



Abdominal Digital Radiography with a Novel Post-Processing Technique: Phantom and Patient Studies

새로운 후처리 기술을 이용한 복부 디지털 방사선 촬영: 팬텀과 환자 연구

Hyein Kang, MD¹ , Eun Sun Lee, MD^{1,2*} , Hyun Jeong Park, MD^{1,2} ,
Byung Kwan Park, MD^{2,3} , Jae Yong Park, MD^{2,4} , Suk-Won Suh, MD^{2,3}

Departments of ¹Radiology, ³Surgery, ⁴Internal Medicine, Chung-Ang University Hospital, Seoul, Korea

²College of Medicine, Chung-Ang University, Seoul, Korea

Purpose The aim of this study was to evaluate the diagnostic image quality of low dose abdominal digital radiography processed with a new post-processing technique.

Materials and Methods Abdominal radiographs from phantom pilot studies were post-processed by the novel and conventional post-processing methods of our institution; the proper dose for the subsequent patient study of 49 subjects was determined by comparing image quality of the two preceding studies. Two radiographs of each patient were taken using the conventional and derived dose protocols with the proposed post-processing method. The image details and quality were evaluated by two radiologists.

Results The radiation dose for the patient study was derived to be half of the conventional method. Overall half-dose image quality with the proposed method was significantly higher than that of the conventional method ($p < 0.05$) with moderate inter-rater agreement ($\kappa = 0.60, 0.47$).

Conclusion By applying the new post-processing technique, half-dose abdominal digital radiography can demonstrate feasible image quality compared to the full-dose images.

Index terms Radiography, Abdominal; Radiography; Image Enhancement; Comparative Study; Radiation Dosage

INTRODUCTION

Digital radiography (DR) has been used to describe digital X-ray imaging system that reads transmitted ray signal immediately after exposure with the detector in place (1, 2). The first DR system described in 1990 was a charge-coupled device slot-scan system

Received July 13, 2019
Revised October 9, 2019
Accepted October 18, 2019

*Corresponding author
Eun Sun Lee, MD
Department of Radiology,
Chung-Ang University
Hospital, 102 Heukseok-ro,
Dongjak-gu, Seoul 06973, Korea.

Tel 82-2-6299-2767
Fax 82-2-6263-1557
E-mail seraph377@cau.ac.kr

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ORCID iDs

Hyein Kang
<https://orcid.org/0000-0001-8425-1760>
Eun Sun Lee
<https://orcid.org/0000-0003-0780-7985>
Hyun Jeong Park
<https://orcid.org/0000-0003-1701-0478>
Byung Kwan Park
<https://orcid.org/0000-0002-2283-8483>
Jae Yong Park
<https://orcid.org/0000-0001-6114-8920>
Suk-Won Suh
<https://orcid.org/0000-0001-6111-9601>

(3). DR technologies have been rapidly progressed and substituted conventional radiography.

Compared to conventional radiography, DR allows improvement image quality and/or reducing radiation dose (4) due to high detective quantum efficiency (DQE), post-processing technique, detector and readout technologies, and various ways of optimizing technical parameters (5, 6). Although, there is a big trade-off between radiation dose and image quality in radiography, recent several studies has shown substantial technical improvement of DR presenting maintained diagnostic imaging quality with lower radiation dose in phantom and clinical studies during the last decade. Precht et al. (6) used multi-frequency processing, which decomposes the image into a series of sub-frequency images and then to fuse these into one single image with optimized contrast, achieved optimal image quality at a dose reduction of 61%. In addition, with new detector designs, other studies shown improved, or maintained image quality with average dose reduction of 30% (7, 8).

Recently developed post-processing software loaded on DR system (GC85A, Samsung Electronics Co., Ltd., Suwon, Korea) performs the noise estimation, noise reduction and noise whitening process to obtain better image quality even with low dose protocol (LD). Generally, when the radiation dose is reduced, the noise increases, and the visibility of the structural information tends to decrease. To overcome this drawback, this software estimates the actual noise component generated in the image acquisition process. Thereafter, the noise can be selectively removed, while avoiding the edge degradation and the loss of structural information of the image. The final noise whitening process filtrates overall low-frequency component of noise to obtain better diagnostic image quality (9).

The objective of this study was to propose a new post-processing technique and determine the diagnostic image quality of low-dose abdominal DR compared to conventional dose by applying the proposed method loaded on GC85A. Qualitative and quantitative evaluations such as signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), overall and detailed image quality were performed for technical and clinical validation of this system.

MATERIALS AND METHODS

Our Institutional Review Board approved this prospective study (IRB No. 1602-002-256). Informed consent was obtained from each patient.

PHANTOM STUDY

Radiographs of an abdominal anthropomorphic phantom (PBU-60, Kyoto Kagaku, Kyoto, Japan) (Fig. 1) were taken with a diagnostic X-ray system with conventional post-processing method of our institution in LD designed for this study under 72 kVp of tube voltage with filtration of 0.1 mm copper for dose reduction (10, 11).

Henceforth, radiographs with reduced dose were taken three times under 75%, 62.5%, 50%, 37.5%, and 25% of the conventional dose in LD. The mean entrance skin dose for each dose level was measured with a Solidose 400 dosimeter (RTI Electronics, Mölndal, Sweden). After image acquisition, the new post-processing technique was applied for all radiographs. This new post-processing technique used the latest version of the post-processing software loaded on the DR system.



Fig. 1. Anthropomorphic phantom used in the phantom study.

Generally, noise in DR system which degrades clinical image quality is categorized by Poisson noise in X-ray source, scattered noise in object, blurring noise by point spreading at scintillator in detector and an electrical noise in detector circuit. Based on these noise characteristics during X-ray imaging procedure, the advanced denoising algorithm of estimated actual noise distribution was conducted. Well-estimated noise distribution enables noise filter based on non-local means algorithm and correlated noise removal technique (12, 13) to reduce the noise in image without scarifying structural information. It returns a covariance map as a measure of noise covariance across the field of view of DR image. Noise covariance map is then used in noise filtration.

Noise filtration is based on vectored non-local means filter (14), but it has several distinguished features which make its application possible in DR imaging. Some of these features are: multi-scale filtering reduces all scales of noise & improves bias-variance tradeoff; NLM-weighting formula is modified to consider the covariance of noise; combined filtration with blocks of different sizes diminishes artifacts near edges; stair-casing artifact is reduced due to the use of patch's mean substitution technique.

By modeling the relationship between X-ray source and captured object as aforementioned, the proposed technique estimated the actual noise component generated in the image acquisition process. This actual noise component is then used for estimation of spatially-varying map of noise covariance, and subdivided into square blocks (e.g., 16×16 pixels). Covariance of noise can be calculated within each such block.

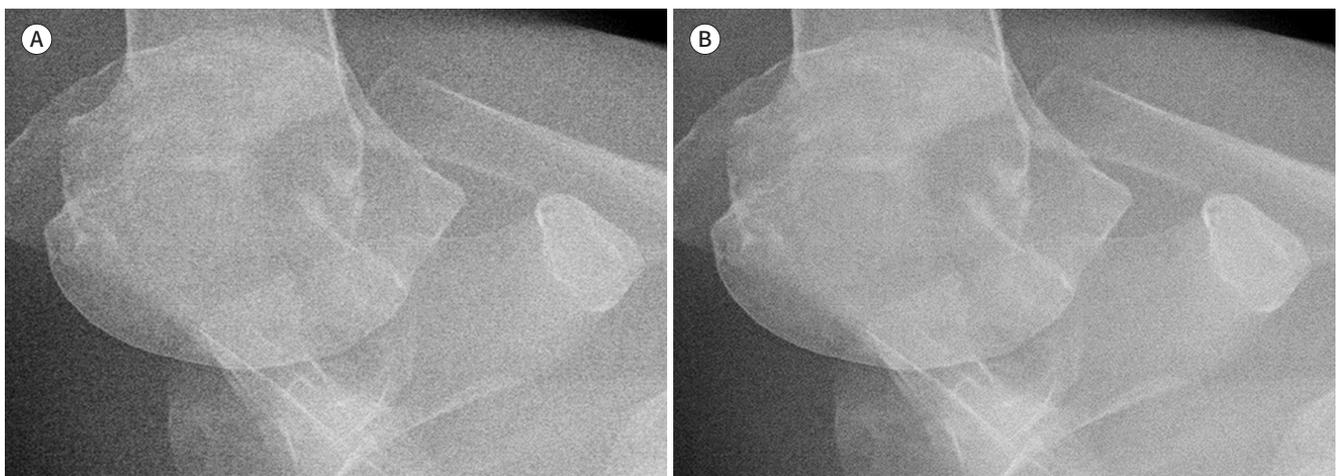
Final filtration was done by means of noise whitening. Once noise covariance map is obtained, in the noise reduction process, the estimated noise component was selectively re-

moved without degrading the edge or structural information of the image. Singular value decomposition of each block covariance is calculated, and inverse square root of covariance matrix is estimated. Inverse square root transform applied to each block transforms original correlated noise into un-correlated white noise. Finally, transformed noise image is added with the source image, giving the resultant image having the noise which spectrum is much closer to white noise spectrum. The overall low-frequency noise was removed to obtain better diagnostic image quality (Fig. 2), which increases the visibility of human observer (9).

Quantitative analysis was performed for post-processed images by an abdominal radiologist with 10-year experience (E.S.L.) in terms of SNRs and CNRs. The radiologist put the same round region of interests (ROIs) of 200 mm² at the right liver tip, ilium, right kidney, stomach gas, sigmoid colon gas, and lateral abdominal walls of each set of three phantom radiographs with the same condition three times. Mean values and standard deviations (SD) were measured to calculate SNR and CNR. SNR and CNR were obtained with the following formula: $SNR = \text{mean}/SD$; $CNR = (\text{mean } 1 - \text{mean } 2)/SD 2$, where mean 1 represented the mean signal value of target ROI, mean 2 was the signal value of the surrounding ROI, and SD was the SD measured on the target ROI.

Qualitative evaluation was independently performed by three radiologists with at least 10 years of experience of abdominal imaging (H.K., E.S.L., and H.J.P.). Image details were evaluated by 5-point scale (1, invisible; 2, blurry and partially visualized; 3, blurry and entirely visualized; 4, clearly and partially visualized; and 5, clearly and entirely visualized) for sharpness and visualization of following items: lateral abdominal walls, peritoneal fat lines, kidneys, psoas muscles, and outlines of covered bony structures. Mean scores of all evaluation criteria and overall quality scores of images acquired with or without additional post-processing at each dose level were compared by drawing polynomial approximation curve. For objective analysis in this study, we used term of "saturation point" defined as the minimum radiation dose level where image quality scores were no longer raised even when more radiation exposure was given.

Fig. 2. Example images of before (A) and after (B) applying the noise whitening technique. The overall low-frequency noise was removed to obtain better diagnostic image quality.



PILOT STUDY

A preliminary patient study was conducted from February 2017 to March 2017 for subjects who needed abdominal radiography clinically. Hereafter, the conventional abdominal radiography protocol of our institution (ORG) was mentioned as ORG under automatic exposure control using 80 kVp of tube voltage without copper filters. For each patient, two abdominal radiographs covering the whole abdomen from the diaphragm to the symphysis pubis were taken at supine position with ORG and one of five levels (80%, 70%, 60%, 50%, 40% of standard dose) of previously defined LD (72 kVp of tube voltage with filtration of 0.1 mm copper), randomly selected. At each level, three patients were included. Therefore, a total of 15 subjects were enrolled in the pilot study. Images from the LD were post-processed using the same technique as the one used in the phantom study.

Estimated radiation exposure was measured in the same manner of the phantom study, and qualitative assessment of obtained images was performed. For qualitative assessment, the same three radiologists from the phantom study (H.K., E.S.L., and H.J.P.) reviewed and scored the quality of images independently using a 5-point scale (1, invisible; 2, blurry and partially visualized; 3, blurry and entirely visualized; 4, clearly and partially visualized; 5, clearly and entirely visualized) on our institutional picture archiving and communication system workstations. Evaluated items included the sharpness and visualization of the following: lateral abdominal walls, properitoneal fat lines, liver, kidneys, psoas muscles, and outlines of covered bony structures. Overall qualitative image quality was also scored with a 5-point scale (1, poor; 2, fair; 3, moderate, 4, good; 5, excellent).

Although statistical analysis was not available due to small sample numbers of each protocol, we made a tentative plan to conclude that the image quality was suboptimal if two of three radiologists evaluated that the overall quality of the post-processed low-dose image (PPLDI) was inferior to the image acquired by ORG with standard dose. Finally, we set the radiation dose level for patient study as the lowest dose with optimal image quality of PPLDI from this pilot study.

SNR and CNR were not calculated since statistical analysis was not available due to small sample number of the pilot study.

PATIENT STUDY

A total 49 patients (M:F = 26:23) with mean age of 57.8 years (range, 20–82 years) who needed abdominal radiographs clinically under the indication of abdominal pain or postoperative follow-up were enrolled in this study from March 2017 to October 2017. Two radiographs were taken in supine position for each subject with 100% dose according to ORG. PPLDI was obtained using a lower dose derived from the pilot study (i.e., half-dose with LD) with a copper filter. Estimated skin dose was measured with the same device used in phantom study for each radiograph.

For quantitative analysis, one radiologist with 10 years of experience in abdominal imaging (E.S.L.) drew round ROIs of 200 mm² at the right liver tip, ilium, and lateral abdominal wall three times each for all radiographs. SNRs were calculated in the same way as described in the preceding phantom study.

Regarding qualitative analysis, two radiologists (E.S.L., H.K.) evaluated image details by

5-point scale (1, invisible; 2, blurry and partially visualized; 3, blurry and entirely visualized; 4, clearly and partially visualized; and 5, clearly and entirely visualized) for sharpness and visualization of following items: lateral abdominal walls, periperitoneal fat lines, kidneys, psoas muscles, and outlines of covered bony structures. Overall image quality was comprehensively scored with a 5-point scale as described in the pilot study (1, poor; 2, fair; 3, moderate, 4, good; and 5, excellent).

STATISTICAL ANALYSIS

For quantitative evaluation of phantom study results, independent *t*-test was used to compare SNRs and CNRs of images with or without post-processing. Paired *t*-test was used to compare quantitative scores of SNRs and CNRs as well as qualitative scores of image qualities in patient study. Weighted Kappa (κ) tests were performed to evaluate inter-rater agreement between the two raters in patient study for qualitative analysis. A threshold for a significance level was $p < 0.05$. All statistical analyses were performed using MedCalc[®] for Windows, version 17.9.2 (MedCalc Software, Ostend, Belgium).

RESULTS

PHANTOM STUDY

QUANTITATIVE ASSESSMENT

SNRs of images post-processed with the proposed method at each dose level were compared to SNRs measured for images by conventional post-processing. Results are shown in Table 1. For all measurement sites, mean values of SNRs of images post-processed with the new method were higher than those of SNRs measured for images acquired with the standard dose using the conventional post-processing method. Except for SNRs measured at ilium, all SNRs of images post-processed with the proposed method were significantly higher than those of images acquired with the conventional setting until the dose was reduced to 50%. SNRs measured at right liver tip and ilium in LD images with or without the proposed post-processing method are shown in Fig. 3. SNRs measured at ilium for images post-processed with the new method were significantly higher than those of images obtained with 100% dose until the dose was reduced to 62.5% in both groups. CNR values did not show sta-

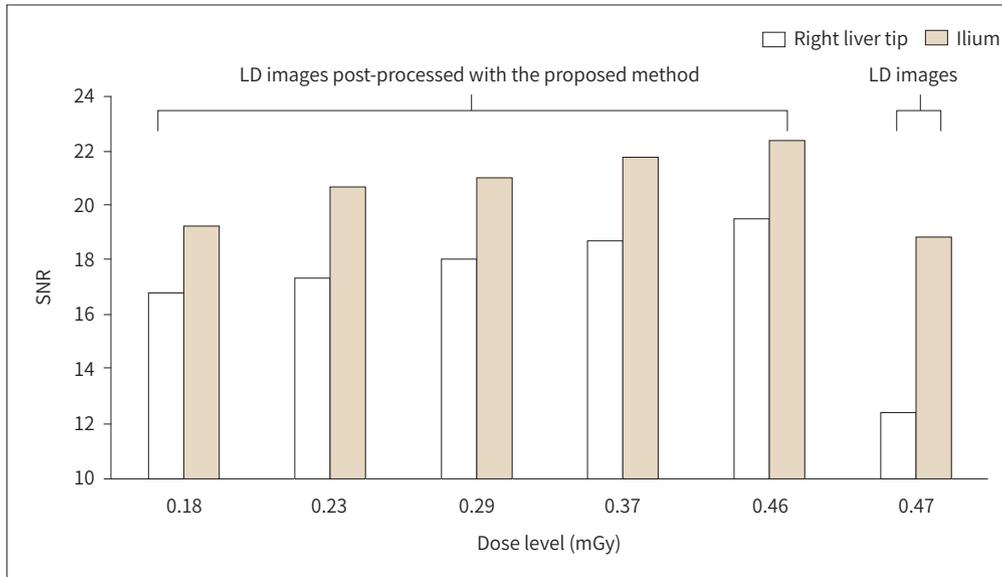
Table 1. Mean Value of Signal-to-Noise Ratio for Each Anatomic Structure in Images Obtained from the Phantom Study

	Standard Dose with Conventional Method	75% Dose	<i>p</i>	62.5% Dose	<i>p</i>	50% Dose	<i>p</i>	37.5% Dose	<i>p</i>	25% Dose	<i>p</i>
Right liver tip	12.41	19.49	<0.05	18.69	<0.05	18.02	<0.05	17.35	<0.05	16.81	<0.05
Right kidney	24.12	33.87	<0.05	31.28	<0.05	28.86	<0.05	26.41	<0.05	23.92	0.741
Ilium	18.83	22.36	0.008	21.76	<0.05	21.03	0.056	20.66	0.0732	19.24	0.526
Stomach gas	23.29	33.01	<0.05	31.15	<0.05	28.54	<0.05	26.33	<0.05	24.16	0.310
S-colon gas	14.82	18.68	<0.05	18.28	<0.05	17.85	<0.05	17.43	<0.05	16.07	<0.05
Lateral abdominal walls	13.06	22.67	<0.05	21.80	<0.05	21.17	<0.05	19.57	<0.05	18.33	<0.05

Fig. 3. Graphs of mean SNR of low-dose images of the phantom study.

Graphs of mean SNR of LD images post-processing with the proposed method and the conventional method of our institution in the phantom study according to each dose level (mGy) measured at the right tip of the liver and ilium.

LD = low dose protocol, SNR = signal-to-noise ratio



tistically significant difference between images with or without applying the new post-processing method.

QUALITATIVE ASSESSMENT

Mean scores of all evaluation criteria (total average scores) and overall quality scores of images acquired with or without the new post-processing method are shown in Table 2. The dose reduction rate showed how much dose could be reduced using the proposed method while the image quality was maintained the same as that with the conventional method as shown in Fig. 4.

PILOT STUDY

At 40% dose, two of three raters evaluated that PPLDI were inferior to ORG images in overall quality. When these scores of the three evaluators were averaged, score of all evaluation criteria of PPLDI was lower than that of ORG images at 40% dose level. Thus, 50% dose level, which was one step higher, was set as the dose level to be used in image acquisition for post-processed group in the following patient study.

PATIENT STUDY

RADIATION DOSE MEASUREMENT

Average values of entrance skin exposure of radiographs are 1.02 mGy and 0.49 mGy in ORG and PPLDI, respectively. Average dose reduction rate after post-processing was 54.56%.

QUANTITATIVE ASSESSMENT

Two radiographs (ORG image, PPLDI, respectively) from one patient acquired in the patient study are shown in Fig. 5. Compared to images acquired by ORG under 100% dose, values of

Table 2. Dose Reduction Rate Calculated from the Saturation Point of the Total Average of Evaluated Criteria and Overall Image Quality Score in the Phantom Study after Applying the New Post-Processing Method

	Conventional Method		New Post-Processing Method	
	Dose (mGy)	Dose (mGy)	Dose (mGy)	Dose Reduction Rate (%)
Total average of evaluation criteria	0.47	0.24		49
Overall image quality	0.44	0.24		48

Fig. 4. Secondary polynomial curve of the phantom study.

Secondary polynomial curve obtained in the qualitative analysis of the phantom study. Overall quality score (A) and average score of each detailed criterion (B). Arrow indicate the amount of the reduced dose.

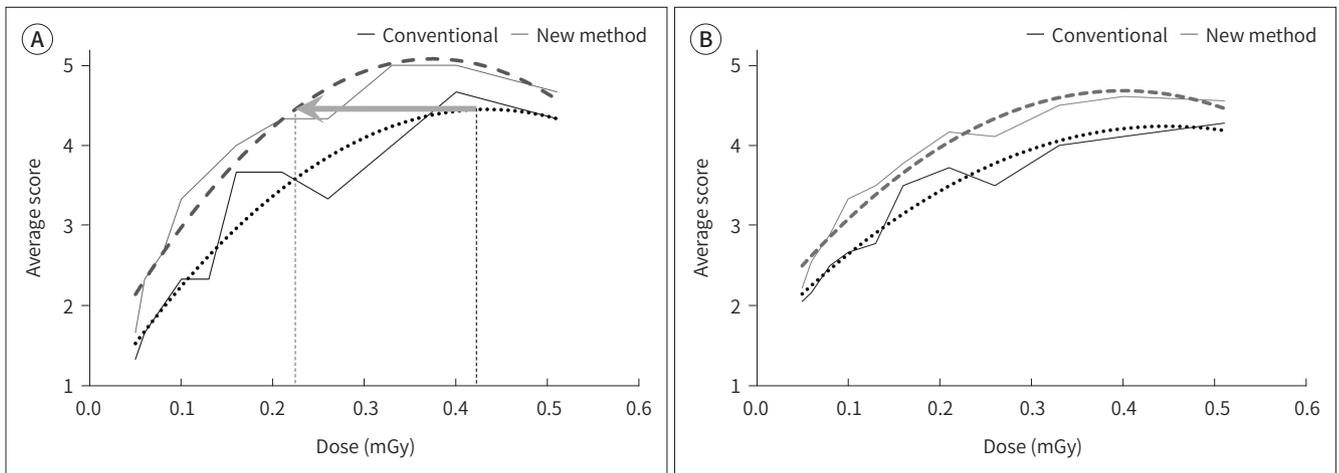


Fig. 5. Two radiographs from one patient acquired in the patient study.

A, B. Conventional abdominal radiography protocol of our institution image (A) and post-processed low-dose image (B); all observers evaluated the mean overall image quality score of (B) as 5, while (A) was 4.5.



Table 3. Mean Signal, Noise, and SNR Values Measured at the Lateral Abdominal Walls, Right Liver Tip, and Ilium for ORG and LD Images from the Patient Study

	Signal		<i>p</i>	Noise		<i>p</i>	SNR		<i>p</i>
	ORG	LD		ORG	LD		ORG	LD	
Right liver tip	10521.89	10786.23	0.293	298.42	413.03	0.162	35.35	32.31	<0.05
Lateral abdominal walls	3567.40	4633.72	<0.05	261.71	333.03	<0.05	13.90	14.23	0.615
Ilium	7438.24	7699.53	0.196	326.22	359.69	<0.05	22.99	21.62	<0.05

LD = low dose protocol, ORG = conventional abdominal radiography protocol of our institution, SNR = signal-to-noise ratio

Table 4. Mean Values of Overall Image Quality Scores and Detailed Qualitative Evaluation Criteria Scores for ORG and LD Images from the Patient Study

	Rater 1		<i>p</i>	Rater 2		<i>p</i>
	ORG	LD		ORG	LD	
Overall image quality	4.449	4.714	<0.05	4.367	4.592	<0.05
Lateral abdominal walls	4.776	4.980	0.096	4.469	4.776	0.096
Properitoneal fat lines	4.612	4.816	0.067	4.347	4.592	0.057
Kidneys	3.612	3.878	0.151	3.327	3.347	0.930
Psoas muscle	4.286	4.449	0.173	3.939	4.041	0.490
Covered bony structures	4.592	4.694	0.200	4.490	4.735	<0.05

LD = low dose protocol, ORG = conventional abdominal radiography protocol of our institution

noise were significantly higher in PPLDIs for lateral abdominal walls and ilium (both $p < 0.05$). Value of signal was also significantly higher in PPLDI for the right abdominal wall (3568.40 in ORG image vs. 4633.72 in PPLDI, $p < 0.05$).

Although SNRs showed no significant differences between the two groups when they were measured for the right abdominal wall, SNRs measured at the liver tip and ilium were significantly higher in ORG images than those in PPLDIs (lateral abdominal walls: 13.90 in ORG images vs. 14.23 in PPLDIs; liver tip: 35.35 in ORG images vs. 32.31 in PPLDIs; ilium: 22.99 in ORG images vs. 21.62 in PPLDIs). Detailed results are shown in Table 3.

QUALITATIVE ASSESSMENT

As shown in Table 4, average scores of all evaluation criteria showed higher values for half-dose PPLDIs than those for ORG images taken under 100% dose by both raters. Scores of spine outlines by rater 2 were significantly higher for PPLDIs than those for ORG images (average: 4.49 for ORG images vs. 4.73 for PPLDI, $p < 0.05$). No significant difference in other evaluation criteria was found.

Overall quality scores by the two raters were significantly higher for PPLDIs than those for ORG images (rater 1: 4.44 for ORG images vs. 4.71 for PPLDI, $p = 0.020$; rater 2: 4.37 for ORG images vs. 4.59 for PPLDI, $p = 0.025$). Inter-rater agreement was moderate for both groups (ORG images, $\kappa = 0.60$; PPLDI, $\kappa = 0.47$).

DISCUSSION

The imaging capabilities of DR are summarized as having high DQE, broad dynamic range,

and possibilities of post-processing, archiving, and transferring for digital data (2). Image processing plays an important role in DR systems. It helps idealize display of digital image on a laser film hardcopy or a reading station monitor (15). A variety of elaborate post-processing techniques have been suggested to help radiologist differentiate between noise and abnormal findings (16).

In DR, there is a reciprocal relationship between SNR and radiation dose. Lower acquisition dose is accompanied by higher image noise and vice versa (16). In this study, we observed that a new post-processing method could reduce patient entrance skin exposure up to 54.56% without reducing diagnostic capabilities or quality of DR image taken with the same X-ray system. This shows that post-processing alone can help prevent image degradation due to dose reduction.

In previous literature, post-processing method using multiscale processing has improved detail representation (e.g., bone contour representation) without increasing noise level (17, 18). In our study, the newly developed post-processing method reduced noise signal with similar algorithm by noise estimation and noise whitening. Thus, overall image quality scores of post-processed images could be higher than those of images without using the new presented method. To validate the function of this new technique, we first performed phantom study. After applying the new post-processing technique with dose lower than the dose used for the conventional post-processing technique, radiographs of phantom showed higher SNR, overall image quality score, and average scores of all evaluation criteria for various anatomic structures (e.g., liver, kidney, ilium, stomach gas). There was no significant difference in CNR between the two groups (ORG images and PPLDI). The proposed technique we used may result in different degrees of signal increase between organs. As a result, CNRs calculated by comparing signals of each adjacent organ were not increased after applying the proposed method.

The pilot study showed the same tendency. The average score of all criteria and overall image quality score were higher for images with PPLDI (LD images using the new post-processing technique) than those for images with ORG. Rater evaluated that the diagnostic quality of PPLDI (lowered up to 50% dose level) was not decreased compared to that with the conventional one. Our results revealed that applying the new post-processing technique half-dose radiograph could decrease patient dose without causing image degradation or lowering the overall diagnostic quality. This was confirmed not only in phantom study, but also in human body study. Based on these results, we performed this technique in patient study.

Results of quantitative analysis of the patient study showed that SNRs measured at lateral abdominal walls were not significantly different between full-dose ORG images and half-dose PPLDIs. However, SNRs measured at right liver tip and ilium were significantly lower in half-dose PPLDIs. Several explanations can be proposed. First, the mean given dose in patient study was 0.21 mGy, lower than 0.29 mGy of phantom study. Lower radiation dose can result higher noise values in patient study. Second, our patients were recruited through outpatient clinics, and clinically needed abdominal radiography from diverse causes, such as abdominal pain or postoperative follow up. These heterogenous condition of patients can be significantly different from abdominal phantom itself, which simulated normal abdomen.

In qualitative analysis, overall image quality scores were significantly higher for PPLDIs

than those for ORG images. Since abdominal radiography is one of the most frequently performed radiology procedure in clinical practice, cutting radiation dose exposure to half can have significant clinical impact due to long-term dose reduction. For example, patients with history of urinary stones who is under regular surveillance with abdominal radiography would benefit from the dose reduction.

In previous literature, observers have complained about the noise in DR images when they are exposed to 1/4 to 1/2 of an appropriate level (19). However, in the presenting pilot and patient studies, rater scored higher values for images obtained with the new post-processing method even with half-dose reduction. These results could be due to the advantage of this post-processing technique that can overcome quality degradation due to dose reduction.

This study has some limitations. In the patient study, the two same abdominal radiographs for one patient were obtained in conventional dose and reduced dose. The minimal radiation hazard might be caused due to redundant image acquisition. However, informed consent was obtained from each patient, and the additional radiation dose from PPLDI would be insignificant since it was approximately under 1 mGy. Second, there were no significant differences in qualitative analysis of detailed criteria in the patient study between PPLDI and ORG images. This might be due to postoperative status of patients enrolled. Radiologic findings such as intra-abdominal drainage tubes, pneumoperitoneum, and ileus were common in the patient group. These clinical setting might have influenced detailed qualitative analysis of image in the patient study by obscuring or overlapping the edge of solid organ, bone, or gas in the digestive tract. Lastly, we used copper filter only in LD for additive dose reduction. Thus, the sole effect of copper filter could not be exactly evaluated. In the previous literature, the dose reduction rate of 0.1-mm copper filter in abdominal radiology obtained in 80 kVp, was reported as 28% in acrylic phantom (11).

In summary, our results showed that the diagnostic capability of abdominal DRs taken under 50% of dose reduction was qualitatively better than conventional radiographs with full dose after applying the new post-processing method. Adopting this proposed method will help reduce patient dose of simple radiographs frequently acquired in daily practice. By applying this new post-processing technique of GC85A, half-dose abdominal DRs showed feasible and replaceable image quality compared to full-dose conventional images.

Author Contributions

Conceptualization, L.E.S.; data curation, L.E.S., K.H.; formal analysis, L.E.S., K.H.; funding acquisition, L.E.S.; investigation, all authors; methodology, L.E.S.; project administration, L.E.S.; resources, all authors; supervision, L.E.S.; validation, L.E.S.; visualization, K.H.; writing—original draft, L.E.S., K.H.; and writing—review & editing, L.E.S., K.H.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

Acknowledgments

This work was supported by Samsung Electronics Co., Ltd., Suwon-si, Korea (grant number: CAUH-20160151). Grants were used to pay for transportation expenses of enrolled patients and labor cost provided to co-authors who participated in the image evaluation during the study.

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새로운 후처리 기술을 이용한 복부 디지털 방사선 촬영: 팬텀과 환자 연구

강혜인¹ · 이은선^{1,2*} · 박현정^{1,2} · 박병관^{2,3} · 박재용^{2,4} · 서석원^{2,3}

목적 새로운 후처리 기술로 처리된 저선량 복부 디지털 방사선 영상의 진단능을 평가하기 위해 이 연구를 진행하게 되었다.

대상과 방법 팬텀과 파일럿 스터디에서 촬영된 복부 방사선 영상을 본 의료기관의 기존 및 새롭게 제시된 후처리 기술을 이용해 처리한 뒤 영상의 질을 비교하였다. 이후 시행된 45명의 환자 연구에 이용된 선량은 앞선 두 연구로부터 도출되었다. 한 환자당 두 장의 복부 방사선 영상이 기존 및 도출된 선량으로 촬영되었고 제시된 후처리 기술로 처리되었다. 영상의 세부 사항과 질을 두 명의 영상학과 의사가 평가하였다.

결과 환자 연구에 이용된 선량은 기존 선량의 절반이었다. 제시된 후처리 기술을 이용해 처리된 절반의 선량으로 촬영된 영상들의 전체 영상 질은 기존 선량으로 촬영된 영상들에 비해 유의미하게 높았고($p < 0.05$) 중등도의 평가자 간 일치도를 보였다($\kappa = 0.60, 0.47$).

결론 새로운 후처리 기술을 적용함으로써, 절반의 선량으로 촬영된 복부 디지털 방사선 영상은 기존의 전체 선량을 이용한 영상과 비교했을 때 비견될 만한 영상의 질을 보였다.

중앙대학교병원 ¹영상의학과, ³외과, ⁴내과,
²중앙대학교 의과대학