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

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Abstract. Knowledge of the composition of urinary stones is an essential part to determine suitable treatments for patients. The aim of this research is to characterize the urinary stones by using dual energy micro CT SkyScan 1173. This technique combines high-energy and low-energy scanning during a single acquisition. Six human urinary stones were scanned in vitro using 80 kV and 120 kV micro CT SkyScan 1173. Projected images were produced by micro CT SkyScan 1173 and then reconstructed using NRecon (in-house software from SkyScan) to obtain a complete 3D image. The urinary stone images were analysed using CT analyser to obtain information of internal structure and Hounsfield Unit (HU) values to determine the information regarding the composition of the urinary stones, respectively. HU values obtained from some regions of interest in the same slice are compared to a reference HU. The analysis shows information of the composition of the six scanned stones obtained. The six stones consist of stone number 1 (calcium+cystine), number 2 (calcium+struvite), number 3 (calcium+cystine+struvite), number 4 (calcium), number 5 (calcium+cystine+struvite), and number 6 (calcium+uric acid). This shows that dual energy micro CT SkyScan 1173 was able to characterize the composition of the urinary stone.

1. Introduction
Urinary stones are composed of waste products or residual substances that the body does not need in urine. When there is excessive waste, or not enough fluid to flush it out, it comes to form stones [1, 2]. The stones have a crystalline structure with the size of more than 1 mm; about 95% of the stones are crystalline components and 5% are organic components [3]. Urinary stones come in different varieties: calcium containing stones, uric acid stones, struvite stones, and cystine stones [1, 2]. Not only can urinary stones be removed by invasive surgery but also by Extra-Corporeal Shockwave Lithotripsy (ESWL) [4], percutaneous nephrolithotripsy, and ureteroscopy. Uric Acid (UA) stones can better be treated with medical dissolution therapy rather than intervention [5]. Therefore, the characterization of urinary stones is necessary to provide suitable treatment parameters during ESWL, which helps correctly diagnose the causal disease, and implement the correct treatment to prevent the recurrence of the disease [4].

Dual energy (DE) computed tomography is becoming a more available imaging method. DE is increasingly being utilized for evaluation of urolithiasis due to its unique ability to determine a urinary stone composition as either UA or non-UA [5]. DE utilizes data from two energy spectra to
discriminate tissues and characterize tissue composition based on differences in the attenuation of photons with different energies by materials [6, 7].

Based on NIST graph, high energy scanning was unable to show the difference of cystine and struvite Hounsfield Unit (HU) that overlapped each other. Dr. Ridwan has discovered that cystine was not detected on the urinary stones by using the high energy CT scanning 120 kV at Hasan Sadikin Hospital. Region of Interest (ROI) from the images appeared homogeneous. Thus, a combination of high energy and low energy for scanning the urinary stones by micro CT SkyScan 1173 is deemed necessary.

Micro CT SkyScan 1173 has made it possible to reach a spatial resolution of 8 µm corresponding to near $5 \times 10^{-7}$ cubic mm voxel size [8]. DE micro CT acquisition is achieved by using different voltages. The object should not be moved between scans and image magnification and pixel size should be the same. We performed a study test of the ability of dual energy micro CT SkyScan 1173 to characterize the urinary stones.

2. Material and methods

Any given material will have different attenuation values when imaged at low and high kV, resulting in a predictable change in the attenuation when imaged by two known X-ray energies. Thus, two materials with similar attenuation values on a single energy but different chemical compositions can be distinguished from one another by analyzing their energy dependent changes in attenuation. The degree of material separation depends on the spectral separation between the high and low energy X-rays, accurate temporal registration and spatial correlation. This combination of high and low energy X-rays is known as dual energy scanning [5].

The method for dual energy micro CT acquisition is done by performing two scans of urinary stones at higher and lower X-ray energy. This can be achieved by using different X-ray filters and applied voltage. The object should not be moved between scans and image magnification and pixel size should be the same [8].

2.1. Preparation of samples

The experimental setup consisted of six urinary stones consecutively obtained from patients who underwent surgery at Hasan Sadikin Hospital. The six urinary stones were scanned using high energy CT of 120 kV. The six urinary stones were arranged as shown in figure 1 below.

![Figure 1](image_url)

The six urinary stones were arranged tier up in the box like figure 1. The material of box was made from mica. For keeping the urinary stones unmoved during the scanning process, there were waxed micas between them. The sample was ready to scan and put into the scanning stage inside the sample chamber to be scanned by the machine.

2.2. Acquisition of data
Dual energy micro CT SkyScan 1173 performed alternately. First, a scanning was performed with high energy of 120 kV, 66 µA, 1000 ms, using a filter, 14.96 µm/pixel, with a rotation step of 0.2°, and a rotation of 180°. The second, a scanning with low energy of 80 kV, 100 µA, 1000 ms, using a filter, 14.96 µm/pixel, with a rotation step of 0.2°, and a rotation of 180°. Post scanning involved reconstruction of the production raw (projection) images obtained, which were different from the scanning direction by NRecon software. The basic of reconstruction was performed based on the principle of Feldkamp back projection algorithm [8]. The reconstruction process produced a set of trans-axial greyscale 2D slice of the sample. Each of the reconstruction image of the urinary stones consisted of hundreds of trans-axial slices with 0.015 mm slice thickness.

A slice was taken from the center of trans-axial urinary stones. A number of ROI were selected inside the inner contours of the urinary stones margins. The ROI geometry was circular with a 15 pixels diameter [9] and the number of pixels involved was 83. The ROI position was selected in the homogeneous regions of the slice. The mean HU from several ROIs on the slice is shown in the table 1 and 2 below.

2.3. Determination of the chemical composition
Several ROI of mean HU were compared with HU from the graph of NIST (National Institute of Standards and Technology). The determination of chemical composition was performed by using percentage. The equation of percentage is represented below [10]:

\[
\text{Percentage} = \frac{P_{ca}}{P_{ca} + P_{str} + P_{cyst} + P_{ua}} \times 100\%
\]

where \(P_{ca}\) is calcium probability in the urinary stones. To obtain \(P_{ca}\) the following formula is used:

\[
P_{ca} = \frac{1}{\sqrt{(HU_{\text{stone80kV}} - HU_{\text{refcal80kV}})^2 - (HU_{\text{stone120kV}} - HU_{\text{refcal120kV}})^2}}
\]

Equation (2) is the probability of calcium on a certain ROI. Similar equation also used to calculate probability of cystine, struvite and uric acid.

3. Results and discussion
Figure 2 is a reconstruction of slice image scanned by using a voltage of 80 kV and a 0.25 mm Cu filter.

![Figure 2](image)

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

Figure 3 is a reconstruction of slice image scan by using a voltage of 120 kV and a 0.25 mm Cu filter. This image is composed of several colors: dark blue, purple, and yellow. The higher mean of HU on a certain ROI (represented by dark blue areas) indicates that the X-ray was highly absorbed by the object. In the image, the mean HU of the dark blue areas was 630.359. The means HU of the shades purple are 335.137; 193.357; 163.624.
The mean HUs from several ROIs from each stone are showed in the table 1 and table 2 below.

Table 1. Mean HU from several ROI for stones number 1-3.

| Composition | Stone number 1 | Stone number 2 | Stone number 3 |
|-------------|----------------|----------------|----------------|
|             | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 |
| Calcium     | 47.67 | 13.27 | 7.30  | 37.52 | 8.35  | 7.43  | 39.11 | 22.33 | 50.63 |
| Cystine     | 19.78 | 55.97 | 70.17 | 30.31 | 32.68 | 9.83  | 22.15 | 35.75 | 19.12 |
| Struvite    | 18.41 | 21.24 | 16.12 | 20.18 | 44.92 | 9.02  | 21.25 | 28.27 | 17.98 |
| Uric acid   | 14.14 | 9.53  | 6.40  | 11.99 | 14.05 | 6.37  | 17.49 | 13.64 | 12.28 |

Table 2. Mean HU from several ROI for stones number 4-6.

| Composition | Stone number 4 | Stone number 5 | Stone number 6 |
|-------------|----------------|----------------|----------------|
|             | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 |
| Calcium     | 684   | 608   | 598   | 302   | 971   | 537   | 676   | 0     | 0     |
| Cystine     | 305   | 172   | 457   | 297   | 78    | 161   | 69    | -75   | -33   |

The determination of the chemical composition was performed by using percentage. The percentage describes the probability of calcium, cystine, struvite, or uric acid on the urinary stones. To calculate the percentage, several ROIs of mean HU on the table 1 and table 2 were substituted in the equation (2). The calculation of chemical composition percentage is showed on the table 3 and table 4 below.

Table 3. The chemical composition percentage for the stones number 1 until 3.

| Composition | Stone number 1 | Stone number 2 | Stone number 3 |
|-------------|----------------|----------------|----------------|
| Calcium     | 47.67 | 13.27 | 7.30  | 37.52 | 8.35  | 7.43  | 39.11 | 22.33 | 50.63 |
| Cystine     | 19.78 | 55.97 | 70.17 | 30.31 | 32.68 | 9.83  | 22.15 | 35.75 | 19.12 |
| Struvite    | 18.41 | 21.24 | 16.12 | 20.18 | 44.92 | 9.02  | 21.25 | 28.27 | 17.98 |
| Uric acid   | 14.14 | 9.53  | 6.40  | 11.99 | 14.05 | 6.37  | 17.49 | 13.64 | 12.28 |

Based on the percentage of the chemical composition percentage from several ROIs, stone number 1 consists of calcium (47.67% and 37.52%) and cystine (55.97% and 70.17%). Stone number 2 consists of calcium (74.78%; 39.11%; 50.63%) and struvite (44.92%). Stone number 3 is composed of struvite (41.95% and 35.41%), cystine (46.95% and 37.63%), and calcium (38.79%). The number 4 is of calcium (65.14%; 48.23%; 66.04%). The number 5 consists of calcium (77.63% and 44.29%), struvite (33.09%), cystine (35.67%). The last stone is composed of calcium (45.42% and 40.70%) and uric acid (48.47% and 40.93%).

Table 4. The chemical composition percentage for the stones number 4 until 6.

| Composition | Stone number 4 | Stone number 5 | Stone number 6 |
|-------------|----------------|----------------|----------------|
|             | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 | ROI 1 | ROI 2 | ROI 3 |
| Calcium     | 47.67 | 13.27 | 7.30  | 37.52 | 8.35  | 7.43  | 39.11 | 22.33 | 50.63 |
| Cystine     | 19.78 | 55.97 | 70.17 | 30.31 | 32.68 | 9.83  | 22.15 | 35.75 | 19.12 |
| Struvite    | 18.41 | 21.24 | 16.12 | 20.18 | 44.92 | 9.02  | 21.25 | 28.27 | 17.98 |
| Uric acid   | 14.14 | 9.53  | 6.40  | 11.99 | 14.05 | 6.37  | 17.49 | 13.64 | 12.28 |
4. **Conclusion**

Dual energy micro CT SkyScan 1173 can be used to characterize the urinary stones based on the mean HU values. The six stones are stone number 1 (calcium+cystine), stone number 2 (calcium+struvite), stone number 3 (calcium+cystine+struvite), stone number 4 (calcium), stone number 5 (calcium+cystine+struvite), and stone number 6 (calcium+uric acid).

**References**

[1] Rodman J S, Sosa R E, Seidman C and Jones R 2007 *No more kidney stones* (New Jersey: John Wiley & Sons Inc) p 539

[2] Bonn A H, Stockholm H T, Bonn R S and Cologne B H 2009 *Urinary stones* (Switzerland: Reinhard Druck) p 4

[3] Schubert G 2006 Stone analysis *J. Urology* 34 146-150

[4] Dalun L 2010 *Characterization of kidney stones* (Singapore: National University of Singapore) p 7

[5] Jepperson M A, Cernigliaro J G, Sella D, Ibrahim E, Thiel D D, Leng S and Haley W E 2013 Dual energy CT for the evaluation of urinary calculi Image interpretation pitfalls and stone mimics *J. Clinical Radiology* 68 e707-e714

[6] Purysko A S, Primak A N, Baker M E, Obuchowski N A, Remer E M, John B and Herts B R 2014 Comparison of radiation dose and image quality from single energy and dual energy CT examinations in the same patients screened for hepatocellular carcinoma *J. Clinical Radiology* 69 e538-e544

[7] Matlaga B R, Kawamoto S and Fishman E 2008 Dual source computed tomography a novel technique to determine stone composition *J. Urology* 72 1164–68

[8] Deveci S, Coskun M, Tekin M I, Peskircioğlu L, Tarhan N C and Ozkardes H 2004 Spiral computed tomography role in determination of chemical compositions of pure and mixed urinary stones an in vitro study *J. Urology* 64 237–240

[9] Claessence *Selecting filter and voltage SkyScan 1173* (Belgium: Bruker micro CT)

[10] Dougherty G 2013 *Pattern recognition and classification* (USA: Springer)

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