

&lt;원저&gt;

# Usefulness Evaluation of Low-dose CT for Emphysema : Compared with High-resolution CT

- 폐기종에 대한 저선량 CT의 유용성 평가: 고해상도 CT와 비교 -

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## — Abstract —

The purpose of this study was to evaluate the usefulness of low-dose CT (LDCT) for emphysema compared with high-resolution CT (HRCT).

Measurements of radiation dose and noise were repeated 3 times in same exposure condition which was similar with obtaining HRCT and LDCT images. We analysed reading results of 146 subjects. Six images per participants selected for emphysema grading. Emphysema was graded for all 6 zones on the left and right sides of the lungs by the consensus reading of two chest radiologists using a 4-point scale. Between the HRCT and LDCT images, diagnostic differences and agreements for emphysema were analyzed by McNemar's and un-weighted kappa tests, and radiation doses and noise by a Mann-Whitney U-test, using the SPSS 19.0 program.

Radiation dose from HRCT was significantly higher than that of LDCT, but the noise was significantly lower in HRCT than in LDCT. Diagnostic agreement for emphysema between HRCT and LDCT images was excellent (k-value=0.88). Emphysema grading scores were not significantly different between HRCT and LDCT images for all six lung zones. Emphysema grading scores from LDCT images were significantly correlated with increased scores on HRCT images ( $r=0.599$ ,  $p < 0.001$ ).

Considering the tradeoff between radiation dose and image noise, LDCT could be used as the gold standard method instead of HRCT for emphysema detection and grading.

**Key words :** High-resolution CT; Low-dose CT; Emphysema; Radiation dose; Image noise

## I. INTRODUCTION

In the field of radiology, imaging modalities have an important role in the detection of emphysema, which is generally expressed as morphological changes of the lung parenchyma<sup>[1]</sup>.

Emphysema was first evaluated by computed

tomography (CT) in 1980s<sup>[2]</sup>. The use of high-resolution CT (HRCT) for emphysema evaluation has increased consistently over the past 2 decades<sup>[3-6]</sup>. HRCT is a powerful diagnostic and prognostic tool for the lung diseases such as emphysema, and is the gold standard for their evaluation<sup>[7]</sup>. The main reason for HRCT use in emphysema is that HRCT has demonstrated improved visualization of changes in lung parenchyma

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using thin-slice thicknesses<sup>[1]</sup> and high-radiation doses<sup>[8,9]</sup>.

Radiation dose from CT is of increasing concern worldwide, because higher medical radiation doses from growing CT use increases cancer risk<sup>[10,11]</sup>.

Low-dose CT (LDCT) was first introduced in the 1990s to reduce the radiation dose risk from chest CT<sup>[12]</sup>, and its utility has been demonstrated in previous studies<sup>[13,14,15]</sup>. Other recent papers also support the possibility of LDCT applications for emphysema quantification instead of HRCT or standard-dose CT (SDCT)<sup>[16-18]</sup>, although image noise can be increased when using a lower value for the tube current-scan time product (mAs, mA × sec); as a result, image noise is inversely proportional to radiation dose<sup>[19]</sup>.

To the best of our knowledge, there have been rarely studies investigating radiation dose and noise in the use of LDCT for emphysema detection. Therefore, The purpose of this study was to evaluate the usefulness of LDCT for emphysema compared with HRCT.

## II. MATERIALS AND METHODS

### 1. Measurements of Radiation Dose and Image Noise

Radiation dose (mGy) was measured at 5 points in an acrylic phantom (10S5-3CT, Radical, USA) using a dose measurement instrument (Unfors Mult-O-Meter 9015, Radical, USA). Image noise (HU, Hounsfield units) was measured at 4 points (1062.1 mm<sup>2</sup>) in a water phantom (AAPM CT Performance Phantom, 76-410-4130, USA) and was defined as the standard deviation of the CT value in HU. Measurements of radiation dose and image noise were repeated 3 times in the same environment, and the mean value was recorded for analysis. The exposure conditions for the radiation dose and noise measurements were 180 mAs for HRCT and 30 mAs for LDCT with a fixed tube voltage of 120 kVp and a slice thickness of 1.2 mm on

a 16-slice system (Brilliance TM CT 16-Slice; Philips, The Netherlands).

### 2. Emphysema Reading on HRCT and LDCT Images

We analyzed retrospectively reading results for emphysema of 146 participants and parameters on HRCT (1.2 mm, 120 kVp, 180 mAs) and LDCT (2.0 mm, 120 kVp, 30 mAs) images without any informations of participants.

Emphysema was graded the system published by Kusaka et al.<sup>[5,6]</sup> : HRCT and LDCT images scanned from the lung apex to the diaphragm, and 6 images per participant, equally spaced through the lungs, were selected for emphysema grading. Two images from each zone of the lungs (upper, the arch of the aorta and above; middle, from the arch of the aorta to the inferior pulmonary vein; and lower, the inferior pulmonary vein and below, including the diaphragm) were acquired. The readers were blinded to the technical parameters used in the CT images acquisition (e.g., kVp, mAs, slice thickness, and resolution). Emphysema was documented as a presence or absence and graded for all 6 zones on the left and right sides of the lungs by the consensus reading of 2 chest radiologists using a 4-point scale: normal (score 0), absence; mild (score 1), up to 15% of the area from one zone; moderate (score 2), between 15 and 30%; and severe (score 3)  $\geq$  30% of the area from one zone. Emphysema was re-graded into 4 categories (normal, total score = 0; mild, total score = 1-6; moderate, total score = 7-12; severe, total score = 13-18) from a total score (ranging from 0 to 18) summed the grades of the six zones of the lungs using a 4-point scale. LDCT images were graded 1 month after grading the HRCT images to avoid bias.

### 3. Statistical Analysis

Data are expressed as the mean and standard deviation for continuous variables and as percentage for categorical variables. The diagnostic differences and agreements for emphysema between the HRCT and

LDCT images were analyzed using McNemar's and unweighted kappa tests. Agreements for the 4 categories of emphysema grading were calculated by a linearly weighted kappa value: A k-value of less than 0.20 indicated poor agreement; a k-value of 0.21-0.40, fair agreement; a k-value of 0.41-0.60, moderate agreement; a k-value of 0.61-0.80, good agreement; and a k-value of 0.81-1.00, excellent agreement. The linear relationships for emphysema grading scores between HRCT and LDCT images were calculated using Pearson's correlation coefficient. The radiation doses and image noise between the HRCT and LDCT images were compared using a Mann-Whitney U-test. The total emphysema grading scores between the HRCT and LDCT images were compared using a paired *t*-test. A value of  $p < 0.05$  was considered to indicate statistical significance. Analyses were performed using the SPSS statistical analysis program (Version 19.0, Chicago, IL, USA).

#### 4. Ethics Statement

This study was waived by the institutional review board of the Daejeon Health Institute of Technology in 2015. Because this study was analyzed retrospectively reading results for emphysema and parameters on

HRCT and LDCT images without any informations of participants.

### III. RESULTS

#### 1. Radiation Dose and Image Noise of HRCT and LDCT Images

The data for radiation dose and image noise measured by HRCT and LDCT are presented in Table 1. The radiation dose from HRCT was significantly higher than that of LDCT (1.95 mGy vs. 0.35 mGy,  $p=0.008$ ), but the image noise was significantly lower in HRCT than in LDCT (40.1 HU vs. 99.6 HU,  $p=0.021$ ).

#### 2. Diagnostic Differences for Emphysema between HRCT and LDCT Images

Emphysema was detected in 26.7% of participants on the HRCT images and in 27.4% of participants on the LDCT images (Table 2); there were no significant differences between the two methods. Among the 146 participants, 36 (24.7%) had emphysema on HRCT images as well as on LDCT images. Three (7.7%) out

**Table 1** Comparisons of radiation dose and image noise between HRCT and LDCT

	HRCT	LDCT	<i>p</i> -value
Radiation dose (mGy)	1.95 (0.54)	0.35 (0.10)	0.008
Image noise (HU)	40.1 (4.3)	99.6 (10.3)	0.021

HRCT, high-resolution CT; HU, Hounsfield units; LDCT, low-dose CT. Data are expressed as the mean (standard deviation). The *p*-value was calculated using a Mann-Whitney U-test.

**Table 2** Emphysema diagnosis differences between HRCT and LDCT images

		LDCT images		Total	<i>p</i> -value
		Em (-)	Em (+)		
HRCT images	Em (-)	103(96.3)	4(3.7)	107(100.0)	1.000
	Em (+)	3(7.7)	36(92.3)	39(100.0)	
Total		106(72.6)	40(27.4)	146(100.0)	

Em, emphysema; HRCT, high-resolution CT; LDCT, low-dose CT. Data are expressed as the number of participants and as a percentage of the total number of participants. The k-value was 0.88 (standard deviation = 0.05; 95% CI = 0.79-0.97), calculated by unweighted kappa. The *p*-value was calculated with McNemar's test.

**Table 3** Emphysema grading agreement for HRCT and LDCT images

Grading	LDCT images				Total	k-value (SE) (95% CI)	
	Normal	Mild	Moderate	Severe			
HRCT images	Normal	103 (96,3)	2 (1,9)	2 (1,9)	0 (0,0)	107 (100,0)	0,71(0,05) (0,61-0,82)
	Mild	3 (10,7)	21 (75,0)	2 (7,1)	2 (7,1)	28 (100,0)	
	Moderate	0 (0,0)	4 (44,4)	4 (44,4)	1 (11,1)	9 (100,0)	
	Severe	0 (0,0)	2 (100,0)	0 (0,0)	0 (0,0)	2 (100,0)	
Total	106 (72,6)	29 (19,9)	8 (5,5)	3 (2,1)	146 (100,0)		

HRCT, high-resolution CT; LDCT, low-dose CT. Data are expressed as the number of participants and as a percentage of the total number of participants. Emphysema was re-graded into 4 categories (normal, total score = 0; mild, total score = 1-6; moderate, total score = 7-12; and severe, total score = 13-18) from the total score summed after grading each of the 6 lung zones on a 4-point scale (normal = 0; mild = 1; moderate = 2; severe = 3). The k-value was calculated with linear weighting.

of 39 participants with emphysema on HRCT images were detected as negative for emphysema on LDCT images, and 4 (3.7%) out of 107 participants without emphysema on HRCT images were detected as positive on LDCT images. The diagnostic agreement for emphysema between HRCT and LDCT images was excellent, with a k-value of 0.88.

### 3. Diagnostic Agreements for Emphysema between HRCT and LDCT Images

The k-value for the 4 emphysema grading categories on HRCT and LDCT images are listed in Table 3. The results showed good agreement, with a k-value of 0.71 (95% CI, 0.61-0.82). Emphysema detection was not significantly different between the two methods (McNemar-Bowker test,  $p=0.569$ ). Of the 106 participants without emphysema on LDCT images, 3 participants were graded as having mild emphysema on HRCT images. Of the 29 participants with mild emphysema on LDCT images, the findings of 8 participants did not agree with that from the HRCT images, four and 2 participants were over-graded with moderate and severe emphysema on HRCT images, respectively. Of the 107 participants without emphysema on HRCT images, 4 participants were over-graded as having mild or moderate emphysema on LDCT images. Four

participants with mild emphysema on HRCT images were over-graded; 2 participants were graded as moderate and 2 as severe on LDCT images. One participant with moderate emphysema on HRCT images was graded as having severe emphysema on LDCT images.

### 4. Emphysema Grading Scores on HRCT and LDCT Images

Emphysema grading scores were not significantly different between HRCT and LDCT images for all six lung zones (Table 4, Figure 1). The total emphysema grading score from LDCT images was higher than that from HRCT images; however, the difference was not statistically significant ( $p=0.734$ ). The relationships between the emphysema grading scores from HRCT and LDCT images are shown in Figure 2. Emphysema grading scores from LDCT images were significantly correlated with increased scores on HRCT images; the correlation coefficient was 0.599 ( $p < 0.001$ ).

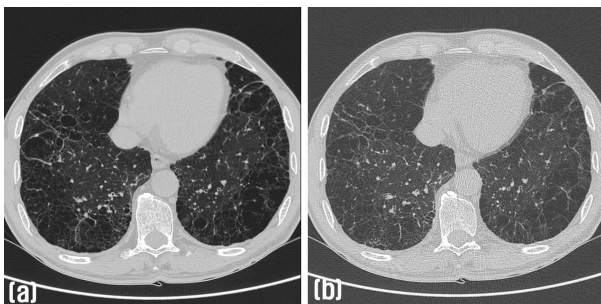
## IV. DISCUSSION

CT is the best diagnostic modality to visualize structures in low-contrast regions such as the

**Table 4** Comparisons of emphysema grading scores between HRCT and LDCT images

Side	Zone	HRCT images	LDCT images	<i>p</i> -value
Right	Upper	0.36 (0.74)	0.34 (0.68)	0.711
	Middle	0.25 (0.57)	0.31 (0.65)	0.239
	Lower	0.22 (0.53)	0.25 (0.59)	0.425
Left	Upper	0.28 (0.64)	0.27 (0.58)	0.895
	Middle	0.23 (0.56)	0.25 (0.56)	0.539
	Lower	0.21 (0.55)	0.20 (0.52)	0.879
Total		1.54 (3.27)	1.62 (3.24)	0.734

HRCT, high-resolution CT; LDCT, low-dose CT. Data are expressed as the mean and standard deviation. The *p*-value was calculated using a paired *t*-test.

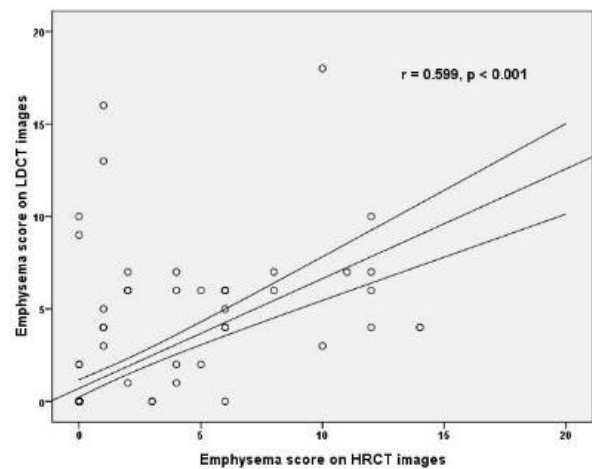


**Figure 1** High-resolution CT (HRCT, a) and low-dose CT (LDCT, b) images for lower zone of lung on same subject. Emphysema grading scores between HRCT and LDCT were not difference in right(3 vs. 3) and left side(3 vs. 3).

lung parenchyma, which can undergo emphysematous changes. The diagnosis of emphysema is limited primarily by image noise, which is inversely related to radiation dose<sup>[19]</sup>.

Radiation dose and image noise in CT generally depend on the choice of technique; parameters such as X-ray tube voltage and the current-time product (mAs) are the most important factors. The current-time product has been commonly used to reduce the radiation dose of CT images in clinical practice. In screening for emphysema, we have to consider reducing the radiation dose by using a lower current-time product. In this study, a reduction from 180 mAs to 30 mAs with a fixed tube voltage of 120 kVp resulted in decreasing the radiation dose of LDCT by up to one-sixth; however, the increase in image noise was 2.5-time larger than that of HRCT.

In our study, subjective emphysema grading was



**Figure 2** A scatterplot shows the relationship between emphysema grading scores on high-resolution and low-dose CT images.

performed according to the guidelines recommending that at least 6 slices with slice thicknesses of 1-2 mm be used in the evaluation of emphysema<sup>[5,6]</sup>. For screening purposes, 6-8 slices are taken distributed over all lung zones. Slice thicknesses were a bit different in HRCT and LDCT images in this study, which may have caused the noise to be increased in the thin slices used in HRCT<sup>[19]</sup>.

LDCT images have been compared with HRCT and SDCT images for the diagnosis of emphysema<sup>[16-18]</sup>. The application of LDCT images to emphysema detection could be considered controversial, as image noise increases when using a lower mAs value<sup>[4,20]</sup>. There are two conflicting studies: A study by Horiuchi et al.<sup>[20]</sup> showed that HRCT images were more sensitive in detecting emphysema than LDCT images (75

subjects vs. 54 subjects). On the other hand, another study found that measurements of the emphysema index, total lung volume, and mean lung density were not affected significantly by a decrease from 150 mAs to 25 mAs<sup>[4]</sup>. In our study, we did not find significant diagnostic differences in emphysema between the HRCT and LDCT images (39 participants vs. 40 participants), and concluded that emphysema detection was not affected by a lower mAs value. The total emphysema grading score was not significantly different between HRCT and LDCT images in this study, which was consistent with the results of previous studies reporting little difference between LDCT and SDCT images<sup>[17]</sup>. Therefore, for screening emphysema, evaluation of emphysema severity by LDCT images can be considered equivalent to HRCT images.

As shown in Figure 2, emphysema grading scores from HRCT images were significantly associated with those from LDCT images; such findings are in agreement with a study reported by Gierada et al.<sup>[16]</sup> which showed that emphysema indices on LDCT and SDCT images were strongly correlated for all attenuation thresholds.

Emphysema has been quantified more objectively with the assistance of computer software<sup>[20]</sup>. A study by Gierada et al.<sup>[16]</sup> using pulmonary analysis software demonstrated that the LDCT technique has a minimal effect on the CT quantification of emphysema, in that CT measurements were not affected by lower mAs values, and their study showed no significant differences between mean and median lung attenuation on LDCT and SDCT images. However, emphysema quantification using software is time-consuming and increases the examination cost; therefore, subjective visual grading is typically used in clinical practice.

Subjective emphysema grading does not evaluate all image slices through the lungs; only 5–6 images are used<sup>[3,5,6]</sup>. However, objective measurement for emphysema quantification uses all image slices collected in spiral scanning mode to obtain volumetric data<sup>[16–18]</sup>.

Emphysema could be overestimated by subjective grading<sup>[4]</sup> as well as by LDCT images<sup>[16]</sup>. In a previous study using macroscopic morphometric measurements as a gold standard in thin-section CT<sup>[4]</sup>, subjective emphysema grading showed less agreement with macroscopic reference standard results ( $r=0.439-0.505$ ,  $p < 0.05$ ) than with objective CT densitometric results ( $r=0.555-0.623$ ,  $p < 0.001$ ). Overestimation of emphysema grading on LDCT images can be avoided by using adaptive iterative dose reduction 3D processing for noise reduction in LDCT, as there are no remarkable differences between LDCT and SDCT images for emphysema quantification<sup>[17]</sup>. In our study, the subjective emphysema grading scores on LDCT images tended to be slightly overestimated compared with those on HRCT images. These results may be explained by the reduction of radiation dose resulting in an increase of noise<sup>[19]</sup> with subjective emphysema grading<sup>[4]</sup> affecting emphysema quantification, and because a software program was not used for noise reduction.

The results of our study are similar (data are not expressed) to the results of a study by Bankier et al.<sup>[4]</sup> in which emphysema was more frequently observed in the upper zone of the lungs than in the middle or lower zones.

This study had a limitation that noise is strongly affected by the reconstruction filter utilized<sup>[19]</sup>, and the use of filters was not investigated in this study.

To summarize, LDCT is effective in terms of reducing radiation dose, although image noise is greater than in HRCT. There was excellent agreement between the HRCT and LDCT images, and the imaging modalities did not show a difference in ability to diagnose emphysema. Therefore, considering the tradeoff between radiation dose and image noise, LDCT could be used as the gold standard method instead of HRCT for emphysema detection and grading.

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•국문초록

## 폐기종에 대한 저선량 CT의 유용성 평가: 고해상도 CT와 비교

이원정

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본 연구에서는 폐기종에 대해 고해상도 CT와 비교한 저선량 CT의 유용성에 대해 평가하였다. 고해상도 CT와 저선량 CT 노출조건에서 선량과 영상 잡음을 3회 반복 측정하였다. 비슷한 노출조건에서 획득한 146명의 고해상도 CT와 저선량 CT 영상에 대해 2명의 흉부영상의학과전문의 합의 판독결과에서 폐기종 소견만을 본 연구에 사용하였다. SPSS ver. 19.0 프로그램 사용하여 고해상도 CT와 저선량 CT 간에 폐기종에 대한 진단 차이는 McNemar's tests, 일치도는 unweighted kappa tests, 선량과 잡음 차이는 Mann-Whitney U-test 로 분석하였다.

선량은 고해상도 CT가 저선량 CT 보다 높았지만(1.95 mGy vs. 0.35 mGy,  $p=0.008$ ), 잡음은 낮았다(40.1 HU vs. 99.6 HU,  $p=0.021$ ). 폐기종 진단에 대해서는 두 영상 간에 높은 일치도를 보였다( $k$ -value=0.88). 폐기종 점수는 두 영상 간에 통계적인 유의한 차이를 보이지 않았고, 높은 상관성을 보였다( $r=0.599$ ,  $p < 0.001$ ).

선량과 잡음을 고려했을 때, 저선량 CT는 폐기종 진단에 표준 진단 방법인 고해상도 CT를 대신하여 사용할 수 있을 것으로 사료된다.

**중심 단어:** 고해상도 CT, 저선량 CT, 폐기종, 방사선 선량, 영상 잡음