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Brief communication (Original)

Patient dose and image quality from the low kilovoltage dynamic liver computed tomography examinations

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Background: In cases of patients with chronic liver disease, lesions were often detected in MRI replacing in computed tomography (CT) test because of the difference in X-ray attenuation that is likely to depend on constituent nodules. Therefore, the importance of pre enhancement study at liver dynamic CT scan is being emphasized.

Objective: To find optimal protocol and to reduce radiation dose without compromising image quality while taking low kilovoltage (kVp) liver dynamic CT examination using MDCT.

Subjects and Methods: Fifty patients under follow-up who were diagnosed of liver cancer have been examined using a 16-slice MDCT scanner, CT body dose phantom, and CT performance phantom for simulation. Contrast noise ratio and noise of water using phantom have been measured and Volume Computed Tomography Dose Index has been measured according to examination methods. Three points of liver parenchyma, aorta, and subcutaneous fat has been measured for CT attenuation value and compared with magnification picture archiving and communication system in 200% and region of interest for the same size.

Results: Scanning parameters were 120 kVp-140 mAs, 120 kVp-120mAs, and 80 kVp-280 mAs. The CNR was 6.87, 3.36, and 7.66 HU, respectively. Also, the noise of water was 6.83, 7.36, and 9.04 HU respectively. The CT attenuation value for the liver parenchyma, aorta, and fat is high about 15, 217, and 19 HU, respectively. Also, CTDIvol decreased to about 47.36%.

Conclusion: Four phase liver dynamic CT examination with low CT kVp setup is a useful tactic to reduce radiation dose and also can provide necessary images for clinical diagnosis when compared to the results from three phase liver dynamic CT.

Keywords: Computed tomography (CT), contrast to noise, dynamic liver CT patient dose, noise

The introduction of helical or spiral computed tomography (CT) in the late 1980's has revolutionized diagnostic medical imaging [1-4]. Single-detector row CT scanners and more recently, multi-detector row CT (MDCT) scanners remarkably increased the clinical indications for CT. As a result, there has been a considerable increase in the number of CT examinations performed and in the average scanned volume obtained per examination [5-8]. Compared to general X-ray, the dose distribution CT differs from that of the X-ray, and a much higher patient radiation dose is reported in CT examination than in a general X-ray [9, 10]. Even if radiation exposure in CT examination is greater than that in other X-ray examinations, the application of CT has been expanded due to its accuracy and reliability in detecting diseases. Also, an interest in the accumulation of radiation has influenced the determination of exposure factors in CT examination [11]. Recently, several studies have shown the relevance of tube voltage and lesion conspicuity [12-15]. In most cases of abdomen CT scan, it is a general practice to use contrast material to draw a contrast in abdominal cavity. Introduction of MDCT has made a great contribution in detecting small nodule by enabling clinicians to scan 3 phase images, arterial, portal and equilibrium phase, from one injection of contrast material. However, when trans- arterial

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chemo-embolization (TACE) was carried out or in the cases of patients with chronic liver disease, lesions were often detected in MRI replacing in CT test because of the difference in X-ray attenuation that is likely to depend on constituent nodules. Therefore, the importance of pre enhancement study at liver dynamic CT scan is being emphasized. As adding an image to examination causes increase in radiation dose. For these reasons, we tried to find out optimal protocol and approach to reduce radiation dose without lowering image quality while taking low kilovoltage (kVp) liver dynamic CT examination using MDCT.

Materials and methods

For the images comparison, data set was collected from 50 patients (40 men and 10 women) who took the same kind of liver dynamic CT examination a year ago and underwent TACE. Mean body weight for 50 patients was 64.7 kg (range 47 to 78 kg) and mean body mass index (BMI) for 50 patients was 23 (range 19.2 to 26.9). The BMI was calculated as weight in kilograms divided by square of height in meters [16]. In addition, the mean age for 50 patients was 56.8 years (range 36 to 75 years).

Methods and Dose Measurements

CT examinations were performed with a 16-slice MDCT scanner (Sensation 16, Siemens Healthcare, Forchheim, Germany). We only selected CT equipment satisfying the inspection criteria of Korea Ministry of Health and Welfare [17, 18]. The regulations from the Korean Ministry of Health and Welfare control the use of diagnostic radiation generators and give the rule for the safety management, installation, and running of CT, MRI, and mammography units. The regulations for CT equipment are as follows: the tolerance for tube voltage is 120±10% kVp, the tolerance for tube current is 250±10% mAs, the uniformity of the CT attenuation value is less than±7, the noise of the CT attenuation value is less than ±7, and the exactness of a slice thickness is 10±1 mm or 5±1 mm. In addition, the tolerance of contrast and spatial resolution is the discrimination of over five pairs in six pairs and fourth rows in eight rows of a CT performance phantom (model 76-410-4130, Fluke Corporation, USA), respectively. After placing an antecubital 18-G intravenous access for all patients, contrast agent transit time (Iopromide, 370 mg iodine/ml; Ultravist 370, Bayer Schering Pharma, Germany) was assessed by application of a test bolus of 10 ml followed by a saline flush of a 120 ml at a flow rate of 3 ml/sec using a dual-head power injector (CT Stellant, Medrad Inc., Indianola, IA). The contrast transit time was defined by the time between the start of the contrast agent injection and CT attenuation value 100 HU in the abdominal aorta at the level of the thoracic spine 12th. For acquisition of the first phase of the liver dynamic CT examination was obtained after 12 seconds since the CT attenuation value 100 HU in the abdominal aorta at the level of the thoracic spine 12th. In addition, it was adjusted as slice thickness 5 mm, slice increment 5 mm when reconstruction the image. In 3 phase liver dynamic CT examinations, scanning parameters were adjusted as followings; tube voltage of 120 kVp, tube current of 140 mAs, pitch of 1 and beam collimator 16× 0.75 mm for arterial phase, tube voltage of 120 kVp, tube current of 120 mAs, pitch of 1 and beam collimator of 16 × 0.75 mm for portal and delayed phase. In 4 phase liver dynamic CT examinations, scanning parameters were adjusted at tube voltage of 80 kVp, tube current of 280 mAs, pitch of 0.6 (different pitch in order to prevent an overload was applied at 4 phase CT scan), beam collimator of 16 × 0.75 mm and pre enhancement study was added. Other parameters were adjusted same as parameters in 3 phase liver dynamic CT examinations. A craniocaudal table movement was used in all case, and the scan volume extended from the dome of diaphragm to the lower margin of kidney. Volume Computed Tomography Dose Index (CTDIvol) was converted to DLP values using the relationship between DLP and CDTIvol; CDTIvol = DLP/irradiated length.

CT attenuation value and noise measurements

Noise measurements were performed with a water block of CT performance phantom. Region of interest (ROI) was set at centre, in twelve o'clock, in three o'clock and in nine o'clock with a diameter of 4 cm from the image of the block filled with water that can measure noise, artifact, and uniformity. Scanning parameters were adjusted same as parameters in 3 phase and 4 phases liver dynamic CT scan.

Contrast to noise ratio (CNR) measurements

CNR measurements were performed with a low contrast resolution block of CT performance phantom [10]. The CNR(C) was defined;

$$C = |S_A - S_B| / \sigma_0 \quad (1)$$

Where S_A and S_B are signal intensities for signal producing structures *A* and *B* in the region of interest and σ_o is the standard deviation of the pure image noise.

CT image analysis

Among the patients who previously underwent 3 phases liver dynamic CT scan one year ago, 50 patients who took follow up CT scan were selected for 4 phases liver dynamic CT scan and their CT attenuation value from 4 phases liver dynamic CT scan with ROI at liver parenchyma, aorta and fat were compared. For data analysis, images set of experimental group were selected from picture archiving and communication system (PACS, PiView Star, Infinity, Korea), and then the correlation between data was analyzed at the image magnification of 200%. An expert abdomen radiologist retrospectively evaluated the 3 and 4 phase liver dynamic CT images obtained from arterial phase protocol. A circular region of interest (ROI) was selected differently as 0.57±0.20 cm^2 at the liver parenchyma and the aorta and as 0.31±0.30 cm^2 at the fat. The ROI was selected 3 times with a slightly different area on a respective part to increase the reliability of the noise measurement.

Statistical analysis

Statistical analyses were performed using the software package statistical package for the social science (SPSS) version 18.0. The CT attenuation value of liver parenchyma, aorta, and subcutaneous fat in each phase (3 phases and 4 phases liver dynamic CT) was measured three times. The CT attenuation value was indicated as mean standard deviation (SD), and concerning the significance test, it was verified by a paired two samples T-test. After measuring the CT attenuation value, SD, and CNR in each parameter (120 kVp – 140 mAs, 120 kVp – 120 mAs, 80 kVp – 280 mAs), the test scores were indicated as mean SD. Concerning the significance test, we used One-way analysis of variance (ANOVA), and for multiple comparison, B method of Tukey was employed. With regard to the significance level of all statistics, p = 0.05.

Results

Comparison CTDIvol between 3 and 4 phases liver dynamic CT examinations

The radiation dose for 4-phase CT scan reduced by 4.39 mGy compared with 3-phase. CTDIvol was 13.66±1.19 mGy for the 3 phase and 9.27±0.74mGy for the 4 phase. These two groups exhibited a statistically significant difference while recording p <0.001. The decline of CTDIvol in 4-phase is about 47.36% compared with that of 3-phase (**Table 1**).

Comparison CT attenuation value between 3 and 4 phases liver dynamic CT examinations

The CT attenuation values of liver parenchyma, aorta, and fat were found as being 61.85±8.14, 288.52±47.05, and -92.24±17.61 HU for the 3 phase CT scan and 76.24±12.65, 505.51±78.6, and -108.82±24.04 HU for the 4 phase CT scan, respectively. Even in these two groups, there was a statistically significant difference (**Table 1**).

Comparison CT attenuation value, SD, and CNR between each parameter

The CT significance testing of attenuation value, SD, and CNR in each CT scan parameter (120 kVp – 140 mAs, 120 kVp – 120 mAs, 80 kVp – 280 mAs) was carried out by One-way ANOVA. CT attenuation value was -0.20 0.41, -0.40±0.50 HU, and -0.95±0.22 HU, respectively. There was a significant statistical difference in three groups, with a p <0.001. Also, in order to discover any difference in any of the three groups, the Tukey's multiple comparison tests were undertaken. The mean value as those two groups (120 kVp – 140 mAs, 120 kVp – 120 mAs) is nearly same, indicating that the two protocols are similar in with respect to a noise. However, 80 kVp – 280 mAs protocol revealed differences. SD values for each CT scan paramenter were 6.83±0.14, 7.36±0.26, and 9.04±0.27 HU, with a p <0.001 and a significant difference in the three groups was confirmed from Tukey's multiple comparison test.

CNR values for each CT scan parameter were -6.87±0.42, -3.36±0.50, and 7.66±0.30 HU, with a p <0.001 and exhibited a significant difference in the three groups. Also, such a significant difference in any of those three groups was confirmed from Tukey's multiple comparison tests (**Table 2**).

Comparison CT image between 3 and 4 phase liver dynamic CT scan

Figure 1 demonstrates the comparison between the 3 and 4 phase liver dynamic CT scan on same patient. The enhanced contrast was observed in the image scanned with low tube voltage than high tube voltage.

Table 1. Comparisons CTDIvol and CT attenuation value between 3 and 4 phase liver dynamic CT examinations

	3 phase (n = 50) Mean±SD	4 phase (n = 50) Mean±SD	t	*p*-value*
CTDIvol (mGy)	13.66±1.19	9.27±0.74	14.449	<0.001
Liver parenchyma CT attenuation value (HU)	61.85±8.14	76.24±12.65	-7.832	<0.001
Aorta CT attenuation value (HU)	288.52±47.05	505.51±78.6	-25.57	<0.001
Fat CT attenuation value (HU)	-92.24±17.61	-108.82±24.04	7.434	<0.001

*Statistically significant <0.05, by paired two sample T-test

Table 2. Comparisons CT attenuation value, SD and CNR depending on the scanning parameters

	120 kVp - 140 mAs (n = 20) Mean±SD	120 kVp - 120 mAs (n = 20) Mean±SD	80 kVp - 280 mAs (n = 20) Mean±SD	F	*p*-value*
CT attenuation value (HU)T	-0.20±0.41a	-0.40±0.50a	-0.95±0.22b	19.21	<0.001
SD (HU)T	6.83±0.14a	7.36±0.26b	9.04±0.27c	510.07	<0.001
CNR (HU)T	6.87±0.42a	3.36±0.50b	7.66±0.30c	1691.09	<0.001

*Statistically significant *p* <0.05, by oneway analysis of variances among groups, the same letters indicates non-significant difference between groups base on Tukey's multiple comparison test

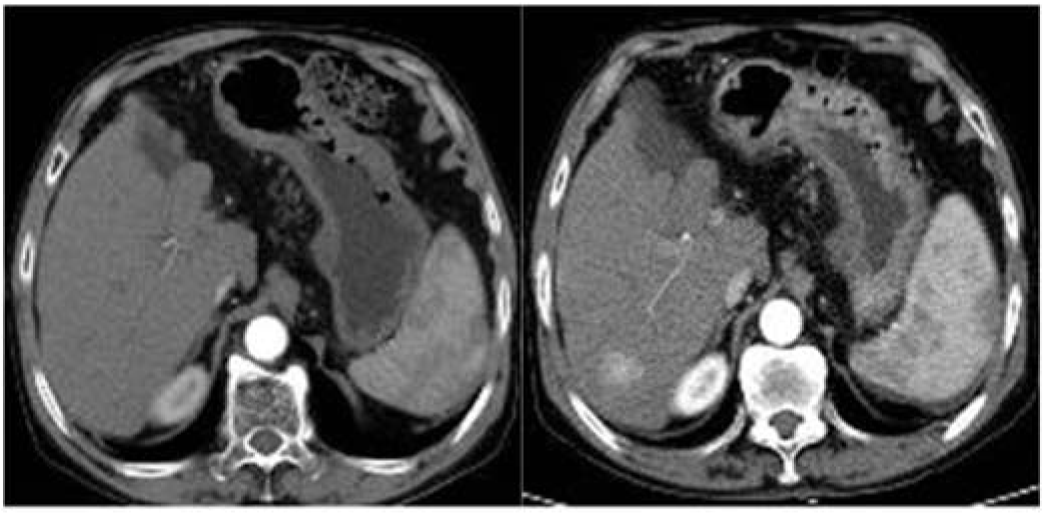

Figure 1. Comparison 3 phase (120 kVp, 140 mAs, Lt.) and 4 phase (80 kVp, 280 mAs, Rt.) liver dynamic CT examinations of the same patient (The hyper vascular lesion on the right image is a new lesion over time at the 80 kVp CT scan).

Discussion

Image quality of a contrast-enhanced CT examination depends on scanning techniques, patient body habitus, concentration of the contrast medium, and other factors such as motion, CT scanner design, and reconstruction algorithm. Image contrast and CNR are affected by factors typically chosen by technologists such as kVp, mA, and pitch, as well as hardware factors that cannot be altered such as type of anode, anode angle, filtration, and type of detectors [14]. In addition, volume, concentration, and rate of administration of CM and cardiac output also affect image contrast [15]. The attenuation of x-ray beam by iodinated contrast agents is affected by the mean energy (kiloelectron volt) of photon beam, which is lower than the applied kVp because of the polychomatic nature of the X-rays [19-21]. With increase in kVp, the photon energy increases and its attenuation decreases. Thus, at lower kVp, there is greater attenuation of X-ray beam and higher contrast. In addition, as a greater attenuation value of iodine-based CM is observed at the K-edge of iodine (33.2keV), the applied kVp should be adjusted so that the photon energy is nearer to the K-edge of iodine [22].

So far, researchers have made effort to find a method to detect disease by adjusting scan time after contrast injection [23-24]. However, in this study, the arterial phase images from 3 and 4 phase liver dynamic CT examination were analyzed by adjusting tube voltage. The CT attenuation value of fat which bears almost no contrast effect appeared to be lower under 80 kVp than 120 kVp. On the other hand, the CT attenuation value at aorta was measured to be higher by 42.46% on average. At the same time, the result from the CNR which represents the contrast to noise ratio between ROI and surrounding parts appeared to be higher in 4 phase liver dynamic CT examination so that it is expected that the probability of detecting small liver cancer will be increased. Also, it has made an outstanding contribution to reduction of radiation dose since it can scan only the liver part without scanning surrounding parts unnecessarily.

In conclusions, the liver dynamic CT examinations used to go through 3 phases, that is arterial, portal, and equilibrium phase. However, if the patients previously underwent TACE or have chronic liver disease, it was hard to detect the disease from arterial phase image and had difficulties in reading. Recently, the importance of pre enhancement study is being emphasized and thus radiation dose became one of the main issues. In this study, when tube voltage was adjusted from 120 kVp to 80 kVp, a significant difference in liver dynamic CT scan result was observed. Although, image noise and CNR values are high for 4 phase low kVp liver dynamic CT (80 kVp - 280 mAs), we observed relatively good diagnostic performance for the detection of HCC in non-obese patients clinically. It is our firm belief that the use of low kVp liver dynamic CT examination can be justified based on reduced radiation exposure, instead of full dose CT examination. The result of this study is the effectiveness of 4 phase liver dynamic CT examinations using low tube voltage was significant.

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