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<원저>

Image Evaluation and Exposure Dose with the Application of Tube Voltage and Adaptive Statistical Iterative Reconstruction of Low Dose Computed Tomography

- 저 선량 전산화단층촬영의 관전압과 적응식 통계적 반복 재구성법 적용에 따른 영상평가 및 피폭선량 -

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— Abstract —

The study has attempted to evaluate and compare the image evaluation and exposure dose by respectively applying filter back projection (FBP), the existing test method, and adaptive statistical iterative reconstruction (ASIR) with different values of tube voltage during the low dose computed tomography (LDCT). With the image reconstruction method as basis, chest phantom was utilized with the FBP and ASIR set at 10%, 20% respectively, and the change of tube voltage (100 kVp, 120 kVp). For image evaluation, back ground noise, signal-noise ratio (SNR) and contrast-noise ratio (CNR) were measured, and, for dose assessment, CTDIvol and DLP were measured respectively. In terms of image evaluation, there was significant difference in ascending aorta (AA) SNR and inpraspinatus muscle (IM) SNR with the different amount of tube voltage ($p < 0.05$). In terms of CTDIvol, the measured values with the same tube voltage of 120 kVp were 2.6 mGy with no-ASIR and 2.17 mGy with 20%-ASIR respectively, decreased by 0.43 mGy, and the values with 100 kVp were 1.61 mGy with no-ASIR and 1.34 mGy with 20%-ASIR, decreased by 0.27 mGy. In terms of DLP, the measured values with 120 kVp were 103.21 mGy·cm with no-ASIR and 85.94 mGy·cm with 20%-ASIR, decreased by 17.27 mGy·cm (about 16.7%), and the values with 100 kVp were 63.84 mGy·cm with no-ASIR and 53.25 mGy·cm with 20%-ASIR, a decrease by 10.62 mGy·cm (about 16.7%). At lower tube voltage, the rate of dose significantly decreased, but the negative effects on image evaluation was shown due to the increase of noise.

Key Words: Chest Phantom, Low dose CT, Adaptive Statistical Iterative Reconstruction, Voltage

Ⅰ. INTRODUCTION

Lung cancer is the most common cause of death worldwide. According to statistics of 2008, about 1520 thousand people were diagnosed with lung cancer and 1310 thousand people died of lung cancer[1]. Up until now, proper and early diagnosis method capable of increasing the survival rate of patients with lung cancer is not available.

Chest X-ray and cytodiagnosis of sputum are proven

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not to be effective for early detection of lung cancer in previous researches. So these methods are not recommended. On the other hand, CT scans are more sensitive for diagnosis of lung diseases comparing to simple chest radiography. With the emergence of spiral multi-detector computed tomography (MDCT) device, the inspection time was shortened, and increase of high resolution and multi-planar reformated image were enabled with thin slice scan.

For this reason, diagnostic value was further improved, but diseases could be overlooked during deciphering because of the increase of the radiation exposure and the vast amount of information due to thin slices. Also, it led to the increase of inspection cost due to the increase of medical fee[2].

Also, CT scan is used clinically in a wide range, and with a few CT scans, radiation of 50 ~ 150 mSv can be received. Considering the fact that CT scan is repeated several times for one patient, this degree of danger is significant.

Especially in the case of children, their organs are growing, they are more sensitive to radiation, the remaining days of their life are longer, and they are likely to get several tests, so their cancer incidence is higher. So their should be efforts to reduce radiation exposure due to CT. Recently, low-dose spiral chest CT scan which reduced the exposure to radiation to 1/8 comparing to low-dose chest CT for the general diagnostic purpose, is attracting attention as a new early diagnosis method[3].

The purpose of screening test is to treat or find diseases when they are treatable. Also a series of tests are included to detect diseases during their silent period among high-risk patients.

The body part that low-dose radiation CT scan is frequently conducted is chest. When setting a protocol, the main factors related to exposure dose are tube voltage (kVp), tube current (mA), irradiation time (sec), and pitch, and according to these, patients' exposure dose varies.

As a way of reducing exposure to radiation, automatic exposure control which the current in a tube is automatically adjusted to maintain the noise in the image constantly, using the filtration filter and low-dose protocol according to the purpose of the inspection locations are being applied[4-5]. By changing such factors related to exposure dose depending on the size and body parts of patients, we can greatly reduce exposure dose and lengthen the life-span of X-ray tubes. Regarding the exposure dose of patients in CT scan, the technical factors that are made in the production process of the machine cannot be changed. Still, operational factors can be reduced by the one who handles the machine so if intended, it is possible to reduce exposure dose but still obtain images of enough diagnostic value.

And CT scanner producers are developing softwares that maintain the quality of image by using iterative reconstruction but reduce exposure dose of radiation. One of the achievements is the technology called 'adaptive statistical iterative reconstruction'. It reduces exposure dose based on the principle of iterative reconstruction and acquires diagnostically valuable images.

ASIR has been introduced which is the algorithm of reconstruction for reducing the dose without lowering the quality of CT images[6]. Recently, its usefulness has been reported, because the diagnostic evaluation of images which applied the ASIR technique became possible[7].

In this study, we would like to compare and evaluate applying FBP which is the previous method of reconstructing images, and applying ASIR when doing LDCT scan, and also the quality of images and radiation dose according to the voltage changes.

II. METHODS

1. subject

The experiment was conducted from November 2015 to December 2015. And the target used anthropomorphic chest phantom (Flukebrome medical, USA) which was consisted of human equivalent materials [Fig. 1]. For CT equipment, 64 MDCT (Optima^{TM} CT660 CT Scanner,

Fig. 1 Anthropomorphic chest phantom

Table 1 Parameter used in anthropomorphic phantom CT scan

Scan Parameter	
Detector Coverage	40 mm
Thickness, Interval	5.0 / 2.5 mm
kVp	120 / 100
mA	60
Rotation Time	0.5 sec
Pitch	0.984 : 1
DFOV	360 mm
Algorithm	Bone

GE healthcare company, USA) was used, and testing conditions are as follows [Fig. 2], [Table 1].

2. Research Methods

1) Image quality evaluation

For image quality evaluation, as for quantitative analysis method, CT number was measured and the level of noise was analyzed. CT number (HounsfieldUnit; HU) and noise in AA and IM in the image were measured with the quantitative analytical method.

Back−ground noise was measured (is located at 1cm in front of the image, in the air) to get signal−to−noise ratio; SNR and contrast−to−noise ratio; CNR[8]. Region of interest was all in the range of 100 ~ 110 cm^2 in the measure, and the average value was

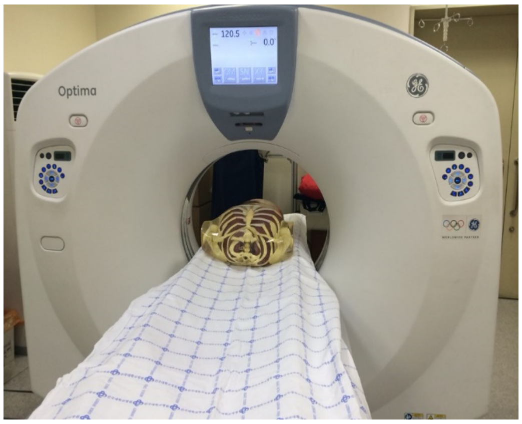

Fig. 2 Computed tomography scanner

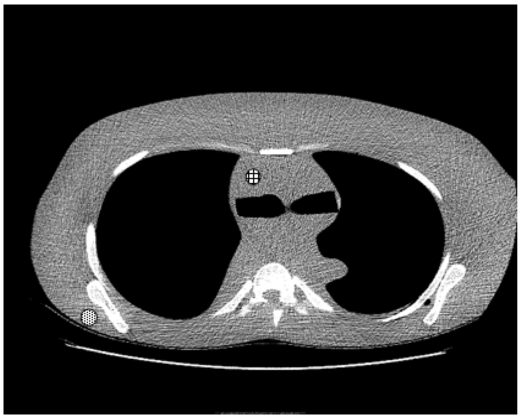

Fig. 3 Phantom image of low-dose. CT number and noise were measured each at infraspinatus muscle(◯) and ascending aorta (⊕)

determined by measuring for six times. Noise in the region of interested interest was defined with HU, standard deviation of CT number [Fig. 3].

SNR and CNR were calculated with the following formula referring the relevant literature[8]: SNR = ascending aorta (or infraspinatus muscle) CT number / back−ground noise. CNR = (infraspinatus muscle CT number − ascending aorta CT number) / back−ground noise.

2) Exposure dose evaluation

Dose assessment was analyzed by recording CTDIvol and DLP which are provided in the equipment. The value of DLP that is measured as exposure dose is obtained by multiplying CTDIvol with length and it refers to the total dose that a patient receives during scanning. It is obtained through the following equation.

Statistical analysis was performed using SPSS (ver. 22.0). After performing the normality test and homogeneity test, ANOVA test was performed. Post-test were performed using multiple comparison by Tukey law.

III. RESULT

As for evaluation of the quality of images, there wasn't significant difference between AA SNR and IM SNR according to applying ASIR ($p>0.05$), and there was significant difference between AA SNR and IM SNR according to kVp ($p<0.05$). Also, there was no significant difference in CNR according to ASIR and change of tube voltage ($P>0.05$).

As for dose assessment, there wasn't significant difference between CTDIvol and DLP. As for CTDIvol, 120kVp, FBP was reduced by 2.6 mGy, 120 kVp, 10%-ASIR was reduced by 2.38 mGy, 120 kVp, 20%-ASIR was reduced to 2.17 mGy by 0.43 mGy, 100 kVp, FBP was reduced by 1.61 mGy, 100 kVp, 10%-ASIR was reduced by 1.48 mGy, 100 kVp, and 20%-ASIR was reduced to 1.34 mGy by 0.27 mGy. Also in DLP, 120 kVp, FBP was reduced by 103.21 mGy·cm, 120 kVp, 10%-ASIR was reduced by 94.57 mGy·cm, 120 kVp, 20%-ASIR was reduced to 85.94 mGy·cm by 17.27 mGy·cm (16.7%). And 100 kVp, FBP was reduced by 63.87 mGy·cm, 100 kVp, 10%-ASIR was reduced by 58.54 mGy·cm, 100 kVp, and 20%-ASIR was reduced to 53.25 mGy·cm by 10.62 mGy·cm (16.7%) [Table 2].

IV. DISCUSSION

Result of the research for collective tests for early detection of lung cancer using low-dose chest CT scan started in Japan and United States since 1990s, has been announced since early 2000s.

According to these research results, low dose chest CT had a very high rate of early lung cancer detection comparing to conventional chest radiograph. It is indicated that about 85% of the detected lung cancer was is an early stage of I group, and about 80% was adenocarcinoma and has a very high rate of survival for 5 years. So it has been suggested that it is very useful for the early detection of lung cancer[9,10].

In the previous study, the screening test using sputum cytology and chest radiography did not prove the decrease in lung cancer. The biggest reason is probably the relatively low sensitivity of sputum cytology and chest radiography in early tumor.

Small pulmonary nodules are common and most of them are not malignant so they require non-invasive diagnostic algorithms to avoid invasive procedure in positive nodes and categorize the detected parts.

Low-dose radiation CT scan is very sensitive to small pulmonary nodules that are frequently found in early lung cancer. LDCT protocol was used in order to minimize the risk of exposure without lowering the sensitivity as for the diagnosis of lung diseases by Naidich and et al.[11] After that, a differential diagnosis of lung diseases, and the clinical usefulness research for screening inspection using LDCT have been made[12].

Table 2 Comparison of dose exposure and image quality between 120 kVp and 100 kVp

	120 FBP	120 A-10	120 A-20	100 FBP	100 A-10	100 A-20	P-value
AA-S	1.4	1.5	1.5	0.8	0.9	0.8	.000
IM-S	2.0	2.2	2.1	1.4	1.4	1.3	.000
CNR	0.6	0.7	0.7	0.6	0.6	0.5	.275
CTDI	2.6	2.4	2.2	1.6	1.5	1.3	.000
DLP	103.0	94.6	85.9	63.9	58.5	53.3	.000

* AA-S; ascending aorta signal to noise ratio, IM-S; infraspinatus muscle signal to noise ratio, CNR; contrast to noise ratio, CTDI; computed tomography dose index, DLP; dose length product, 120; 120kVp, 100; 100kVp, A-10; adaptive statistical iterative reconstruction 10%, FBP; filtered back projection

The reason for having interest in screening inspection of lung disease by LDCT was because it was possible to obtain images with high sensitivity for detecting the disease while reducing the dose.

Whether early diagnosis depending on screening test raises survival rate is debated because it is affected by lead time bias, length time bias, and overdiagnosis bias. Lead time bias refers to the screened group detecting disease at an early stage, making it look like it increased survival rate but the point of death being the same as that of the unscreened group.

Actually, early detection of disease and early treatment do not affect natural progress of diseases. Bach et al.[13] reported that LDCT increased the diagnosis for lung cancer and the cure rate, but did not significantly reduce the risk of advanced lung cancer or death from lung cancer.

This CT scan is also known to be the most exposure among diagnostic regions[14]. The inspector and the manufacturer are putting a lot of effort to reduce exposure dose while having CT scan.

Recently, ASIR has been developed, which improves the quality of the image reducing the noise based on the iterative reconstruction principle. It became possible to realize the diagnostically valuable images with low dose scan by applying ASIR which repeatedly reconstruct the image statistically from the method of relying on the traditional reverse projection[15]. Such reconstruction method reduces patients' exposure dose and created images with the diagnostically valuable quality.

ASIR method makes the noise map based on reverse projection method (FBP) which is the reconstruction of the previous image, and it is the new way of reconstructing images which appropriately blends with the original image of the subject by constructing a statistical model and through the FBP process. Formula of ASIR is as follows.

$$X = \text{argmin}\{L(Ax,\ y) + \text{alphaG}(x)\} \quad \text{Formula} \quad (1)$$

In function above, X is the pixel values of the image which may consequently represent, and alphaG(x) is function which stably maintains pixels of the image. For example, these are process such as smoothing and edge enhancement. L is the statistical function of Projection data, and A is the noise model and contains the value of the pixel based on algebraic matrix transformation and noise value[16].

ASIR can be applied differently from 10% to 100%, and it looks like a artificial image when applied to 100% because image noise becomes too small. It was not verified whether it was appropriate to raise ASIR up to 100% for diagnosis. But most users prefer the level of 30% or 40%, which is appropriate ASIR level that reduces noise and offers the same diagnostic information as images that do not apply ASIR.

Objective evaluation and subjective evaluation for the evaluation of chest CT images highly corresponded to each other. However, subjective evaluation may differ among those who evaluate so objective evaluation of SNR and CNR, which is obtained by measuring CT number and noise, can guarantee more reliability.

Therefore, it is required to test the appropriateness of exposure dose by conducting objective evaluation of images that is gained from the exposure dose used in the chest low-dose radiation protocol in clinical setting. For objective evaluation of images in chest CT scan, CT number and noise are mainly measured in aorta ascendens or aorta descendens in tracheal bifurcation. The reason for this is these areas have relatively larger measuring parts compared to other areas and consist only of blood, bringing up comparatively consistent measurement result. In this study as well, CT number and noise were measured from the same size of AA and IM located in tracheal bifurcation, and SNR and CNR were obtained.

In this research, artificial is applied by only 10% and 20%, and the research was performed in this range. A. K. Hara et al. reported that it is possible to reduce the image noise up to 65% by applying ASIR during CT scan, and also reported that exposure dose of radiation can be reduced up to 30% ~ 50%. Also, ASIR algorithm has been reported to help checking for obese patients[17]. In addition, K. Kalra et al. reported that about 30% of dose can be reduced by applying ASIR during chest CT scan. In this research, about 16.7% of dose could be reduced by applying low-dose CT scan without degradation of image quality.

The limitation of this study is that ASIR algorithm is limited to GE equipment, and it targeted Phantom. If future studies target patients, it is believed to be able to see various results.

Ⅴ. CONCLUSION

Dose could be reduced without the change of the image quality in FBP and ASIR 10%, 20% according to the reconstruction method. During the low dose chest CT scan, it is good recommended to apply ASIR 20% during the inspection. And it appeared that dose was significantly reduced in 120 kVp and 100 kVp according to the change of tube voltage, but it showed poor image quality because of noise increases.

But in the nature of low-dose test, it is believed to be advantageous to recommend and diagnose moderately with respect to patients of medical examinations and follow-up patients. If ASIR applies to multiple clinical parts, it is considered to be able to reduce the dose while maintaining the quality of the image, so it is believed to be the positive factor for the test.

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•국문초록

저 선량 전산화단층촬영의 관전압과 적응식 통계적 반복 재구성법 적용에 따른 영상평가 및 피폭선량

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저 선량 흉부 전산화단층촬영(low dose computed tomography; LDCT)검사 시 기존의 검사방법인 필터보정역투영법인 FBP(filted back projection)와 적응식 통계적 반복 재구성법인 ASIR(adaptive statistical iterative reconstruction)의 적용 및 관전압 변화에 따른 영상의 화질과 피폭선량을 비교 평가해 보고자 하였다.

흉부 phantom을 이용하여 재구성방법에 따라 FBP와 ASIR적용(10%, 20%)을 하였고, 관전압(100kVp, 120kVp)에 변화를 주어 실험을 하였다. 화질평가를 위해 back-ground noise와 signal-noise ratio(SNR), contrast-noise ratio(CNR)를 구하였으며, 선량평가를 위해 CTDIvol과 DLP를 구하였다.

화질평가에 있어 kVp에 따른 ascending aorta(AA) SNR과 inpraspinatus muscle(IM) SNR은 AA SNR과 IM SNR은 유의한 차이가 있었다($p < 0.05$). 선량평가에 있어 CTDIvol과 DLP는 유의한 차이가 있었으며($p < 0.05$), CTDIvol은 120 kVp, FBP가 2.6 mGy, 120 kVp, 10%-ASIR가 2.38 mGy, 120kVp, 20%-ASIR가 2.17 mGy로 0.43 mGy 감소하였고, 100 kVp, FBP가 1.61 mGy, 100 kVp, 10%-ASIR가 1.48 mGy, 100 kVp, 20%-ASIR가 1.34 mGy로 0.27 mGy 감소하였다. 또한 DLP에서는 120 kVp, FBP가 103.21 mGy·cm, 120 kVp, 10%-ASIR가 94.57 mGy·cm, 120 kVp, 20%-ASIR가 85.94 mGy·cm로 17.27 mGy·cm(16.7%) 감소하였고, 100 kVp, FBP가 63.87 mGy·cm, 100 kVp, 10%-ASIR가 58.54 mGy·cm, 100 kVp, 20%-ASIR가 53.25 mGy·cm로 10.62 mGy·cm(16.7%)로 감소하였다.

재구성방법에 따른 FBP와 ASIR 10%, 20%에서는 화질의 변화 없이 선량을 줄일 수 있어 흉부 low dose CT검사 시 ASIR 20%적용하여 검사하는 것이 좋으며, 관전압 변화에 따른 120 kVp와 100 kVp에서는 선량은 크게 줄어들었지만, noise가 증가하여 화질이 떨어지는 것으로 나타났다.

중심 단어: 흉부 팬텀, 저 선량 전산화단층촬영, 적응식 통계적 반복 재구성법, 관전압