Journal of Physics: Conference Series **739** (2016) 012074 doi:10.1088/1742-6596/739/1/012074

Single energy micro CT SkyScan 1173 for the characterization of urinary stone

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Abstract. A urinary stone is a solid piece of material produced from crystallization of excreted substances in the urine. Knowledge of the composition of urinary stones is essential to determine the suitable treatment for the patient. The aim of this research was to characterize urinary stones using single energy micro CT SkyScan 1173. Six human urinary stones were scanned in vitro using 80 kV in micro CT SkyScan 1173. The produced projection, images, were reconstructed using NRecon (in-house software from SkyScan). The images of urinary stones were analyzed using CT Analyser (CT An) to obtain information of the internal structure and the Hounsfield Unit (HU) value to determine the information regarding the composition of the urinary stones, respectively. The average HU values from certain region of interests in the same slice were compared with spectral curves of known materials from National Institute of Standards and Technology (NIST). From the analysis, the composition of the six scanned stones were obtained. Two stones are composed of cystine, two are composed of struvite, two other stones are composed of struvite+cystine. In conclusion, the single energy micro CT with 80 kV can be used identifying cystine and struvite urinary stone.

1. Introduction

The urinary stone is a hard mass developed from crystals separated from the urine within the urinary tract[1]. If the crystals remain tiny enough, they will pass out of the body in the urine[2]. In some cases, the passage of the stones down the urethra could possibly cause spasms and irritation, which cause blood to appear in the urine[1].

Knowledge of the composition of urinary stones is essential to determine the suitable treatment for the patient[3]. Non-invasive methods have been applied to obtain information about the composition of calculi with some limitation[4]. Uric acid, struvite and Calcium Oxalate (CaOx) have identified by 120 kV Helical CT but CaOx and CaP cannot be differentiated from struvite and Cystine. Then, high resolution of the micro CT produced good images of calculi[5]. Dividing UA and non-UA used Dual Energy (DE) on the capacity between 80 kV and 120 kV[6]. This research determined composition of urinary stones based on the average HU value by using single energy micro CT SkyScan 1173.

2. Materials and method

Urinary stones are composed of residual substances that the body does not need. They formed stone in the urine which supersaturated. Some of these stones are so small similar to grainsl[7]. Urinary stones consist of different varieties, such as calcium stone, uric acid stone, struvite stone and cystine stone[3,7]. When amounts of calcium and oxalate accumulated in the urine, they form calcium oxalate stone. Uric acid is formed by product of metabolism process involving proteins in the urines. Cystinuria is an uncommon genetic disorder causing kidney to excrete much cystine amino acid in the urine, later formed as stone. Struvite is found in female whose abnormal urinary tracts and it is usually very difficult to remove[3,7,8]. Each of these stones has different characteristics and fragility, for example uric acid is radiolucent which easier to remove compared with the other kinds[9].

There are various treatment for urinary calculi based on the position, size and composition of the stone. Stones whose position in the distal urethra and urinary bladder are removed by urethroscopy and cystoscopy. Large stone could be fragmented by lithotripsy. Stones in the kidney and proximal urethra could be treated by ureteroscopy, surgery, percutaneous nephrolithotomy or extracorporeal shock wave lithotripsy[10].

Variety of urinary stones could be identified by CT scan. However there should be a valid justification and SOP of CT Scan using several methods such as micro CT SkyScan 1173. SkyScan 1173 is a high energy micro CT scanning device with 130 kV and 300 µA X-ray source for large and dense objects. The spatial resolution is up to 5 µm/pixel and the precision is up to 200 mm in length and 140 in diameter. The device is equipped with aluminum, copper, and brass filters by default. Users can add custom filters when necessary. Objects on micro CT can rotate up to 360º and rotation step is up to 0.2º. The detectors is a flat panel converting X-ray to visible light. The visible light is converted to electric current which is displayed as digital image[11].

The raw (projection) images is produced by absorption of X-ray which pass an object. The amount of the reduction of X-rays in a certain thickness, attenuation coefficient and intensity X-ray are showed by the following equation.

$$\frac{dI}{dx} = -\mu I \tag{1}$$

In this research, six human urinary stones were scanned in vitro by micro CT SkyScan 1173 with 80 kV. The stones were placed in the appropriate holder showed in figure 1. The stones were selected based on the same geometrical size.

The sample was placed inside the object chamber and was scanned with parameters listed on table 1.

Table 1. Parameters scanning for urinary stones.

Parameters	Value
Source voltage	80 kV
Source current	100 µA
Camera pixel size	50 µm
Exposure	1000 ms
Image pixel size	14.96 µm
Object to source	109.200 mm
Camera to source	364 mm
Filter	Al 1 mm
Rotation step	0.2 deg
Rotation	180 deg
Image format	TIFF
Depth	16 bits

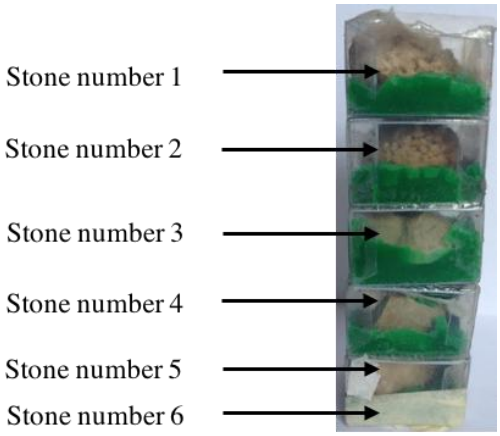

Figure 1. The six urinary stones would be scanned by single energy micro CT SkyScan 1173.

The raw images, obtained from different scanning direction, were reconstructed by NRecon software whose Feldkamp backprojection algorithm[12]. The reconstruction process produced a set of trans-axial greyscale 2D slices of the urinary stone. One of slice is analysed by CT analyser with following procedure.

2.1. Determine the slice which would be analysed

Each reconstructed image of the stone consists of hundred trans-axial slices with a thickness of 0.015 mm. A slice was taken from the center part of the stone which represented the information of the stone.

2.2. Determine the ROI (Region of Interest)

An ROI is an observation area which the average HU value was calculated. Some point, geometric shape, size, position and number of pixels, were selected appropriately. In this study, the geometric shape was circular with diameter of 15 pixels and the number of pixels was 83 pixels. The ROI position were selected on homogeneous areas on the slice. Homogeneous areas could be determined by the grayscale of image. Several ROI from the same slice whose the average value of HU were calculated.

2.3. Calibration HU

The HU value of water depends on the voltage parameters. The image of water was produced by scanning water using the same voltage parameter of scanned stone.

2.4. Histogram Analysis

The histogram provided information regarding of the gray level, attenuation coefficient and HU for the selected ROI. In this study, the average HU value of a specific ROI would be analysed.

2.5. Classification of the stones

The classification could be done by collecting the average HU from the selected ROIs on a single slice, plotting into graph, digitizing the X-ray spectrum of SkyScan 1173 and comparing the HU of the stones with spectral curves of known materials from NIST. This procedure presented the probability of the composition of the stones.

3. Results and discussion

The slice image, produced by scanning with 80 kV and a 0.25 mm Cu filter, is showed on figure 2. This image was composed of several colors: dark blue, purple and yellow. Several colors obtained composition of urinary stone.

Average HU value of water was required as the calibration values to analyze the image (in HU). The water was scanned with a small tube of 2 cm in diameter adjusted to the average diameter of the stone. Parameters of water scanning such as voltage, current, duration of exposure, resolution and position the same radiation parameters on the stones. HU value of water was 1291.

In the figure2, the average HU value of the dark blue areas was 748.118. The average HU value of shades of purple were 372.33; 276.842; 249.013. Higher value of the average HU, dark blue areas, indicated the X-ray which was highly absorbed by the object.

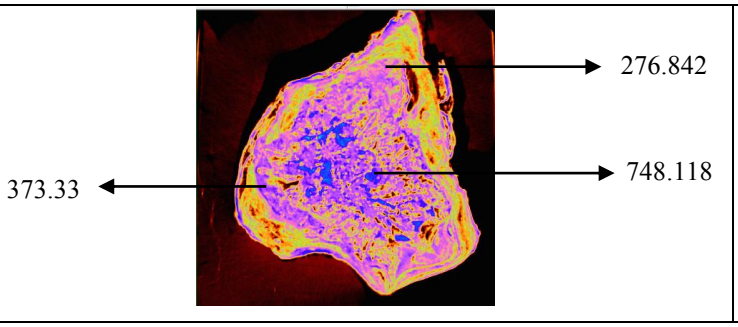

Figure 2. A slice on the stone number 1 by 80 kV. The numbers are the corresponding HU values.

Average HU value from ROI on the same slice was presented in table 2. Based on the table 2, showed different average HU value from ROI on the same slice. If the stone had some average HU value on the same slice, the stone was heterogeneous compositions. There were some stone which the average HU value whose similar. Then average HU value from table 2 was plotted on a graph. The graph represented average HU value each stone and HU from spectral curves of known materials from NIST.

Table 2. Average HU value of several ROI for six urinary stone.

Number of the stones	1	2	3	4	5	6
ROI 1	748.118	189.65	401.289	683.872	580.02	536.872
ROI 2	276.842	638.53	263.961	608.404	301.693	676.323
ROI 3	249.013	1162.26	152.819	597.972	971.224	0
ROI 4	372.33	308.504				0

The plotted based on the table 2 was in the following graph.

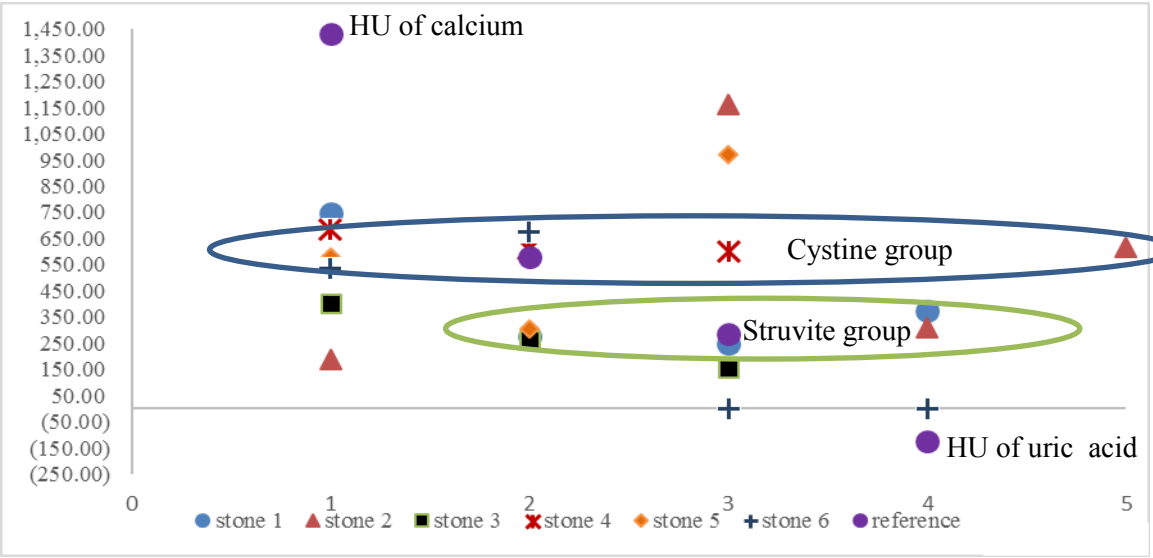

Figure 3. The graph of HU for six urinary stones and HU of materials from NIST

From figure 3, there were two group urinary stones which HU value were the same. The blue line represent the cystine group which consist of urinary stones number 2, 4, 5, 6. The green line represent the struvite group which consist of urinary stones number 1, 2, 3, 5. None stone whose HU value is near with HU of calcium and HU of uric acid. Calcium and uric acid stone could not be identified using 80 kV.

4. Conclusion

Single energy micro CT SkyScan 1173 could be used to characterize urinary stones based on the average HU value. The low energy used in this study could be used identifying cystine and struvite in the six urinary stones. Then, the doctor would determine the suitable treatment for the patient. None stone whose HU value is near with HU of calcium and HU of uric acid. Calcium and uric acid stone could not be identified using 80 kV.

Acknowledgments

The author would like to thank Hasan Sadikin Hospital in Bandung for urinary stones samples. This study was fully supported by RIK (Riset & Inovasi KK), LPPM, Institut Teknologi Bandung (237h/I1.C01/PL/2015).

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