# Analysis of CT Number Value According To Tube Voltage by CT Equipment Manufacturer

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***Abstract***

***Background/Objectives***: *The purpose of this study is to provide the basic data for imaging by analyzing the difference of a CT number according to the set energy of each CT equipment manufacturer.*

***Methods/Statistical analysis***: *In this study, the CT equipment analysis is targeted at the equipment manufactured by Siemens, GE, Canon, and Philips. In this reference, the phantom used by the Nuclear Associates 76-410 CT phantom and its own phantom. Here, the tube exposure was fixed at 250mAs, while the exposure conditions were changed to 140Kv, 120Kv, 100Kv and 80Kv. In this case, the experiment was repeated twice, and the CT number of the material was measured and analyzed with the same size regions of interest (ROI) in each phantom image.*

***Findings***: *The results showed that the CT number of the material was found to decrease, as the tube voltage decreased in all five materials of AAPM. Additionally, when the same tube voltage was set, the GE equipment showed the lowest CT number values for all five AAPM materials. It is noted that in the self-made 6% contrast agent phantom, the CT number increased gradually as the tube voltage decreased. Finally, when the same tube voltage was set, the Siemens equipment showed the lowest CT number in this case.*

***Improvements/Applications***: *The prevailing discipline in this study noted that when medical institutions use CT numbers to read or measure images, it is necessary to identify and utilize the range of variation in the CT number of the material, and calculate that number according to the tube voltage of the equipment being used. In particular, it is considered that these results are significant, and the calibrations noted should be used for the determination of patient diagnosis with a different range of criteria for each manufacturer, whereby the active CT number correction is also necessary to be performed in each case with the different equipment being utilized for CT evaluation for patient health outcomes.*

***Keywords***: *Tube Voltage, CT number, HU, Phantom, Computed Tomography*

## 1. Introduction

To begin with, Computed Tomography (CT) introduces the concept that the absorption of finer images can be obtained, by introducing the difference in the number of photons from the difference in the degree of blackening of the X-ray image transmitted through the human body. The development of the spiral CT using Slip ring technology, introduced in 1991 and Multi-detector CT (MDCT), which was introduced in 1998, have improved the imaging speed and the development of various image reconstruction techniques, thereby with the use of relatively small doses allow the creation of images for diagnosis and the clinical usefulness to benefit patient outcomes was thereby significantly improved [1], and the importance of medical imaging was thus established. For this reason, the increases in the number of tests using CT every year is realized as the same phenomenon all over the world. According to the statistics as noted from the Korea Health Insurance Review and Assessment Service, 1,991 pieces of CT equipment were installed in Korea, and 5,945,598 patients were reported to have used CT equipment 10,434,092 times during the year [2]. At the core, the CT image basically compares the intrinsic linear attenuation cofficiency of the substance with water to produce a CT number (CT Number, HU) of the tissue, and displays it as a grayscale image based on this figure. (Equation 1).

$$\text{CT number} = 1{,}000 \times (\mu - \mu\text{water}) / \mu\text{water} \tag{1}$$

In this instance, the density of the substance can be predicted by the calculation of a CT number in the image of the medical institution, and the numerical value can be used to determine the disease present in the patient. To this end, the unit of the CT number value is HU (Hounsfield Unit), which is usually 0 for water, -1,000 HU for air, and about 1,000 HU for bone. Actually, this value is an average value, and it has a natural range of variation within these calculations. For example, the CT number values are used directly by medical institutions to diagnose patient's diseases, such as the case with determining typical calcium measurements in the coronary artery of the heart [3]. In addition, the CT number is widely used to determine diseases, which means that the measurement of the CT number is clinically important for improving patient health outcomes. Therefore, this study analyzed the CT data of various materials according to the set tube voltage and analyzed the CT data of four manufacturers with high distribution frequency and usage preference among CT equipment used in Korea, aiming to provide the results as basic data for image diagnoses going forward.

## 2. Materials And Methods

To begin with, the pieces of CT equipment used in this study were 128 slice MDCT (Somatom Definition Flash, Siemens, Erlangen, Germany) from Siemens, 128 slice MDCT (750 HD, GE Healthcare, Waukesha, USA) from GE, and 320 slice MDCT (Aquilion one, Toshiba, Medical Systems, Tochigi-ken, Japan) from Canon, and 256 slice MDCT (ICT256, Philips healthcare, Amsterdam, Netherlands) from Philips. In this reference, all the equipment was passed according the quality control of the special medical equipment under Article 38 of the Korean Medical Law, and was subsequently used in the medical institutions for patient examination. For this reason, no additional calibration was performed for this study.

In this study, the in-house Phantoms used five materials of linear evaluation block (Acryl, Nylon, Polycarbonate, Polyethylene, and polystyrene) of the Nuclear Associates 76-410 CT Phantom (Fig. 1), and a CT contrast agent made by the American Association of Physicists in Medicine (AAPM) which was able to express a high CT number (Fig. 2). Here, the in-house phantoms performed the preliminary experiments by filling CT contrast agents (Iopamiro 370, Bracco Imaging, Milan, Italy) with 2%, 4%, 6%, 8%, and 10% solutions in cylinders to determine the CT numbers to find the appropriate concentration, and therefore a solution of 6% concentration was used and one additional cylinder filled with reference water was added (Fig. 2).

To obtain CT numbers, this study measured 5 materials of the linearity evaluation block of Nuclear Associates 76-410 CT phantom, and 8 materials of 6% contrast solution, with water and air.

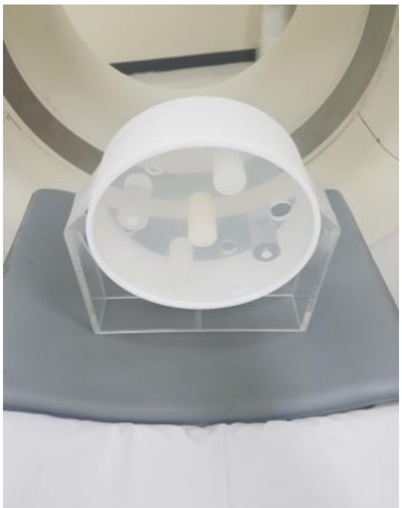

**Fig. 1. AAPM phantom**

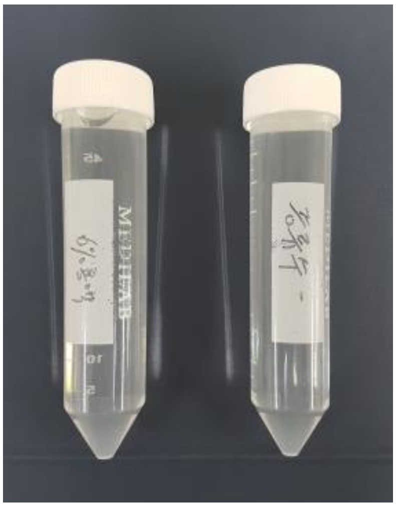

**Fig. 2. Self-made phantom**

As noted, the Phantom's shooting conditions used 140Kv, 120Kv, 100Kv and 80Kv for each stage. It was impossible to set 140Kv tube voltage only on Toshiba equipment, therefore 135Kv was used. In this case, the tube current was fixed at 250 mAs, and the image reconstruction was performed using a filtered backprojection (FBP) method, and there was noted a standard algorithm provided by each manufacturer.

The experiment was repeated twice shooting, and the CT numbers of materials were measured in the regions of interest (ROI) of the same size (20 mm2 ± 0.5) in each phantom image, to compare the mean values and analyze the rate of change (Fig. 3).

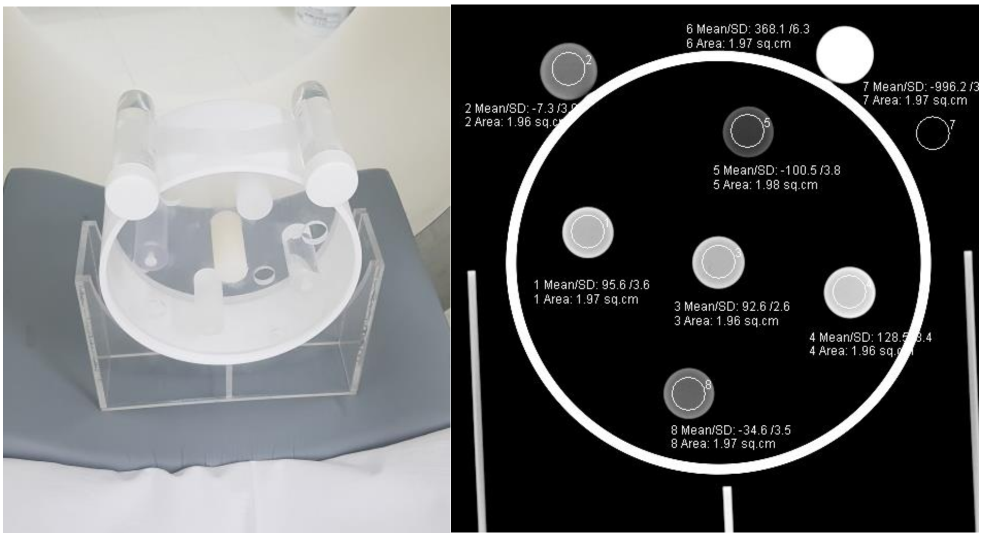


**Fig. 3. CT number measurement of 8 materials**

## 3. RESULTS

### *3.1 Evaluation of CT number linearity by manufacturer of AAPM phantom material*

According to the evaluation, in the CT number linearity evaluation of the Nuclear Associates 76-410 CT phantom, the CT number value gradually decreased as the tube voltage decreased for all five materials. When the same tube voltages were set for the four devices, it was noted that GE's equipment measured low CT number values for all five materials: Acryl, Nylon, Polycarbonate, Polyethylene, and Polystyrene (Table 1).

Upon review, the CT number of Acryl was 140 Kv, the maximum value was 138.55 HU at Philips, and the minimum value was 119.79 HU at GE, showing 15.66% difference. The difference was 19.51% at 120 Kv, 21.24% at 100 Kvv, and 30.92% at 80 Kv respectively.

It is noted that the CT number value of nylon was 140 Kv, the maximum value was 103.51 HU at Philips, and the minimum value was 89.06 HU at GE, showing 16.23% difference. The difference was 17.58% at 120 Kv, 28.89% at 100 Kv, and 36.93% at 80 Kv respectively.

Next, the CT number of polycarbonate was 140 Kv, the maximum value was 104.40 HU in SIEMENS and the minimum value was 90.44 HU in GE. The difference was 16.53% at 120 Kv, 20.97% at 100 Kv, and 36.93% at 80 Kv.

Additionally, the CT number of polyethylene was 140 Kv, the maximum value was -89.58 HU at Philips, and the minimum value was -106.76 HU at GE, showing 16.10% difference. The difference was 17.39% at 120 Kv, 16.31% at 100 Kv and 14.42% at 80 Kv respectively.

Finally, the CT number of polystyrene was 140 Kv, the maximum value was -20.61 HU at Philips, and the minimum value was -39.74 HU at GE, showing 92.82% difference. The difference was 46.50% at 120 Kv, 49.48% at 100 Kv, and 22.35% at 80 Kv respectively.

**Table 1. CT number according to tube voltage by manufacturer of AAPM phantom material**

| | | Acryl | Nylon | Polycarbonate | Polyethylene | Polystyrene |
|---|---|---|---|---|---|---|
| 140Kv (135kv) | SIEMENS | 134.10 | 101.00 | 104.40 | -93.50 | -27.00 |
| | GE | 119.79 | 89.06 | 90.44 | -106.76 | -39.74 |
| | Toshiba | 134.44 | 95.73 | 97.73 | -96.60 | -31.97 |
| | Philips | 138.55 | 103.51 | 103.05 | -89.58 | -20.61 |
| 120Kv | SIEMENS | 127.90 | 93.80 | 97.70 | -101.80 | -35.20 |
| | GE | 114.05 | 82.27 | 83.87 | -115.34 | -48.21 |
| | Toshiba | 136.30 | 95.73 | 97.73 | -99.21 | -37.10 |
| | Philips | 128.41 | 96.73 | 94.78 | -98.81 | -32.91 |
| 100Kv | SIEMENS | 120.50 | 84.20 | 89.00 | -113.40 | -46.40 |
| | GE | 105.25 | 71.41 | 73.57 | -128.55 | -60.90 |
| | Toshiba | 127.60 | 83.54 | 84.44 | -112.50 | -47.23 |
| | Philips | 125.18 | 92.04 | 87.10 | -110.52 | -40.75 |
| 80Kv | SIEMENS | 110.50 | 70.00 | 76.60 | -131.70 | -63.80 |
| | GE | 89.96 | 53.18 | 55.94 | -150.70 | -82.80 |
| | Toshiba | 117.78 | 60.71 | 64.50 | -135.42 | -70.79 |
| | Philips | 103.92 | 67.72 | 67.46 | -134.27 | -67.67 |

### *3.2 Measurement of CT number by manufacturer of self-made phantom materials*

#### *3.2.1 Contrast solution(6%) of self-made phantom*

In this respect, the Phantom's 6% contrast agent solution was found to gradually increase in CT number as the tube voltage decreased in all four manufacturer’s equipment tests. Therefore, at 140 Kv, the measured maximum value was noted at 339.9 HU for GE and the minimum value was 316.6 HU for SIEMENS, showing a 6.85% difference. As noted, the difference was 10.63% at 120 Kv, 8.22% at 100 Kv, and 9.02% at 80 Kv respectively (Table 2).

**Table 2. CT number of 6% contrast agent solution phantom by manufacturer's tube voltage**

| | 140 Kv (135Kv) | 120 Kv | 100 Kv | 80 Kv |
|---|---|---|---|---|
| SIEMENS | 316.60 | 368.10 | 450.00 | 592.80 |
| GE | 339.90 | 398.10 | 484.89 | 619.71 |
| Toshiba | 374.16 | 411.92 | 490.31 | 620.81 |
| philips | 337.86 | 392.49 | 476.27 | 610.65 |

***3.2.2 Air of self-made phantom***

Going further, as noted in air, the difference between the maximum value and the minimum value according to the tube voltage was 0.3 HU for Siemens and 1.85 HU for Philips, which remained within CT number 2 HU, while GE showed a difference of 2.07 HU and Toshiba showed a difference of 13.34 HU (Table 3).

**Table 3. CT number of measured air**

| | 140 Kv(135 Kv) | 120 Kv | 100 Kv | 80 Kv |
|---|---|---|---|---|
| SIEMENS | -996.40 | -996.20 | -996.10 | -995.80 |
| GE | -1000.18 | -998.11 | -999.59 | -1001.10 |
| Toshiba | -1004.98 | -999.79 | -1004.36 | -991.64 |
| philips | -999.55 | -1000.87 | -1000.77 | -999.02 |

***3.2.3 Water of self-made phantom***

As seen in water, the difference between the maximum value and the minimum value according to the tube voltage was kept within 1.4 HU for Siemens, 1.47 HU CT number 2 HU for Toshiba, and 2.86 HU for GE and 4.13 HU for Philips (Table 4).

**Table 4. CT number of measured water**

| | 140kv(135kv) | 120kv | 100kv | 80kv |
|---|---|---|---|---|
| SIEMENS | -6.60 | -7.30 | -7.40 | -6.00 |
| GE | -8.73 | -9.36 | -9.81 | -11.59 |
| Toshiba | 0.35 | 0.80 | 0.77 | -0.67 |
| philips | 1.05 | -0.22 | -2.26 | -3.08 |

## 4. DISCUSSION

In recent years, medical imaging has made a lot of progress to helping determine patient disease and assist in the diagnosis of those diseases. Among them, CT scans are a superior tool to utilize for any patient diagnostic examinations. In this regard, the CT numbers that can be measured on CT images are used in many applications. For this reason, CT numbers can be used to identify diseases, distinguish disease characteristics, and measured values which are used to replace tests in a completely different field. In this context, each voxel in the CT number values is assigned a CT number value, and the CT number value provides a quantitative value of the tissue attenuation at each voxel [4]. Although the reliability of HU as an absolute value that has been reported as being low since the beginning of the use of CTs, some mass characteristics can be identified in a simple and easy way through the measured CT number values [5]. For this reason, there are many cases where the CT number is used for diagnosis in the clinic. It is well established and widely used to characterize the detection of cystic lesions, adrenal gland adenomas, and liver fat in a non-enhanced CT by the criteria of HU [6–8]. That is to say, that the adrenal adenoma is rich in lipids, less susceptible, and the contrast agent quickly escapes from delayed images in that case. When the density of lesions is less than 10HU on the adrenal gland, it is determined as adenoma, and no additional test is performed, but an autopsy is recommended when there is a lesion of more than 10HU on an image before enhancing on adrenal gland, or and when the contrast agents falls down to less than 60% on the delayed phase [9]. In particular, if the contrast enhancement is greater than 15HU, it can be considered as a malignant tumor. Going forward, if the difference before and after contrast enhancement is within 10 HU, it can be considered as a benign tumor [10]. In addition, CT number values are used in various areas such as abdominal fat measurement and bone density measurement using CT numbers, and incorrect CT numbers may provide incorrect information in determining a substance as noted to be present in the patient. Therefore, these values must be accurate and consistent with CT equipment from different manufacturers, and healthcare practitioners must be aware of the necessity to calculate these values when using CT equipment in the diagnosis of patient diseases.

Therefore, the CT number scale is calibrated in order that the CT number value for water is 0 HU and for air -1000 HU at all tube energies used. Between these two fixed values, all materials are given CT number values. These values are used in the field of imaging medicine for the clinical determination of imaging in those cases[11 ].

The results of this study (Table 1), Acryl, showed that when a patient who performed a 120Kv tube voltage test with Siemens equipment and performed the next follow-up test with GE's 100Kv tube voltage test, the CT number of the same material was from 237.90 HU to 105.25 HU, showing a result of 22.65 HU lower. It is thought that this noted difference in numerical values can affect the results in a program that reads a range of values, or a disease judged to be above or below the reference value according to the diagnosis based on those values. As can be seen in this study, it was found that the CT number of the material could be different even at the same tube voltage setting depending on the manufacturers, and that the difference could be increased when using low tube voltage. Even if the tube voltage was set different in one device, it has been shown that the resulting CT number value was seen to have been increased or decreased depending on the materials. Likewise, previous studies also showed the same phenomenon, and differences could be caused by various reasons, such as filtration of x-ray beam and correction of beam hardening during image reconstruction [12]. In this way, medical institutions are noted as being larger than before, and they have to perform a large number of patient tests, and the equipment used in those institutions is also from various manufacturers and versions, even within the same hospital or healthcare facility. This makes it impossible for a patient to continue testing on the same device in some instances. It is believed that this reality can cause new problems in image diagnosis as it is used for patient care in the healthcare environment. This study was limited by using only one piece of equipment from each manufacturer, but the picture is clear and meaningful as this result is evaluated. The equipment manufacturer prefers low dose examination in the clinic, and therefore there needs to be a system to inform the CT number value expressed by each equipment according to the set tube voltage. In addition, further studies on various versions of equipment by manufacturer are needed.

## 5. Conclusion

Generally speaking, it is thought that it is necessary to recognize and utilize the range of variation of CT number value, according to the tube voltage setting of the representative material used when reading or measuring an image using CT number in a medical institution. In particular, in the case of a test with a certain range or standard of CT number values, it is considered that it should be used for diagnosis with a different range of criteria for each manufacturer. In this way, the criteria used for calibrating the equipment of the CT will produce the most accurate measurement of disease for the evaluation of disease for patients for better patient outcomes going forward.

## ACKNOWLEDGMENTS

This Study was from the 2019 Academic Research Support project of Hanseo University.

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