper by Kim Gu (8) et al., referring to the paper by Heyer (9), et al., fit to this paper (eqs. 1, 2). In SNR and CNR formulas, HU is the hounsfield unit and SD is the standard deviation.

$$\text{SNR} = \frac{ROI\ (HU)}{Background\ (SD)} \qquad (1)$$

$$\text{CNR} = \frac{ROI\ (HU) - Background\ (HU)}{Background\ (SD)} \qquad (2)$$

Results were analyzed with one-way ANOVA using SPSS 28.0 version. As a result of the analysis, post-analysis was additionally performed using Tukey test for results with a p value of less than 0.05.

3. Results

In SNR measurement results, SNRs for ASIR, DLIR-Medium, and DLIR-High at the psoas were 67.32 ± 7.86, 106.95 ± 15.06, and 74.17 ± 9.61 ($p < 0.001$), respectively. These values were 63.63 ± 14.14, 116.3 ± 32.7, and 80.47 ± 19.41 at the fat, 60.96 ± 8.99, 92.28 ± 12.64, and 64.9 ± 7.64 in the aorta, 75.24 ± 12.78, 114.75 ± 20.52, and 80.03 ± 13.82 in the liver, and 70.05 ± 6.41, 113.64 ± 11.91, and 78.19 ± 7.58 in the spleen, respectively (all $p < 0.001$, Table 1). In Tukey test results, for all analyses, DLIR-High showed the highest SNR where DLIR-Medium and ASIR did not show statistically significant difference in SNR (a.c < b).

Table 1: SNR measurement result according to ASIR, DLIR High, DLIR-Medium method

Region	Protocol	M±SD	F	P	Post-hoc
Psoas muscle	ASIR-V 30%[a]	67.32±7.86	35.346	p<0.001	a.c < b
	DLIR-High[b]	106.95±15.06			
	DLIR-Medium[c]	74.17±9.61			
Fat	ASIR-V 30%[a]	63.63±14.14	13.192	p<0.001	a.c < b
	DLIR-High[b]	116.3±32.7			
	DLIR-Medium[c]	80.47±19.41			
Aorta	ASIR-V 30%[a]	60.96±8.99	29.192	p<0.001	a.c < b
	DLIR-High[b]	92.28±12.64			
	DLIR-Medium[c]	64.9±7.64			
Liver	ASIR-V 30%[a]	75.24±12.78	17.993	p<0.001	a.c < b
	DLIR-High[b]	114.75±20.52			
	DLIR-Medium[c]	80.03±13.82			
Spleen	ASIR-V 30%[a]	70.05±6.41	67.032	p<0.001	a.c < b
	DLIR-High[b]	113.64±11.91			
	DLIR-Medium[c]	78.19±7.58			
Total	ASIR-V 30%[a]	67.44±11.22	90.531	p<0.001	a< c < b
	DLIR-High[b]	107.7±20.44			
	DLIR-Medium[c]	75.55±13.29			

SNR; signal to noise ratio, SD; standard deviation

†; Post-hoc were analyzed by Tukey method

In CNR measurement results, CNRs for ASIR, DLIR-High, and DLIR-Medium 56.49 ± 33.51, 98.67 ± 87.0, and 72.01 ± 52.35 at psoas and 47.11 ± 28.06, 84.39 ± 75.55, and 60.78 ± 44.64 at fat, respectively, and there were no significant differences between the groups (all $p > 0.05$, Table 2). These values were 61.6 ± 36.49, 105.62 ± 92.25, and 77.82 ± 56.14 in the aorta, 59.21 ± 35.07, 102.49 ± 89.83, and 75.13 ± 54.35 in the liver, and 59.85 ± 35.47, 104.83 ± 92.44, and 76.32 ± 55.48 in the spleen, respectively.

In results of analyzing all measurement areas comprehensively, ASIR, DLIR-High, and DLIR-Medium had values of 56.85 ± 32.85, 105.23 ± 86.9, and 72.41 ± 50.94, respectively, showing statistically significant differences among them. In post-analysis results, DLIR-High had the highest the value. However, values of DLIR-Medium and ASIR did not show statistically significant difference.

Table 2: CNR measurement result according to ASIR, DLIR High, DLIR-Medium method

Region	Protocol	M±SD	F	P	Post-hoc†
Psoas muscle	ASIR-V 30%	56.49±33.51	1.194	p>0.05	n/a‡
	DLIR-High	98.67±87.04			
	DLIR-Medium	72.01±52.35			
Fat	ASIR-V 30%	47.11±28.06	1.257	p>0.05	n/a
	DLIR-High	84.39±75.55			
	DLIR-Medium	60.78±44.64			
Aorta	ASIR-V 30%	61.6±36.49	1.145	p>0.05	n/a
	DLIR-High	105.62±92.25			
	DLIR-Medium	77.82±56.14			
Liver	ASIR-V 30%	59.21±35.07	1.173	p>0.05	n/a
	DLIR-High	102.49±89.83			
	DLIR-Medium	75.13±54.35			
Spleen	ASIR-V 30%	59.85±35.47	1.206	p>0.05	n/a
	DLIR-High	104.83±92.44			
	DLIR-Medium	76.32±55.48			
Total	ASIR-V 30%[a]	56.85±32.85	7.928	p<0.01	a.c < b
	DLIR-High[b]	105.23±86.9			
	DLIR-Medium[c]	72.41±50.94			

SNR; signal to noise ratio, SD; standard deviation

†; Post-hoc were analyzed by Tukey method

4. Discussion

This research compared DLIR algorithm with ASIR technique, an existing reconstruction technique, by reconstructing images of patients who received dynamic liver CT scan applying DLIR algorithm. In the evaluation results, the DLIR technique improved the SNR by increasing the image signal and reducing the noise compared to ASIR. In CNR measurement results, it was also revealed that the DLIR-High had the highest value among all algorithms, followed by DLIR-Medium and ASIR, with the latter two showing no statistically significant difference. However, when the value of CNR was compared comprehensively, it showed statistically significant difference in order of ASIR < DLIR-Medium < DLIR-High algorithms. Comparing this result with the study of Hata et al., the same pattern was found. Research results of Hata et al. also showed that DLIR- High had higher SNR and higher CNR in order of ASIR-V 60% < DLIR-Medium < DLIR- High (10). In addition, image evaluation showed that CNR was only a yardstick that could simply distinguish the image. It is strongly affected by image noise without reflecting sharpness of the boundary to detect the lesion. This happens because the border of organ in the image under DLIR-High is less clear (5).

DLIR technique used in this study is the next generation image reconstruction algorithm using deep neural network. This algorithm can distinguish noise and signal by learning repeatedly through phantom image of the laboratory and enormous data of the clinical patients mathematically. According to preceding researches, DLIR can improve SNR and increase CNR by reducing noise and maintaining image texture compared with the IR technique (11).

Traditionally, the method of reducing the radiation dose in the CT scans can reduce the dose efficiently by reducing the tube voltage because the dose is linearly proportional to the square of the tube voltage (12). Later, FBP was developed as a technology that can effectively reconstruct excellent CT images under the condition of normal radiation dose for past several decades.

However, sinogram can cause high noise, degrade image quality, and reduce diagnosis accuracy, getting out of ideal function together with the reduction of tube voltage (13). To complement these weaknesses of FBP, IR technique has been used until recently. When high strength of IR is used, it can change the texture of noise and cause a problem that makes the image appear to have stain (14).

The purpose of DLIR is to provide an image exceeding existing ASIR-V technology in terms of image quality and overall performance. DLIR algorithm features DNN trained with high quality FBP dataset of normal dose to learn how to distinguish noise and signal and suppress noise intelligently (15).

The limitation of this study is that the relation between reconstructed image quality and disease was not established by applying various variables according to the scan protocol.

5. Conclusion

In the comparison of DLIR technique developed newly for the same purpose of ASIR, which has been developed and used to reduce the noise of image and exposure dose, it was shown that the DLIR technique could lead to excellent improvement. However, as the DLIR-High technique might provide a sense of difference unfamiliar to the reading doctor when comparing with existing images, it is deemed to compare images and find the optimal value through more follow-up researches.

In conclusion, DLIR showed results of improving SNR and CNR by reducing the noise without causing image distortion. However, since the stronger DLIR intensity, the more the image blurring is increased, it is significant to find the appropriate value for DLIR strength. Therefore, follow-up research that satisfies both the scan and image quality in diverse dose environments through phantom research is needed.

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