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Dose Reduction Method for Chest CT using a Combination of Examination Condition Control and Iterative Reconstruction

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ABSTRACT

We aimed to evaluate the radiation dose and image quality by changing the Scout view voltage in low-dose chest CT (LDCT) and applying scan parameters such as AEC (auto exposure control) and ASIR (adaptive statistical iterative reconstruction) to find the optimal protocol. Scout view voltage was varied at 80, 100, 120, 140 kV and after measuring the dose 5 times using the existing low-dose chest CT protocol, the appropriate kV was selected for the study using the Dose report provided by the equipment. After taking a basic LDCT shot at 120 kV, 30 mAs, ASIR 50% was applied to this condition. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) were assessed by measuring Background noise (B/N). For dose comparison, $CTDI_{vol}$ and DLP provided by the equipment were compared and analyzed using the formulas. The results indicated that the protocol of scout 140 + LDCT + ASIR 50 + AEC reduced radiation exposure and improved image quality compared to traditional LDCT, providing an optimal protocol. As demonstrated in the experiment, LDCT screenings for asymptomatic normal individuals are crucial, as they involve concerns over excessive radiation exposure per examination. Therefore, applying appropriate parameters is important, and it is expected to contribute positively to the public health in future LDCT based health screenings.

Keywords: Low Dose Chest CT(LDCT), Adaptive Statistical Iterative Reconstruction(ASIR), Auto Exposure Control(AEC), $CTDI_{vol}$, Signal-to-Noise Ratio(SNR), Contrast-to-Noise Ratio(CNR)

I. INTRODUCTION

In the lung cancer pilot project, it was found that 56% of the detected lung cancer patients were diagnosed with early stage(1, 2 stage) lung cancer, which is more than twice the proportion of early stage(21% of confirmed cases between 2011 and 2015) lung cancer among all lung cancer patients in Korea. Out of 5,719 participants in lung cancer screening, 29 were diagnosed (25 with confirmed staging). Considering international cases, it is estimated that about 20 more people, which is 15% of those currently undergoing follow up or diagnostic tests, will be additionally diagnosed among those suspected of having lung cancer[1-3]. Moreover, while conducting screenings for asymptomatic healthy individuals, low dose chest CT (LDCT), which only involves about 1/5th of the radiation exposure of a regular CT scan, not only allows for a less burdensome examination but also enables the detection of fine lung lesions that cannot be seen with chest X rays alone. Interest in lung disease screening with chest LDCT arises because it allows for obtaining highly sensitive images for detecting diseases while reducing radiation exposure. Additionally, it is non-invasive, requires no special pre-treatment or contrast agents, has a short examination time, and is cost effective[4].

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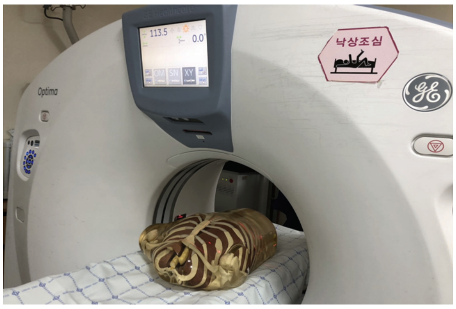
However, even with chest LDCT, the radiation dose is tens of times higher than that of chest X ray examinations, which is a very important factor in medical radiation exposure. As a national health examination project targeting asymptomatic groups for early diagnosis, the minimum radiation dose is required. In this study, we aimed to evaluate the radiation dose and image quality by changing the Scout view voltage in LDCT and applying scan parameters such as AEC(auto exposure control) and ASIR(adaptive statistical iterative reconstruction) to find the optimal protocol.

II. MATERIAL AND METHODS

1. Material

A 64 MDCT(OptimaTM CT 660 CT Scanner, GE healthcare company, USA) equipment was used, and the phantom was a tissue-equivalent human model phantom(RSD Opaque Thorax Phantom, Universal Medical, USA) composed of bone, air, and soft tissue(Fig. 1).



(A) Phantom settings on CT

(B) chest phantom

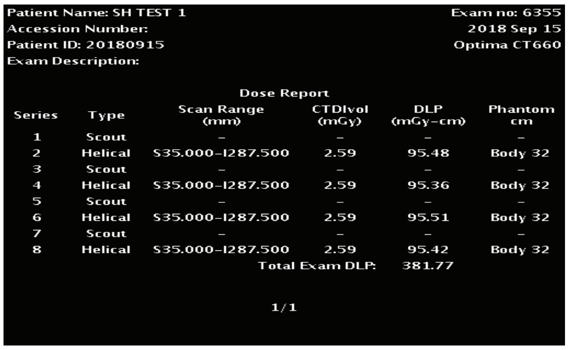
Fig. 1. Material Experiments.

2. Method

2.1. Experimental method

Scout view voltage was varied at 80, 100, 120, 140 kV, and after measuring the dose 5 times using the existing low-dose chest CT protocol, the appropriate kV was selected for the study using the dose report provided by the equipment(Fig. 2).

The scan range was set from T-spine level 1 to 12. Based on the experiments, the existing conventional LDCT and various parameter-applied protocols were compared (Table 1). After taking a basic LDCT shot at 120 kV, 30 mAs, ASIR 50% was applied to this condition. Subsequently, experiments were conducted sequentially adding ASIR 50%, AEC, lung algorithm and a 20 mm Detector coverage to Scout 140 kV. Noise, CT number values, SNR, CNR were measured using GE's workstation for 5 repetitions and the average value was calculated.



Patient Name: SH TEST 1 Exam no: 6355
Accession Number: 2018 Sep 15
Patient ID: 20180915 Optima CT660
Exam Description:

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	S35.000-I287.500	2.59	95.48	Body 32
3	Scout	-	-	-	-
4	Helical	S35.000-I287.500	2.59	95.36	Body 32
5	Scout	-	-	-	-
6	Helical	S35.000-I287.500	2.59	95.51	Body 32
7	Scout	-	-	-	-
8	Helical	S35.000-I287.500	2.59	95.42	Body 32
			Total Exam DLP:	381.77	

1/1

Fig. 2. Dose report due to scout change.

2.2. Image acquisition

The noise measurement point was set identically for each scan site, 8 cm above and 8 cm to the right of the isocenter(Fig. 3).

The area was set to 350 mm2. For this study, images of the mediastinum at the location of the bronchial bifurcation from the 5 experiments were used.

Table 1. Protocol according to the parameter change

Abbreviation	kV	mAs	AEC	ASIR(%)	Detector coverage (mm)
S120 + LDCT	120	30	smart mA		40
S120 + LDCT + ASIR 50	120	30	smart mA	50	40
S140 + LDCT + ASIR 50	140	30	smart mA	50	40
S140 + LDCT + ASIR 50 + AEC	140	25	smart mA	50	40
S140 + LDCT + ASIR 50 + AEC + D20	140	25	smart mA	50	20

* S120 : Scout 120 kV, S140 : Scout 140 kV, LDCT : Low dose CT, ASIR : Adaptive Statistical Iterative Reconstruction, AEC : Auto Exposure Control, D20 : Detector 20 mm

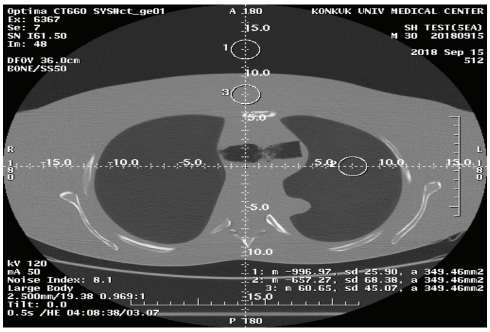


Fig. 3. ROI settings in phantom

2.3. Image quality evaluation

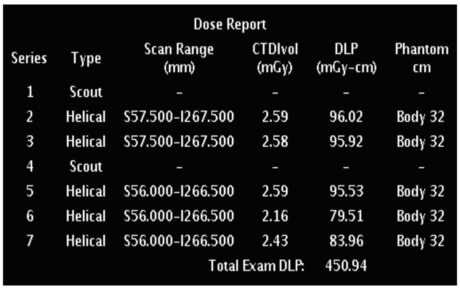
Signal to noise ratio (SNR) and contrast to noise ratio (CNR) were assessed by measuring Background noise(B/N). B/N was measured at Superior 3 cm, 3 cm in front of the image in the air. SNR and CNR were calculated using the formulas referenced in the literature[5]. SNR and CNR were measured at CT number and background noise at right 8 cm or superior 10 cm. Noise within the region of interest was defined as the standard deviation (SD) of the CT number(HU). To minimize measurement errors, 5 measurements were taken.

2.4. Dose evaluation

For dose comparison, $CTDI_{vol}$ and dose length product(DLP) provided by the equipment were compared and analyzed using the formulas below(Fig. 4).

$$CTDI_{vol} = \frac{CTDI_w}{\Pi tch} \quad (1)$$

$$DLP = CTDI_{vol} \times Length\,of\,scan \quad (2)$$



Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
2	Helical	S57.500-I267.500	2.59	96.02	Body 32
3	Helical	S57.500-I267.500	2.58	95.92	Body 32
4	Scout	-	-	-	-
5	Helical	S56.000-I266.500	2.59	95.53	Body 32
6	Helical	S56.000-I266.500	2.16	79.51	Body 32
7	Helical	S56.000-I266.500	2.43	83.96	Body 32
			Total Exam DLP:	450.94	

Fig. 4. Dose report due to $CTDI_{vol}$ and DLP

III. RESULT

1. Scout kV dose and image quality evaluation

1.1. Dose evaluation

As a result of repeating the experiment 5 times at Scout 80, 100, 120, 140 kV, the $CTDI_{vol}$ was the same at 2.59 mGy, and the average DLP was measured at 95.44 mGy·cm, showing no significant difference in dose with varying kV(Table 2).

Table 2. Comparison of Radiation Dose($CTDI_{vol}$ and DLP) with Change of kVp

kVp	CTDIvol (mGy)	DLP (mGy·cm)
80	2.59	95.48
100	2.59	95.36
120	2.59	95.51
140	2.59	95.42

1.2. Image quality evaluation

At Right 8cm, the SD values were 90.52 at 80 kV, 86.73 at 100 kV, 83.82 at 120 kV, and 67.18 at 140 kV, showing a decrease in noise as the kV increased(Table 3). A similar result was observed at Superior 10 cm. That is, at both Right 8 cm and Superior 10 cm, the SD value decreased as the kV increased, reducing the noise level.

As the kV increased, the SNR values of each ROI showed a significant increase, and the CNR values also increased, confirming an improvement in image quality.

Table 3. Evaluation of Image with Change of kV

kV	RT8			S10		S3	
	HU	SD	SNR	HU	SD	SNR	B/N	CNR
80	-640.53	90.52	18.74	57.21	80.7	1.67	34.17	20.41
100	-638.31	86.73	19.07	57.75	75.05	1.72	33.46	20.80
120	-640.83	83.82	19.48	58.05	66.8	1.76	32.89	21.24
140	-639.53	67.18	20.53	58.75	62.05	1.88	31.14	22.42

* RT8 : right 8 cm, S10: superior 10 cm, S3: superior 3 cm,

2. Scan parameter kV dose and image quality evaluation

2.1. Dose evaluation

Initially, the $CTDI_{vol}$ value was measured at the maximum of 2.59 mGy in the existing S120 + LDCT images, and when S(scout)140 + LDCT + ASIR 50 + AEC was applied, the $CTDI_{vol}$ value showed the minimum at 2.16 mGy(Table 4).

Table 4. Comparison of Radiation Dose($CTDI_{vol}$ and DLP) with Change of Protocol

Protocol	$CTDI_{vol}$ (mGy)	DLP (mGy·cm)
S120 + LDCT	2.59	96.02
S120 + LDCT + ASIR 50	2.58	95.92
S140 + LDCT + ASIR 50	2.59	95.53
S140 + LDCT + ASIR 50 + AEC	2.16	79.51
S140 + LDCT + ASIR 50 + AEC + D20	2.43	83.96

The DLP value in the existing S120 + LDCT was measured at 96.02 mGy·cm, and in the case of S120 + LDCT + ASIR 50, the DLP value was 95.92 mGy·cm, confirming a reduction of 0.1 mGy·cm compared to the existing S120 + LDCT. Next, in the case of S140 + LDCT + ASIR 50, compared to applying Scout 120 kV, the DLP value was reduced to 95.53 mGy·cm, showing a reduction of 0.49 mGy·cm from the existing LDCT. Moreover, when S140 + LDCT + ASIR 50 + AEC was used, the DLP value was significantly measured at 79.51 mGy·cm, showing the lowest dose with a significant difference of 16.51 mGy·cm compared to the existing S120 + LDCT. Lastly, when the settings were changed to S140 + LDCT + ASIR 50 + AEC + D20 for dose evaluation, although the DLP value increased to 83.96 mGy·cm compared to a Detector Coverage of 40 mm, it still showed a lower dose by 12.06 mGy·cm compared to the existing protocols.

2.2. Image quality evaluation

When compared to the existing LDCT, applying ASIR together showed a decrease of 3.59 in the SD value at Right 8 cm, and applying S140 + LDCT + ASIR 50 showed a decrease of 12.47 in the SD value. Also, when using S140 + LDCT + ASIR 50 + AEC, there was a significant decrease in the SD value by 4.68 compared to the existing LDCT, and when changing the Detector coverage from 40 mm to 20 mm, the SD value decreased by 6.04 compared to the existing LDCT. A unique SD value difference was also observed at Superior 8 cm(Table 5).

The SNR value was the lowest at 2.36 in the existing LDCT and was the highest at 2.78 when S140 + LDCT + ASIR 50 + AEC was applied, indicating superior imaging.

The CNR value was the lowest at 0.5 in the existing LDCT and significantly increased when S140 + LDCT + ASIR 50 + AEC was applied.

Table 5. Evaluation of Image with Change of Protocol

P	RT8			S10			S3	
	HU	SD	SNR	HU	SD	SNR	B/N	CNR
1	-649.43	70.24	21.88	60.29	55.3	2.03	29.67	19.85
2	-650.49	66.65	26.72	61.94	40	2.54	24.34	24.18
3	-654.5	57.77	27.54	58.31	38.81	2.45	23.76	25.09
4	-653.14	65.56	27.73	64.91	45.89	2.75	23.55	24.97
5	-655.5	64.2	25.37	59.09	42.9	2.34	25.9	23.03

*P: Protocol, 1: S120 + LDCT, 2: S120 + LDCT + ASIR 50, 3: S140 + LDCT + ASIR 50, 4: S140 + LDCT + ASIR 50 + AEC, 5: S140 + LDCT + ASIR 50 + AEC + D20

IV. DISCUSSION

With increasing public interest and concern about CT scans and radiation exposure, various technologies have been developed to reduce radiation. Not able among these are AEC, which automatically adjusts the tube current according to the thickness; ASIR, which statistically reconstructs images repeatedly to selectively reduce image noise; and Adaptive Collimator, which eliminates unnecessary scattered radiation and protects areas outside the examination area[6-8]. The use of AEC has been proven effective in reducing patient radiation dose in several studies. In the case of AEC, it is known that Rotational AEC can reduce radiation dose by up to 20%, as mentioned in a paper by Lehmann KJ et al. Therefore, this study also adopted the AEC technique, as well as the ASIR technique as another method of dose reduction[9]. A. K. Hara et al. reported that using ASIR in CT scans can reduce image noise by up to 65% and radiation dose by 30% to 50%. K. Kalra et al. reported that using ASIR in chest CT scans can reduce the dose by about 30%[10-11]. To obtain images of appropriate diagnostic value while reducing noise, most users prefer ASIR settings between 30-50%, and many consider 50% ASIR to be the appropriate balance point for reducing noise while maintaining diagnostic image quality[10]. Based on this, 50% ASIR was applied in this paper. During the experiment, applying a higher Scout kV than a lower Scout kV showed no change in $CTDI_{vol}$ but a significant change in noise values, so Scout 140 kV was applied to LDCT, and additional Scan parameters were used. Compared to the existing conventional LDCT, the image with S140 + LDCT + ASIR 50 + AEC applied showed the lowest DLP value and significant improvements in SNR and CNR, indicating enhanced image quality. Furthermore, in comparing two protocols, the lowest noise and CT number values were achieved with S140 + LDCT + ASIR 50 + AEC + D20. Among these, the protocol of S140 + LDCT + ASIR 50 + AEC showed the lowest radiation dose with an appropriate image quality. A limitation of this study is that it was conducted using phantom experiments rather than human trials and only applied GE's ASIR program, suggesting the need for further research.

V. CONCLUSION

This study conducted phantom experiments applying various parameters to low-dose chest CT scans. The results indicated that the protocol of S140 + LDCT + ASIR 50 + AEC reduced radiation exposure and improved image quality compared to traditional LDCT, providing an optimal protocol. As demonstrated in the experiment, LDCT screenings for asymptomatic normal individuals are crucial, as they involve concerns over excessive radiation exposure per examination. In conclusion, if ASIR is applied to the chest part, it is considered with the dose written much more that examination is possible. Therefore, depending on the application of appropriate parameters, CTDIvol and DLP were reduced by up to 17%. It is expected that LDCT-based health screening will positively contribute to public health in the future.

Reference

[1] S. H. Yoon, J. H. Hong, E. J. Hwang, H. K. Kim, H. J. Lim, Y. J. Suh, H. Y. Kim, J. M. Goo,

"Significant abnormalities other than lung cancer in korean lung cancer CT screening", Journal of The Korean Society of Radiology, Vol. 80, No. 5, pp. 837-848, 2019.
https://doi.org/10.3348/jksr.2019.80.5.837

[2] A. Tzedakis, J. Damilakis, K. Perisinakis, J. Stratakis, N. Gourtsoyiannis, "The effect of z overscanning on patient effective dose from multidetector helical computed tomography examinations", Medical Physics, Vol. 32, No. 6, pp. 1621-1629, 2005.
https://doi.org/10.1118/1.1924309

[3] "Ministry of Health and Welfare", Cancer prevention and early detection by national cancer screening, Department of Disease Policy, 2018.

[4] D. P. Naidich, C. H. Marshall, C. Gribbin, R. S. Arams, D. I. McCauley, "Low-dose CT of the lungs: preliminary observations", Radiology, Vol. 175, No. 3, pp. 123-128, 1990.
http://dx.doi.org/10.1148/radiology.175.3.2343122

[5] C. M. Heyer, P. S. Mohr, S. P. Lemburg, S. A. Peters, V. Nicolas, "Image quality and radiation exposure at pulmonary CT angiography with 100- or 120-kVp protocol: prospective randomized study", Radiology, Vol. 245, No. 2, pp. 577-583, 2007.
http://dx.doi.org/10.1148/radiol.2452061919

[6] S. Sone, T. Nakayama, T. Honda, K. Tsushima, F. Li, M. Haniuda, Y. Takahashi, T. Suzuki, T. Yamanda, R. Kondo, T. Hanaoka, F. Takayama, K. Kubo, H. Fushimi, "Long-term follow-up study of a population-based 1996–1998 mass screening programme for lung cancer using mobile low-dose spiral computed tomography", Lung Cancer, Vol. 58, No. 3, pp. 329-341, 2007.
http://dx.doi.org/10.1016/j.lungcan.2007.06.022

[7] D. H. Yang, H. W. Goo, "Pediatric 16-slice CT Protocols: Radiation Dose and Image Quality", Journal of the Korean Radiological Society, Vol. 59, No. 5, pp. 333-347, 2008.
http://dx.doi.org/10.3348/jkrs.2008.59.5.333

[8] H. W. Goo, "Pediatric CT: understanding of radiation dose and optimization of imaging techniques", Journal of the Korean Radiological Society, Vol. 52, No. 1, pp. 1-5, 2005.
http://dx.doi.org/10.3348/jkrs.2005.52.1.1

[9] K. J. Lehmann, J. Wild, M. Georgi, "Clinical use of software-controlled x-ray tube modulation with "Smart-Scan" in spiral CT", Aktuelle Radiol, Vol. 7, No. 3, pp. 156-158, 1997.

[10] A. K. Hara, R. G. Paden, A. C. Silva, J. L. Kujak, H. J. Lawder, W. Pavlicek, "Iterative reconstruction technique for reducing body radiation dose at CT: feasibility study", American Journal of Roentgenology, Vol. 193, No. 3, pp. 764-771, 2009.
https://doi.org/10.2214/ajr.09.2397

[11] A. C. Silva, H. J. Lawder, A. Hara, J. Kujak, W. Pavlicek, "Innovations in CT Dose Reduction Strategy: Application of the Adaptive Statistical Iterative Reconstruction Algorithm", American Journal of Roentgenology, Vol. 1994, No. 1, pp. 191-199, 2010. https://doi.org/10.2214/AJR.09.2953

검사 조건 제어와 반복 재구성의 조합을 이용한 흉부 CT의 선량 저감화 방안

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요 약

저선량흉부 CT (Low Dose chest CT, LDCT)에서 Scout 관전압을 변화시키고 scan parameter인 자동노출제어장치(Auto Exposure Control, AEC)와 적응식 반복재구성기법(Adaptive Statistical Iterative Reconstruction, ASIR)등을 적용하여 최적의 프로토콜을 찾음으로써 방사선 피폭선량과 화질을 평가하고자 하였다. Scout 관전압을 80, 100, 120, 140 kV로 변화시키며 LDCT 프로토콜로 5회 반복 측정 후 선량을 비교하기 위해 장비에서 제공된 Dose report를 이용하여 연구 목적에 적합한 관전압을 선택하였다. 120 kV, 30 mAs의 조건으로 기본 LDCT 촬영한 후, 이 조건에 ASIR 50%를 적용하였으며 신호대잡음비와 대조도대잡음비를 평가하기 위해 배경의 노이즈를 측정하였다. 선량 비교를 위해 장비에서 제공되는 $CTDI_{vol}$과 선량길이곱(Dose length product, DLP)를 식을 이용하여 비교 분석하였다. 그 결과 S140 + LDCT + ASIR 50 + AEC를 적용한 프로토콜에서 고식적인 LCDT보다 방사선 피폭선량을 감소시키고 영상의 질을 향상시켰으며 최적의 프로토콜을 얻을 수 있었으며 LDCT는 매 검사 시 필요 이상의 피폭선량이 우려되기 때문에 적절한 Parameter를 적용하는 것이 중요하며, 향후 LDCT를 이용한 건강검진에서 국민의 건강에 이바지 하는데 긍정적인 요인으로 작용될 것으로 사료된다.

중심단어: 저선량흉부 CT, 반복재구성기법, 자동노출제어장치, $CTDI_{vol}$, 신호대잡음비, 대조도대잡음비

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