Contrast mediums discrimination by spectral photon-counting CT imaging

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ABSTRACT

We discriminated various concentrations' contrast mediums by spectral photon-counting CT imaging. Contrast media increase the contrast of tissues in x-ray computed tomography (CT) imaging. Conventional x-ray CT uses contrast agent liquids including high x-ray absorption materials like iodine. Spectral photon-counting computed tomography (SPCCT) imaging has the capability of discriminate each contrast mediums with low concentration in one scan by their K-edge if its energy is located in the detectable energy range. The purpose of our research is to reveal the discriminability of contrast mediums by K-edge imaging under the various conditions of concentration included in a water included acrylic phantom with low x-ray exposure.

Keywords: K-edge imaging, photon-counting, computed tomography, Spectral CT, contrast media, material decomposition,

1. INTRODUCTION

Recently, photon-counting detector (PCD) has been developed for medical use [1-4]. CT imaging with photon-counting detector has two advantages over conventional CT imaging used energy integrating detector qualitatively. Firstly, it has little degradation from electric noise because PCD acquires number of photons and doesn't accumulate electric noise if PCD's threshold is enough larger than the heights of pulses caused by electric noise [5]. It makes good image quality even in low x-ray exposure. Secondly, PCD with energy discrimination capability can acquire x-ray spectra directly [1-5]. The number of PCD's energy windows depends on its design. Hence, SPCCT can discriminate materials by its K-edge if the energy is in the detectable energy range. Various K-edge imaging method has been researched [6-8].

K-edge is elemental specific discontinuity in x-ray attenuation coefficient. If PCD can discriminate the photons below and above K-edge energy range, it can be specific by subtraction of its above energy CT image from its below energy CT image. K-edge subtraction CT (KESCT) imaging of contrast media like iodine, gadolinium has been researched [7-11].

Iodine is mainly used in conventional CT's contrast medium [12]. There are other elements for contrast media in other imaging techniques and they marks different tissues. If SPCCT can discriminate them, it has the possibility of acquiring some contrast mediums' map in one CT scan. Low concentration and good discriminability contrast medium is desired for reducing side effects. There are little researches that investigated the discriminability in low concentration and in high x-ray absorbed condition by large phantom comparatively.

The purpose of our research is to reveal the discriminability of contrast mediums by K-edge imaging under the various conditions of concentration included in a water included acrylic phantom with low x-ray exposure. In this study, we investigated the contrast mediums that were already used in clinical applications because they were already provided enough evidence of safety.

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2. SPECTRA OF X-RAY TRANSMITTED THROUGH CONTRAST MEDIA

X-ray spectra through some contrast media used in Japan were acquired to choose the target to reveal KESCT imaging discriminability. Enough x-ray absorption and K-edge discrimination were needed in original concentrations for KESCT because contrast mediums are diluted in human body. To compare with x-ray absorption of human body, x-ray spectra through normal saline solution (NSS) was acquired.

2.1 Experimental setup

Figure 1 shows the schematic view of this measurement. Acrylic cylinders filled with contrast mediums or NSS were illuminated by x-ray (L8121 (Hamamatsu Photonics), 120 kV). Energy integrating type flat panel CdTe imager or photon counting type one-pixel CdTe spectrometer acquired radiograph or x-ray spectra. Acrylic cylinders were moved to acquire spectra of each point by the spectrometer. They were also moved to acquire radiographs of them to reduce the differences of each cylinders' exposures caused by the distances' differences between x-ray tube and each cylinder. Pencil x-ray were illuminated by a lead collimator (ϕ 1mm) when spectra were acquired with low radiation dose to reduce pile-up effect. Cone beam x-ray were illuminated when radiograph was acquired. Table 1 and 2 shows the experimental conditions.

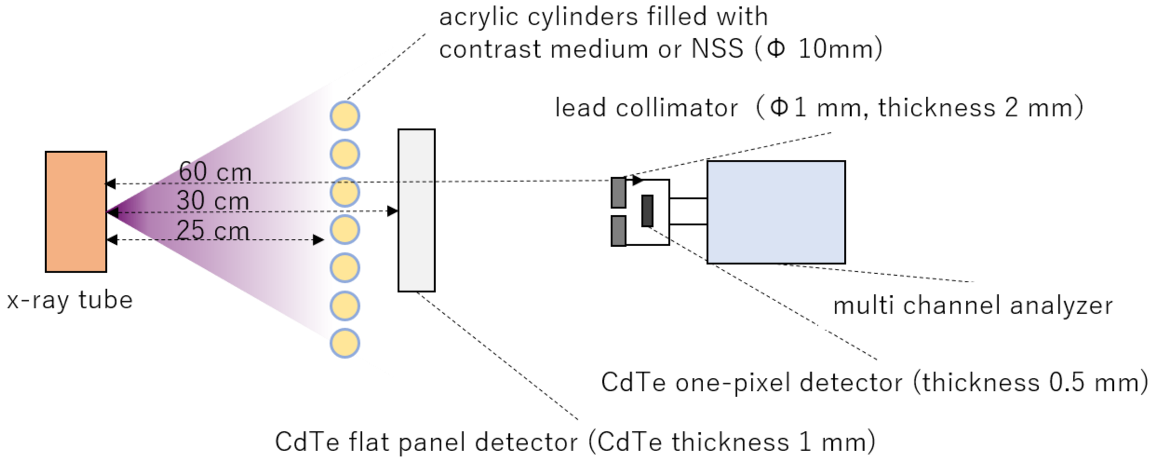

Figure 1. a schematic view of spectra and radiography measurement of x-ray transmitted through contrast media

Table 1. experimental conditions of radiography measurement

Tube voltage	120 kV
Tube current	80 μA
Detector	ANS-FPD4X2S01S (ANSeeN Inc.)
Frame rate	50 frames per second
Pixel pitch	0.1 mm
Exposure time	5 seconds

Table 2. experimental conditions of spectra measurement

Tube voltage	120 kV
Tube current	5 μA
Detector	ANS-XDS1101S01 (ANSeeN Inc.)
Pixel pitch	0.5 mm
Exposure time	100 seconds (per each point)

Radiograph of contrast media

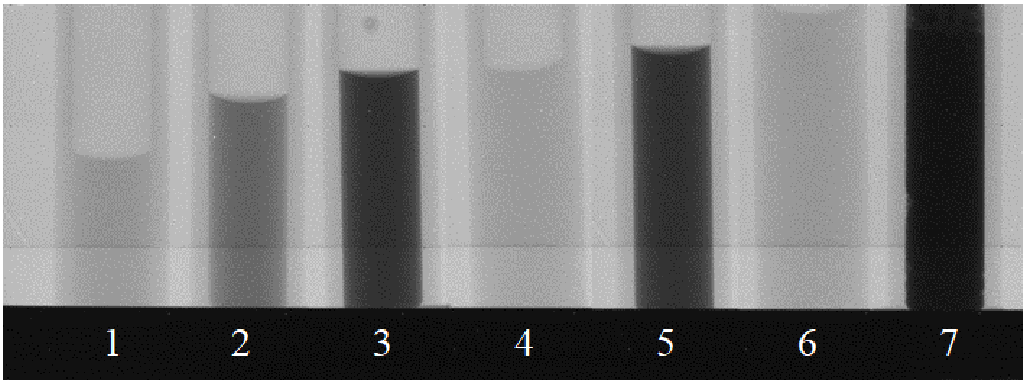

Figure 2. a radiograph of acrylic cylinders filled with contrast mediums and NSS, some radiographs composited

Table 3. contrast mediums' descriptions

#	Name	Main element	Specific
1	Ferucarbotran	oxidized iron	magnetic resonance imaging (MRI) contrast medium
2	Gadopentetate Meglumine	gadolinium	MRI contrast medium
3	Iopamidol	iodine	CT contrast medium
4	NSS	normal saline solution	-
5	Iohexol	iodine	CT contrast medium
6	Bothdel Oral Solution	manganese chloride	MRI contrast medium
7	Baricon meal	barium sulfate	radiography contrast medium

Figure 2 shows the radiograph of acrylic cylinders filled with contrast mediums and NSS. Table 3 Shows the contrast mediums' descriptions. The number of Figure 2 correspond to the number of Table 3. There are not large differences of x-ray absorption among NSS, Ferucarbotran and Bothdel Oral Solution.

Spectra of x-ray transmitted through contrast media

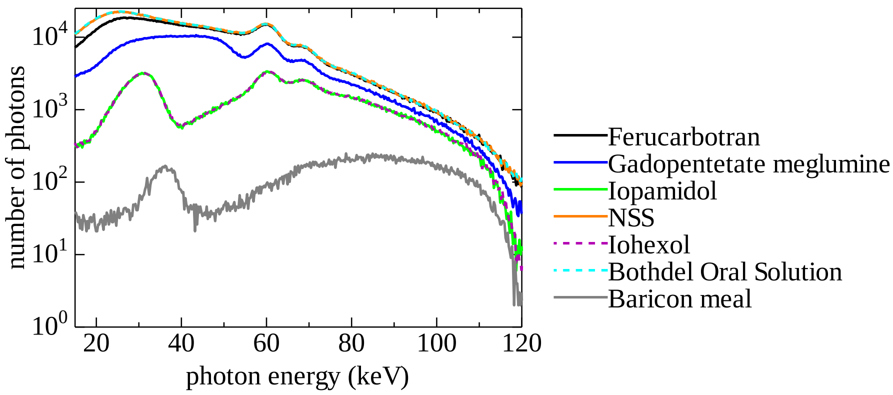

Figure 3. spectra of x-ray transmitted through contrast media

Figure 3 shows the spectra of x-ray transmitted through contrast media. Iopamidol and Iohexol are almost same x-ray attenuation and their K-edge (Iodine: 33.2 keV) were appeared in the spectra. Gadopentetate meglumine's K-edge (Gadolinium: 50.2 keV) and Baricon meal's K-edge (Barium: 37.4 keV) were also appeared in the spectra.

3. KESCT IMAGING OF GADOPENTETATE MEGLUMINE

To verify the discriminability of Gadopentetate meglumine in low concentration, we performed KESCT imaging.

3.1 Experimental setup

Figure 4 shows the schematic view of KESCT imaging. Table 4 shows the experimental conditions of KESCT imaging. Fan beam x-ray were illuminated, and projection data were acquired by a photon counting imager with energy discrimination capability. Because of it has only two energy thresholds, two energy range projection data (40 – 50 keV, 50 – 60 keV) were obtained in twice rotations. The concentrations were two-fold diluted by NSS and measured repeatedly.

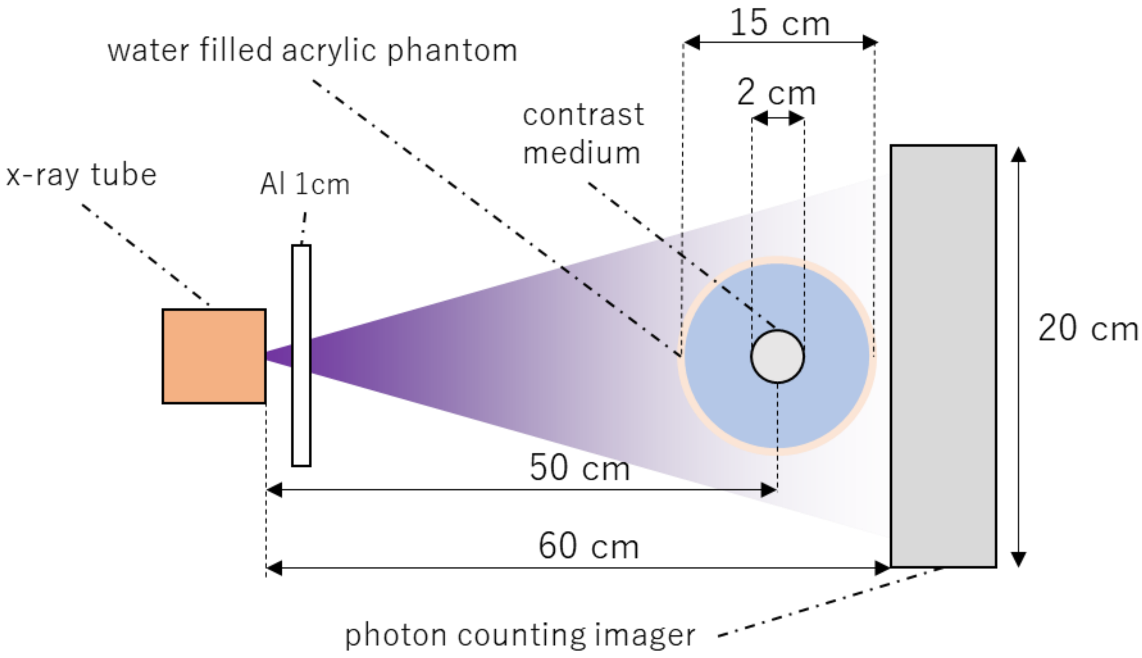

Figure 4. a schematic view of KESCT imaging

Table 4. experimental conditions of KESCT imaging

X-ray tube	L8121 (Hamamatsu Photonics)
Applied voltage	140 kV
Applied current	500 μA
Detector	XC-Hydra (XCounter)
Frame rate	10 frames per second
Measurement time	36 seconds
Pixel pitch	0.1 mm (detector and CT image respectively)
CT reconstruction method	Filtered back projection

3.2 KESCT method

KESCT has mainly two imaging method, one is projection domain method, and the other is image domain method [11]. We used image domain method after their images were converted to Hounsfield unit(HU) value. Even though background tissues don't have K-edge between two adjacent energy range, they take different x-ray absorption coefficients. Moreover, soft tissues' CT value (HU) has little differences even though energy range was different. Hence, it is assumed that image domain method with after their images were conversed to HU value can discriminate specific material and the others well.

3.3 CT images

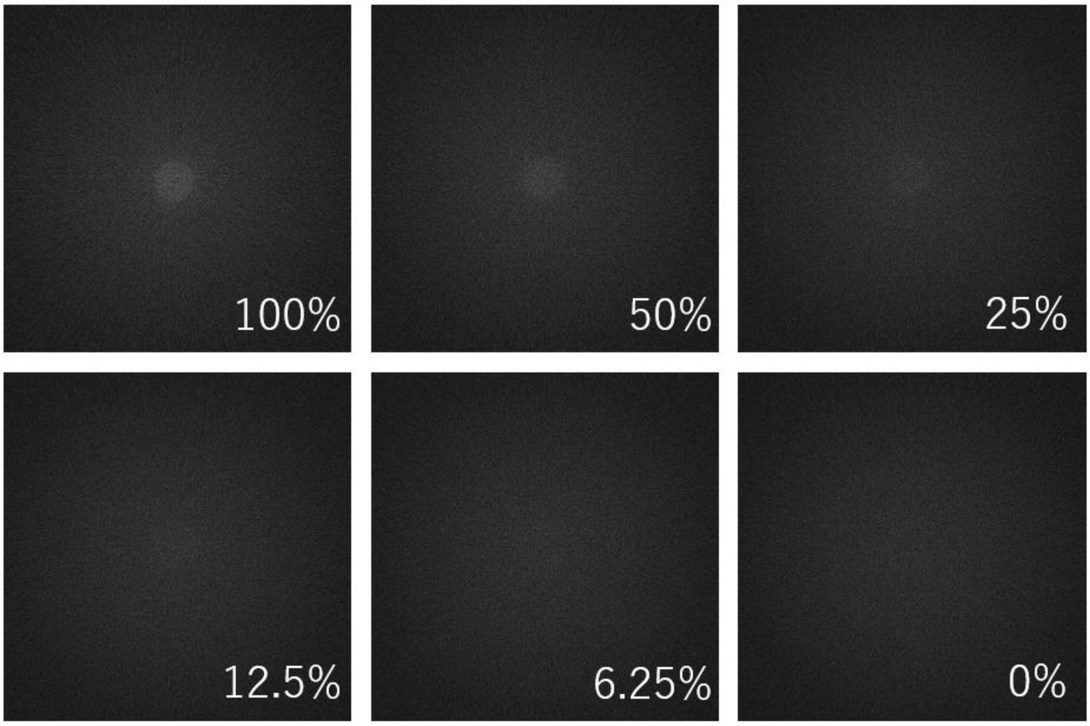

Figure 5. CT images obtained by KESCT imaging, suffix is concentration of Gadopentetate meglumine, window level: 95000, window width: 21000

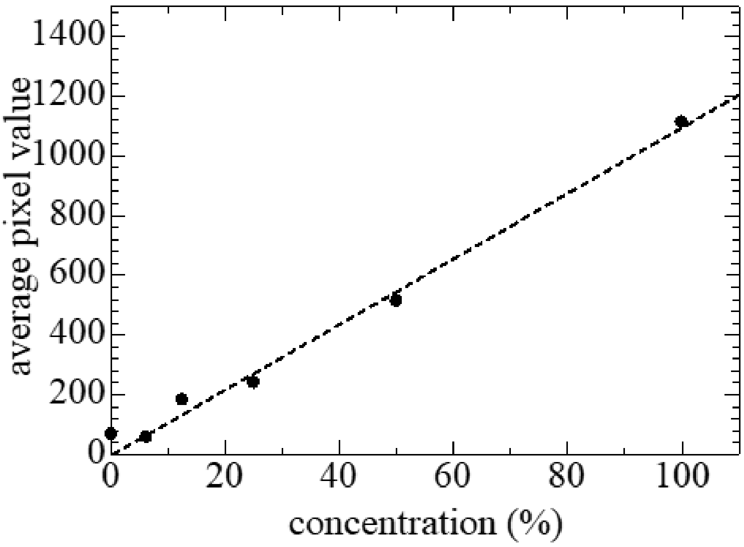

Figure 6. concentration of Gadopentetate meglumine versus average value of 50×50 pixels of Gadopentetate meglumine regions, 0% indicates NSS's average value. Dashed line shows a linear fitting of the results. The graph is expected to cross the origin owing to the conversion process to HU value.

Figure 5 shows the CT images obtained by KESCT imaging. From these images, the image its concentration 6.25 % can be discriminated between contrast media and background slightly but it's not easy to do that. Figure 6 shows the concentration of Gadopentetate meglumine versus average value of 50×50 pixels of Gadopentetate meglumine regions. At the concentration 6.25%, the average value is lower than NSS's average value (0%). It can be indicated that KESCT images of Gadopentetate meglumine can discriminate over 12.5 % in this condition. Figure 6 also shows that around the center of images are brighter than the corner of images. It shows that the bad granularity made pixels much higher or lower value and unclearly discrimination of low concentration KESCT imaging. It is assumed that the granularity and lack of number of pixels made NSS's average value higher than zero. Figure 7 shows the numbers of photons of projection values at an angle, energy range is 50 – 60 keV, the concentration of Gadopentetate meglumine is 100%. The numbers of photons that x-ray penetrated center of the phantom is around 10. If the x-ray exposure enough higher than this measurement, it has possibilities that the concentration of Gadopentetate meglumine lower than 12.5 % can be discriminated clearly. It is needed that to investigate the low concentration discriminability of amount of x-ray exposure.

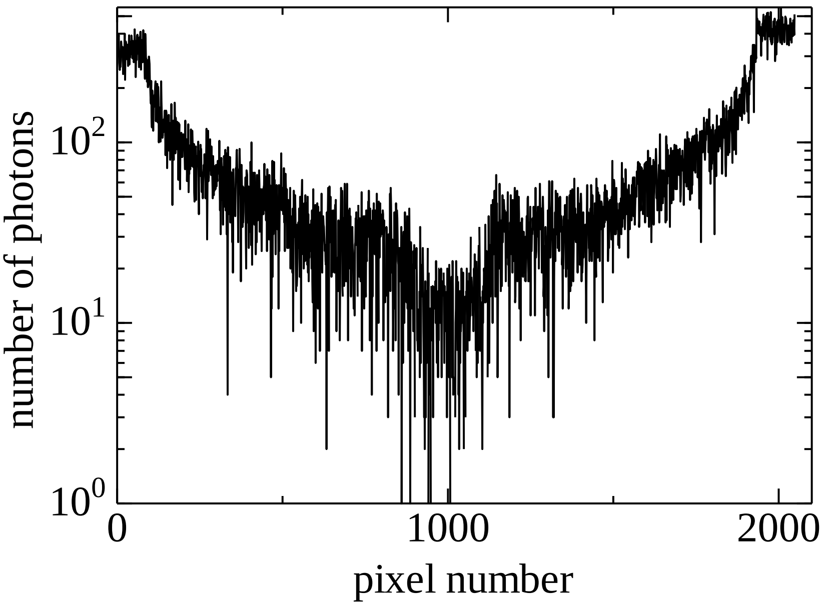

Figure 7. the numbers of photons of projection values at an angle, energy range is 50 – 60 keV, the concentration of Gadopentetate meglumine is 100%.

4. CONCLUSIONS

We discriminated various concentrations' contrast mediums by spectral photon-counting CT imaging. From x-ray spectra transmitted through contrast mediums, Gadopentetate meglumine (MRI contrast medium) was good for KESCT imaging because of its x-ray attenuation and K-edge energy in conventional various contrast mediums. KESCT images indicated that it could be discriminated at that concentration 12.5% and if x-ray was exposure higher than this measurement's one, it has possibilities that the concentration of Gadopentetate meglumine lower than 12.5 % can be discriminated clearly.

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