Urinary Stones Clustering on each layer based on Hounsfield Units Values from Micro CT-SkyScan Images

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Abstract The appropriate treatment method for the patient with urinary stones can be determined from the information of the mineral composition of urinary stones. The prediction of the stone type could improve the selection of the interventional modalities. The study aimed to determine the type of the urinary stone for each layer based on the value of Housefield Units (HU) from micro CT-SkyScan images. Five samples were cleaned with 75% alcohol and distilled water. Micro skyScan 1173 was used to scan urinary stones with applied current and voltage of 66 mA and 120 kV respectively. NRecon software was used to reconstruct the projected image. Region of Interest (ROI) was set at each layer and analyzed both qualitatively and quantitatively. The determination of chemical constituents of stones/fragments was performed using Energy Dispersive X-Ray Spectroscopy. The chemical compositions of calcium oxalate monohydrate, struvite, a mix of calcium oxalate and calcium phosphate, a mix of calcium oxalate and struvite and calcium phosphate, uric acid were accurately identified based on the micro SkyScan images with the mean HU. Micro SkyScan images could predict the chemical composition for each layer of urinary stones. However, more samples are needed for clustering various types of urinary stones based on HU value.

1. Introduction
Urinary stones are produced from the pathological biomineralization process in the urinary tract [1]. This has been known to people since ancient Greece [2]. Intrinsic and extrinsic factors cause the emergence of this disease. Some of these factors are gender, age, ethnicity, race, family background, the anatomy of urinary tract stones, climate, drinking water, diet, and lifestyle [3,4]. In terms of the number of sufferers, there has been an increase in several countries, such as 1-5% in Asia, 5-9% in Europe, 13% in North America, 20% in Saudi Arabia [5-13]. Comparison of male and female sufferers (3: 2), but the gender ratio is possible to change due to increased obesity, changes in diet, and decreased fluid intake [14-17]. Besides that the urinary stone recurrence rate> 50% in about 10 years [18,19]. In general, the composition of the urinary stone consists of crystals or organic material with a typical ratio of each patient. Organic materials and crystals that are commonly found are calcium oxalate, calcium phosphate, struvite, uric acid, and cystine [20]. In addition to these compounds, the results of the study found 82 compounds in kidney stones, but only 7 compounds that have a meeting
of more than 1% in kidney stones. The amount of monomineral and dual mineral in kidney stones is about 34% and 44%, respectively [21].

Knowledge of stone composition is essential to explain the etiology and pathology of the formation and growth of urinary stones. Besides, this is crucial in the selection of appropriate medical measures for the treatment of patients [22]. For example, for treatment with extracorporeal shock wave lithotripsy (ESWL), it is crucial to know the stone’s variability and friability because each stone has a specific frequency for breaking. Preliminary studies on urinary stones have reported some information on composition, structure, and mineralogy [23]. However, the analysis of urinary stone structures in the last decade generally uses destructive analysis methods and reports the composition of urinary stones based on major minerals in urinary stones [24-27]. Furthermore, there is no satisfactory explanation, especially the composition of stones in each layer by the non-destructive analysis method.

Micro-computed tomography (micro-CT) is a method for non-destructive analysis of the composition and morphology of urinary stones. This tool was used in several fields of science, such as medicine, engineering, forensic, and history, uniquely to reconstruct 2-D and 3-D images [28-35]. Utilization for the first urinary stone analysis by Cleveland et al. [36]. Leni et al. have also reported urinary stone grouping based on edge detection using a semi-automatic threshold [37]. In this study, micro-CT images were used to distinguish urinary stones constituent minerals with different Hounsfield Unit values in each layer.

2. Materials and Methods

2.1. Material

Five urinary stones were used in this study. This was obtained after the Percutaneous Nephrolithotomy process from the urology laboratory of Hasan Sadikin Hospital in Bandung. The RSHS Bandung has granted Ethical institutional approval for the study. Urinary stones are chosen based on size, color, and shape. The diameter of the stone was 16 mm, 21 mm, 24 mm, 28 mm and 32 mm and had a mixture of black, white, gray, brown, dark brown and brownish-yellow.

![Figure 1 Urinary stones after Percutaneous Nephrolithotomy](image)

The stones were washed with deionized water to clean debris such as mucus, blood, and casts then the specimens have been stored in a sterile environment for Micro-CT characterization. After micro-CT measurement, the sample was then cut to the longitudinal axis using a precision low speed saw. The drying oven was used to dry stones at a constant temperature of 50°C for 24 h. Figure 1 shows the five stones used in this study.

2.2 Methods

Micro-CT SkyScan 1173 was used to scan urinary stones. Scanning parameters that have been applied, such as voltage, current, Aluminum filter, exposure, rotation step, image pixel size with each 120 kV, 66 µA, 1.0 mm, 1000 ms, 0.2°, 17.10 mm respectively. Reconstruction of images in 2-dimensional and 3-dimensional using Nreconstruction software (NRecon 1.7.1.0). Reconstruction parameters applied...
are ring artifact correction 15, beam hardening 8%, smoothing 1, header file length 1134 bytes. Qualitative and quantitative analysis of the reagent of interest gives information about the difference in density based on differences in the color of the urinary stone and the material's response to X-rays in the x-ray attenuation level. Hu value was obtained from the analysis using CT software analyzer. Furthermore, this value was validated by the results of the urinary stone analysis using Energy Dispersive X-Ray Spectroscopy (EDS) [38].

3. Results and discussion
The surface and slice inside the stone can be displayed microscopically to the maximum. Appearance is not limited to the point of view or individual parts and does not damage the stone. Also, this results in a high-resolution stone analysis with excellent structure, relatively fast data acquisition (4h 2m 20s) for scanning 1200 projected images on stone samples with diameters from 1.2 to 3.4 cm.

Image reconstruction of 5 urinary stones was analyzed qualitatively and quantitatively. The results of image reconstruction using NRecon software on the longitudinal or z-axis direction with ring artifact correction 15, beam hardening 8%, smoothing one shown in Figure 2:

![Figure 2](image)

**Figure 2** (a) Projection and reconstruction image of several urinary stones with micro CT (b) Image reconstruction of stone sample number 3 and review points in each layer

The left side of the panel in figure 2 was a projection image at 0° angle of three urinary stones. Scanning on these objects up to 240° with rotation step 2°. Image reconstruction has been carried out and produce images on the right. Reconstructive images on several slices show a different appearance because three samples placed in holders have varying lengths and widths. The slice in 1225 was the middle part of the three samples. So, this was used as a slice to be analyzed by CT software analyzer, which is representative of the nature of urinary stones. Micro CT and EDS analyzed image (b) according to the specified review points. The area of observation after this referred to as layers 1, 2, 3, 4, 5 was determined from the middle (core) to the outside. Information on a gray level, X-ray attenuation, and Hounsfield units in each layer shown in table 1. The value of Hu in each layer was validated with the element content in each layer with EDS. in table 1 shows the value of Hu in some minerals over-lapping.
Urine stone grouping based on Hu value in each layer was shown in Figure 3. The minerals that appear are quite varied when viewed from morphology and X-ray attenuation (gray level). Such as the presence of low attenuation, high attenuation, and dark areas such as holes indicated that there are no minerals.
Figure 3. Grouping of kidney stone layers based on HU values

Sample 1 in figure 3 with EDS was a type of pure calcium oxalate. The Hu value from table 1 in this sample was 1381.410 ± 164.934. Calcium oxalate monohydrate (COM) has a higher X-ray attenuation (gray level) (lighter gray) than calcium oxalate dihydrate (COD) [39]. Sample 1 cannot be classified with certainty monohydrate or dihydrate. However, carbon atoms in layers 1 and 3 have smaller amounts compared to other layers.

The second sample with EDS was a Struvite with a percentage of C atoms that were almost the same but smaller than the first sample. Visually, this sample appears to have layers and darker compared to other samples, and this is because the X-ray attenuation was lower than others. The third sample with EDS was a COM urinary stone in addition to the third layer, which has a mixture of COM and phosphate types. Although in the picture, it looks the same grayscale, but in the third layer, there was phosphate 1%. The fourth stone using EDS was a mixture of COM and struvite in layer one and a mixture of COM and phosphate in other layers. The fifth stone was a type of uric acid in all five layers, although there are visible gray differences. Visually the urinary stone slice consists of layers, and we can speculate about the history of stones formations. If viewed from the gray level parameters, the bright white to dark gray areas have the highest attenuation to low.

4. Conclusions

High-resolution micro CT in urinary stone images can analyze stones non-destructively. However, over-lapping of the value of Hu in several mineral constituent stones was still found in this study. The correlation between Hu value and stones chemical composition can be determined with additional data from EDS but cannot explain with certainty the relationship between the Hu value and the percentage of elements contained in each layer.

References

[1] Bazin, D, Daudon, M, Combes, C, Rey, C 2012 Chem Review 112 5092–5120.
[2] Modlin M 1980 S Afr Adr Medical Journal 58 652-655
[3] Gray, D, Laing, M, Nel, F, Naudé, J.H. 1982 Afr Med Journal 61 121–125.
[4] Scales, C.D, Smith, A.C, Hanley, J.M Saigal, C.S 2012 Eur Urol 62 160 165
[5] Jing Z, GuoZeng W, Ning J, JiaWei Y, Yan G and Fang Y 2010 Urol Res 38 1111-1115
[6] Penniston KL, McLaren ID, Greenlee RT, and Nakada SY 2011 Journal Urol 185 1731-1736
[7] Hiroki Fukuhara, Osamu Ichiyanagi, Hiroshi Kakizaki, Sei Naito, Norihiko Tsuchiya 2016 urolithiasis 44 529–537.
[8] Yasui T, Iguchi M, Suzuki S, Kohri K 2008 Urology 71 209–213
[9] Brikowski TH, Lotan Y, Pearle MS 2008 Proc Natl Acad Sci USA 105 9841–9846
[10] Fwu CW, Eggers PW, Kimmel PL, Kusek JW, Kirkali Z 2013 Kidney Int 83 479–486
[11] Edvardsson VO, Indridason OS, Haraldsson G, Kjartansson O, Palsson R 2013 Kidney Int 83 146–152
[12] Lo SS, Johnston R, Al Sameraaiai A, Metcalf PA, Rice ML, Masters JG 2010 BJU Int 106 96–101
[13] Zhang, Guang-Na., Ouyang, Jian-Ming., Xue, Jun-Fa., Shang, Yun-Feng 2013 Biomimetic Materials, Sensors and Systems 33 4039–4045
[14] Scales CD Jr, Curtis LH, Norris RD, Springhart WP, Sur RL, Schulman KA, and Preminger GM 2007 Urol 177 979-982
[15] Johnson CM, Wilson DM, O’Fallon WM, Malek RS and Kurland LT 1979 Kidney Int 16 624–631
[16] Lieske JC, Peña de la Vega LS, Sleizak JM, Bergstralh EJ, Leibson CL, Ho KL and Gettman MT 2006 Kidney Int 69 760–764
[17] Strope SA, Wolf JS Jr, and Hollenbeck Bk 2010 Urology 75 543–546
[18] Ozturk U, Sener NC, Goktug HN, Nalbant L, Gucuk A and Imamoglu MA 2013 Urol Int 91 345–349
[19] Lao M, Kogan BA, White MD and Feustel PJ 2014 J Urol 191 440–444
[20] Selvaraju, R. et al. 2013 Elsevier 114 650-657
[21] Kocademir, Mustafa, Baykal, Abdulhadi., Kumru, Mustafa., Tahmaz M. Lutfu 2016 Molecular and Biomolecular Spectroscopy 160 1-7
[22] Mandel, I.M. 2007 Humana Press 69–81
[23] Giannossi, M.L. 2013 Medical Geochemistry 67–90.
[24] Aysha Habib Khan, Sheharbano Imran, Jamsheer Talati, Lena Jafri 2018 Urol 59 32-37.
[25] Muhammed A. P. Manzoor, M. Mujeeburahiman, Punchappady-Devasya 2018 Urolithiasis
[26] Behnam Keshavarzi, Nasrin Yavar Ashayeri, Farid Moore, Dariush Irani, Sina Asadi 2016 Minerals 131 1-14
[27] Vivek K. Singh & Pradeep K. Rai Kidney 2014 Biophys Rev 6 291–310
[28] Davood Rouholamin and Neil Hopkinson 2014 Journal Engineering Manufacture 1–14
[29] Matthew G Teeter, Paul Brophy, Douglas DR Naudie and David W Holdsworth 2012 Journal Engineering in Medicine 226 263–267
[30] Patrick L. Jambura, René Kindlimann, Faviel López-Romero, Giuseppe Marrama, Cathrin Pfaf, sebastian stumpf, Julia türtsch, Charlie J. Underwood, David J. Ward & Jürgen Kriwet 2019 Scientific report 9:9652
[31] R. Muller, H. Van Campenhout, B. Van Damme, G. Van Der Perre, J. Dequeker, T. Hildebrand, And P. Ruegsegger 1998 Bone 23 59–66
[32] Violette Mulota, Ndyoe Fatou-Toutiea, Hayat Benkhelifaa, Didier Pathierc, Denis Flicka 2019 Journal of Food Engineering 262 13–21
[33] Mary L. Bouxsein, Stephen K Boyd, Blaine A Christiansen, Robert E Guldberg, Karl J Jepsen, and Ralph Muller 2010 Journal of Bone and Mineral Research 25 1468–1486
[34] Hongyan Yu1, Yihuai Zhang, Maxim Lebedev, Zhenliang Wang Andrew Squelch, Michael Verrall5, Stefan Iglauer 2019 Marine and Petroleum Geology
[35] Licheng Zhua and Maryam Naebeb 2019 The Journal of The Textile Institute
[36] Cleveland RO, McAteer JA, Muller R 2001 J Acoust Soc Am 110:1733
[37] Fitri L A, Warty Y, Haryanto F, Fauzi U, and Latief F D E 2019 IOP Journal of Physics: Conf. Series 1248
[38] Warty Y, Haryanto F, Fitri L. A, Haekal M, Herman H A 2019 Journal Biomedical Physics and
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