Spectral CT Analysis of Hounsfield Unit (HU) according to MonoE (keV) and Dilution Ratio of the Contrast Agent: Use of Spectral CT

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ABSTRACT

The purpose of this study was to analyze the changes in the values of Hounsfield Unit (HU) according to the changes in monoenergy (keV) and dilution ratio of the contrast agent, using the spectral CT. Spectral CT was used as the testing device, while 20 cc syringe phantom was used to set a total of six dilution ratios of the contrast agent: 8:2, 7:3, 6:4, 5:5, 4:6, and 3:7. Here, the non-ionic iodine solution (350 mg/ml) was used as a contrast agent. The syringe axial image was reconstructed by adjusting the obtained data on nine MonoE levels; 40 keV, 45 keV, 50 keV, 55 keV, 60 keV, 65 keV, 70 keV, 75 keV, and 80 keV. The HU values were measured at the three points of the reconstructed syringe axial image. The measurements were taken 1,620 times in total. In the analysis of the HU values according to the changes in keV and dilution ratio of the contrast agent, the highest and lowest HU values were obtained from dilution ratio 8:2 and dilution ratio 3:7, respectively, across every MonoE in the comparison of HU according to dilution ratio per MonoE ($p<0.05$), while the highest and lowest HU values were obtained from 40 keV and 80 keV, respectively, across all dilution ratios in the comparison of HU according to MonoE per dilution ratio ($p<0.05$). For the correlation per each parameter, a negative correlation of -15.014 ± 0.298 was found for HU per keV (R^2=0.519) and a negative correlation of -61.372 ± 3.608 was found for HU per dilution ratio (R^2=0.152) ($p<0.05$). To conclude, an increase in keV or dilution ratio of the contrast agent was shown to decrease the HU, and the findings in this study are anticipated to serve as the basic data in the research of HU-related parameters in Spectral CT.

Keywords: Spectral CT, keV, contrast agent dilution ratio, HU

Ⅰ. INTRODUCTION

Computed tomography (CT) involves the data obtained through the rotation of the X-ray irradiation device that are reconstructed as a cross-sectional image of the 3D structure of the human body based on computerized calculations. With the advancement of the computer technology, the CT device continuously advanced, and of note is the marked changes in medical science through the development of the multi-detector CT (MDCT) in the late 1990s[1].

Compared to the conventional single-detector CT, the MDCT enabled to reduce the testing time by extending the scope of the data collection at a single rotation of the tube[2]. The reduced testing time in turn decreases the use of enthesis for the movement, and implies the possibility of testing a larger number of patients within limited time. In the U.S., the

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number of CT tests exponential increased by approximately 2,133% in 26 years, from 3 million cases in 1980 to 67 million cases in 2006[3,4]. The limitation of MDCT, however, is that a quantitative analysis cannot be performed for the lesions as two materials of different atomic numbers but a similar level of attenuation coefficient cannot be differentiated[5]. To overcome this limitation, the spectral CT was developed.

In Spectral CT, the analyses of the HU and keV and of the HU and the contrast agent provide the basic data that are prerequisite to the Spectral CT. The present study thus aims to analyze the correlation between the HU and keV and between the HU and dilution ratio of the contrast agent in Spectral CT, to provide the basic data for future studies regarding Spectral CT.

Ⅱ. MATERIALS AND METHODS

In Spectral CT, the image is obtained through simultaneous but separate receipt of the high-energy and low-energy irradiations of the polyenergy from the dual-layer detector. In addition, the reconstruction of virtual monoenergetic image (VMI) in 40 keV - 200 keV range is possible so that the dose of the contrast agent can be controlled[6]. VMI allows an increase or a decrease in the Hounsfield Unit (HU) according to the unique atomic number of a substance, which makes it easy to distinguish between target substances[7]. It is thus of critical importance to understand the relationship between the HU and the atomic number of substances. It is also fundamentally essential to establish the relationship between the HU and a number of parameters that may alter the attenuation coefficient of tissues. While there may be a variety of such external factors, the most influential parameter is the contrast agent, which can alter the attenuation coefficient of tissues in a target area to create a difference in contrast from the surrounding structures[8]. The contrast agent is thus utilized in many different tests such as angiography and the differentiation between a tumor and an angioma[9-11].

Table 1. Scan Parameter

Condition	Value
kVp	120 kVp
mAs	105 mAs
ST	2.00 mm
Scan time	1.93 sec
FOV	50 mm
Length	57 mm

*. ST-Slice Thickness, FOV-Field of View

1. Experimental device and phantom

In this study, a CT device (IQon Spectral CT, Philips, Netherlands) was used for imaging analysis, while a 20 cc syringe was used as the phantom. Here, a nonionic iodine contrast agent (350 mg/mL) was used. To set the syringe at the same height as the abdominal aorta, a pillow was used as a prop for support[Fig 1].

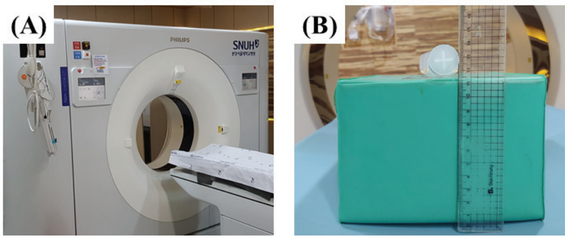

Fig. 1. IQon Spectral CT (A) and pillow to match the height of the abdominal aorta (B).

2. Experimental procedures

The contrast agent was mixed with saline in the 20 cc syringe for dilution in the ratios of 8:2, 7:3, 6:4, 5:5, 4:6, and 3:7. Each syringe after dilution was placed on the pillow and the tip of the syringe needle was set to the iso-center by adjusting the position of the table at 44 vertically and -77.5 horizontally. The CT imaging test was performed in the following conditions: tube voltage 120 kVp, tube current 105 mAs, slice thickness 2 mm, scan time 1.93 sec, FOV 50 mm, and length 57 mm, which were identical across all tests[Table 1]. For reliability, the tests were repeated ten times in the identical conditions for each dilution ratio.

3. Measurements

The data obtained from the scan were reconstructed for each dilution ratio at monoenergy (MonoE) 40 keV, 45 keV, 50 keV, 55 keV, 60 keV, 65 keV, 70 keV, 75 keV, and 80 keV, using the IQon-Spectral CT V4.7.5 program, while each reconstructed image was set to the ROI of 349.4 mm square (sq) to generate 56 axial sections from each image. The HU was measured at the following three points; the first slice (-103.7 mm), the 28th slice (-77.7 mm), and the 56th slice (-50.7 mm). From the measurement data, 10 times of scan data were obtained for each of the six different dilution ratios, and through the measurements at the three phantom points on the nine reconstructed MonoE images of each test, a total of 1,620 HU values were collected.

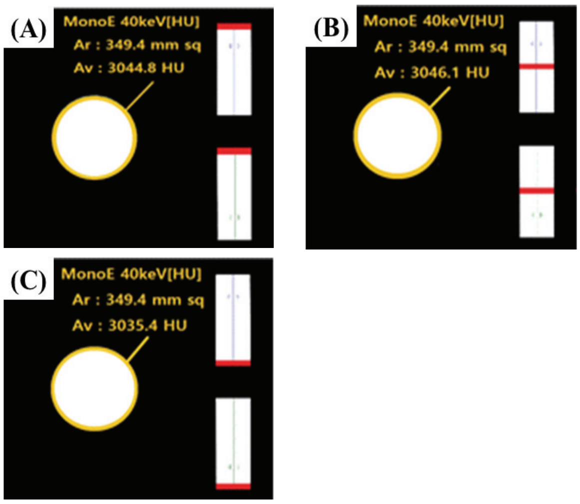

Fig. 2. Measurement Data at dilution ratio 8:2 and 40 keV, first slice (A) and 28th slice (B) and 56th slice (C). Arrow is the chosen axial slice image of syringe.

2.4. Statistical analysis

To analyze the mean values of the HU data per dilution ratio and per keV, the two way ANOVA test was performed using a statistical software (SPSS 18.0, IBM, USA). Dunnett test was used for the post-hoc analysis, and multiple regression analysis was performed to verify the correlations. Here, statistical significance was set as $p \leq 0.05$.

Table 2. The HU values according to keV and dilution rate changes

		Dilution Rate(Contrast Media : Normal Saline)						p
		8:2	7:3	6:4	5:5	4:6	3:7	
keV	40	3040.62±4.86	3036.20±3.40	3027.82±2.39	3005.13±4.67	2980.56±4.19	2948.91±4.37	.000
	45	3024.50±4.58	3017.15±3.51	3005.58±2.47	2978.86±4.74	2949.87±4.12	2912.66±4.23	.000
	50	3004.54±4.49	2995.14±3.72	2978.60±11.22	2949.68±4.82	2915.98±4.10	2872.24±4.14	.000
	55	2982.74±4.44	2971.00±3.93	2953.49±2.71	2918.21±4.91	2879.27±4.08	2827.35±4.06	.000
	60	2959.46±4.43	2945.37±4.09	2925.02±2.71	2884.67±4.98	2839.54±4.05	2776.00±3.92	.000
	65	2935.16±4.42	2918.62±4.21	2894.87±2.84	2848.97±5.03	2795.78±4.04	2704.61±8.32	.000
	70	2910.03±4.46	2890.77±4.29	2863.11±3.00	2806.16±24.11	2745.10±3.99	2361.67±29.31	.000
	75	2853.44±11.50	2814.50±6.76	2770.76±6.83	2691.06±22.29	2587.51±3.47	2002.68±24.06	.000
	80	2521.57±18.23	2443.00±6.96	2386.10±7.09	2304.25±5.76	2216.63±2.99	1716.06±19.88	.000
p		.000	.000	.000	.000	.000	.000	

* Post hoc test with Dunnett showed p<0.05 in all variables

Ⅲ. RESULT

The measured values of CT number (HU) according to the changes of MonoE (keV) in 20 cc syringes with varying dilution ratios, as obtained using the spectral CT, are presented in [Table 2].

1. Comparison of HU according to dilution ratio per MonoE

At 40 keV, the highest HU and the lowest HU were 3040.62±4.86 at dilution ratio 8:2 and 2948.91±4.37 at dilution ratio 3:7, respectively ($p<0.05$). At 45 keV, the highest HU and the lowest HU were 3024.50±4.58 at dilution ratio 8:2 and 2912.66±4.23 at dilution ratio 3:7, respectively ($p<0.05$). At 50 keV, the highest HU and the lowest HU were 3004.54±4.49 at dilution ratio 8:2 and 2872.24±4.14 at dilution ratio 3:7, respectively ($p<0.05$). At 55 keV, the highest HU and the lowest HU were 2982.74±4.44 at dilution ratio 8:2 and 2827.35±4.06 at dilution ratio 3:7, respectively ($p<0.05$). At 60 keV, the highest HU and the lowest HU were 2959.46±4.48 at dilution ratio 8:2 and 2776.00±3.92 at dilution ratio 3:7, respectively ($p<0.05$). At 65 keV, the highest HU and the lowest HU were 2935.16±4.42 at dilution ratio 8:2 and 2704.61±8.32 at dilution ratio 3:7, respectively ($p<0.05$). At 70 keV, the highest HU and the lowest HU were 2910.03±4.46 at dilution ratio 8:2 and 2361.67±29.31 at dilution ratio 3:7, respectively ($p<0.05$). At 75 keV, the highest HU and the lowest HU were 2853.44±11.50 at dilution ratio 8:2 and 2002.68±24.06 at dilution ratio 3:7, respectively ($p<0.05$), and at 80 keV, the highest HU and the lowest HU were 2521.57±18.23 at dilution ratio 8:2 and 1716.06±19.88 at dilution ratio 3:7, respectively ($p<0.05$).

2. Comparison of HU according to MonoE per dilution ratio

At dilution ratio 8:2, the highest HU and the lowest HU were 3040.62±4.86 at 40 keV and 2521.57±18.23 at 80 keV, respectively ($p<0.05$). At dilution ratio 7:3, the highest HU and the lowest HU were 3036.20±3.40 at 40 keV and 2443.00±6.96 at 80 keV, respectively ($p<0.05$). At dilution ratio 6:4, the highest HU and the lowest HU were 3027.82±2.39 at 40 keV and 2386.10±7.09 at 80 keV, respectively ($p<0.05$). At dilution ratio 5:5, the highest HU and the lowest HU were 3005.13±4.67 at 40 keV and 2804.25±5.78 at 80 keV, respectively ($p<0.05$). At dilution ratio 4:6, the highest HU and the lowest HU were 2980.56±4.19 at 40 keV and 2216.68±2.99 at 80 keV, respectively ($p<0.05$). At dilution ratio 3:7, the highest HU and the lowest HU were 2948.91±4.37 at 40 keV and 1716.06±19.88 at 80 keV, respectively ($p<0.05$).

3. Correlation analysis for HU per MonoE and per dilution ratio

The multiple regression analysis found a negative correlation of -15.014 ± 0.298 (R^2=0.519) for the HU per keV and a negative correlation of -61.372 ± 3.608 (R^2=0.152) for the HU per dilution ratio[Table 3].

Table 3. Multiple linear regression analysis of HU values according to keV and dilution rate changes.

Variables	β±SE	R^2	p
keV	-15.014±0.298	.519	.000
Dilution Rate	-61.372±3.608	.152	.000

*. SE-Standard Errors

Ⅳ. DISCUSSION

In spectral CT, the images are reconstructed in various MonoE (keV), so that the HU varies according to the changes in keV and dilution ratio of the contrast agent. However, there is a general lack of studies analyzing the correlation of the HU with keV or dilution ratio of the contrast agent. The present study thus aimed to use a phantom to analyze the correlation between the HU and keV as well as dilution ratio of the contrast agent.

For the analysis, the images were reconstructed on nine levels of MonoE (40 - 80 keV), while the contrast agent was varied in dilution ratio on six levels from 8:2 to 3:7, and as a result, a total of 1,620 data were obtained. The results showed that the HU had a negative correlation of -15.014±0.298 with the changes in keV and a negative correlation of -61.372±3.608 with the changes in dilution ratio of the contrast agent.

In Ha et al.[12], where abdominal CT was performed, the image using 100 kVp tube voltage was reported to have shown higher HU values for the abdominal organs than the image using 120 kVp tube voltage. In Wintermark et al.[13], the use of the contrast agent in CT was reported to have led to higher HU values at 80 kVp than at 120 kVp.

The results in the studies by Ha et al. and Wintermark et al. collectively indicated that an increase in kVp decreased the HU values. In this study, the finding that an increase in keV led to a fall in the HU may be noteworthy, but since keV is not equivalent to kVp, the study cannot be said to coincide with the previous studies. Nevertheless, as in kVp, the negative correlation between keV and the HU may be significant.

In Yamaychi et al.[14], where the HU values were compared after the reconstruction based on 40 keV and 70 keV in Dual-Energy CT, the reconstructed image at 40 keV was reported to have shown higher HU values than the image at 70 keV. In Rassouli et al.[15], where Spectral CT was used for the reconstruction at 40 keV, 60 keV, 80 keV, and 100 keV, after which the HU values were compared, an increase in keV was reported to have led to a fall in the HU. The two studies agreed with the present study in that the HU values decreased with an increase in MonoE (keV) in Dual Energy CT and in Spectral CT. Nonetheless, the two studies differed from the present study in that the relation with the contrast agent had not been analyzed, and that a smaller range of MonoE was applied; 40 keV and 70 keV in the study by Yamaychi et al. and 40 keV, 60 keV, 80 keV, and 100 keV in the study by Rassouli et al.

Using the contrast agent after dilution decreases the concentration, and reduced concentration causes the viscosity of the contrast agent to fall. Seeliger et al.[16] reported that the viscosity of the contrast agent was an important factor related to Contrast Induced Nephropathy (CIN), one of the side effects of the contrast agent. Bak et al.[17] reported that the use of a low concentration of contrast agent could reduce the exposure dose for patients in the angiography using the Automatic Exposure Control (AEC). The use of the contrast agent after dilution can thus prevent such side effects as CIN and reduce the exposure dose. Hence, it is preferable to use the contrast agent after dilution as it leads to a safer CT test. However, as it is difficult to lower the concentration of the contrast agent to a level that degrades the imaging quality, analyzing the correlation between the Hu and dilution ratio of the contrast agent is crucial.

Kim[18] analyzed the HU values for the peripheral arterial image of MDCT between the original solution of the contrast agent and the contrast agent of 7:3 dilution ratio, to report that the HU showed no significant difference between the original solution and the diluted solution of the contrast agent. Lee et al.[19], in the MDCT test of the carotid artery, also reported no significant difference in the HU between the original solution of the contrast agent and the contrast agent of 9:1 and 8:2 dilution ratios. However, the two studies focused on the correlation between the HU and the contrast agent in MDCT, while there is still a general lack of studies analyzing the correlation between the HU and the contrast agent in spectral CT. It is thus anticipated that the analysis of the HU according to dilution ratio of the contrast agent per MonoE in spectral CT in this study would provide highly significant data.

The limitations in this study are that the phantom size could not be varied and that only 350 mg/ml iodine content in the contrast agent was used so that the analysis could not be performed according to the changes in iodine content. The unified testing condition of 120 kVp and 105 mAs was another limitation. Nevertheless, the significance of this study lies in the quantitative analysis of the correlation between the HU and keV and between the HU and dilution ratio of the contrast agent, through the use of spectral CT.

Ⅴ. CONCLUSION

In the spectral CT analysis, the HU and keV showed a negative correlation, where an increase in keV led to a fall in the HU, while the HU and dilution ratio of the contrast agent also showed a negative correlation, where an increase in dilution ratio of the contrast agent led to a fall in the HU. To conclude, the findings in this study are anticipated to serve as the basic data in studies analyzing the HU using spectral CT, according to the changes in the phantom size, the changes in the content of the contrast agent, and the changes in the testing conditions.

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단색에너지(keV)와 조영제 희석비율 변화에 따른 HU(Hounsfield Unit)값 분석: Spectral CT 이용

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요 약

본 연구의 목적은 Spectral CT에서 단색에너지(keV)와 조영제 희석비율의 변화에 따른 HU 값의 변화를 분석하고자 하였다. 검사장비로는 Spectral CT를 사용하였고, 20 cc syringe의 팬텀을 이용하여 조영제의 희석비율을 8:2, 7:3, 6:4, 5:5, 4:6, 3:7 총 6단계로 설정하였다. 이때 조영제는 비이온성 요오드 조영제(350 mg/ml)를 이용하였다. 획득한 데이터를 IQon-Spectral CT V4.7.5 프로그램을 사용하여 Monoenergy(MonoE) 40 keV, 45 keV, 50 keV, 55 keV, 60 keV, 65 keV, 70 keV, 75 keV, 80 keV 총 9단계로 변화시켜 syringe axial 영상을 재구성하였다. 재구성한 syringe axial 단면 영상의 세 위치에서 HU 값을 측정하였으며, 총 1,620회 측정하였다. keV와 조영제 희석비율의 변화에 따른 HU 값을 분석한 결과, MonoE별 희석비율에 따른 HU 비교에서 모든 MonoE에서의 HU 값이 희석비율 8:2에서 가장 높았으며 3:7에서 가장 낮았다($p<0.05$). 희석비율별 MonoE에 따른 HU 비교에서 모든 희석비율에서의 HU 값이 40 keV에서 가장 높았으며 80 keV에서 가장 낮았다($p<0.05$). 인자별 상관성은 keV에 따른 HU 값은 -15.014 ± 0.298의 음의 상관성($R^2=0.519$)이 있었고 희석비율에 따른 HU값 은 -61.372 ± 3.608의 음의 상관성($R^2=0.152$)이 있었다($p<0.05$). 결론적으로 keV 값과 조영제 희석비율이 증가할수록 HU 값은 감소하는 것을 확인하였으며 본 연구가 Spectral CT의 HU 값 관련 인자 연구에 있어 기초자료를 제공할 수 있을 것이라 사료된다.

중심단어: Spectral CT, keV, 조영제 희석비율, HU

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