

Hounsfield Measurements for Detection of Stone Composition, Density, and Overall Hardness – A Brief Report

Mircea Merticariu^{1,2*}, Stefan Rasca^{3,4}, Dan-Valentin Anghelescu^{3,5}, Corina-Ioana Merticariu⁶

***Corresponding author:**

Mircea Merticariu, MD
CF2 Hospital, Bucharest, Romania
Marasti Boulevard, no. 63, 011464
1st District, Bucharest, Romania
E-mail: merticariu@gmail.com

¹"Titu Maiorescu" University of Medicine and Pharmacy, Bucharest, Romania

²Department of Urology, CF2 Hospital, Bucharest, Romania

³"Carol Davila" University of Medicine and Pharmacy, Bucharest, Romania

⁴Department of Urology, "Prof. Dr. Theodor Burghele" Hospital, Bucharest, Romania

⁵Department of Orthopaedic Surgery, Emergency University Hospital, Bucharest, Romania

⁶Department of Ophthalmology, "Dr. Victor Gomoiu" Children's Clinical Hospital, Bucharest, Romania

ABSTRACT

Having in mind the continuous development of computed tomography imaging, the aim of this review is to discover the latest information based on Hounsfield measurements that can aid the modern urologist in establishing a better diagnosis and treatment for the lithiasis of the urinary tract. We conducted a literature search in PubMed and UpToDate databases using the key words in order to discover the latest publications that address computed tomography in urological pathology. The series of studies presented in this review show great promise and although there is no consensus to clearly guide clinical practice, further studies should be conducted. It seems CT scan differentiation criteria based on Hounsfield units is available, and that more and more studies are closing into what we hope will soon be standardized and widely available for the general practitioner: clear range values that will accurately predict stone density. Most importantly, in the near future, we strive to be able to detect stone overall hardness before initiating the therapy, a cornerstone in Urology all over the world.

Key words: density and hardness, Hounsfield units, urinary stone composition

INTRODUCTION

The most common cause of obstructive hydronephrosis or uretero-hydronephrosis in young adults are renal and ureteral stones. In women with the age between 20 and 60 years, hydronephrosis due to pregnancy and gynecological pathology is second most common, and for the age group above 60 years old, prostate pathology (benign and malignant) is more common for hydronephrosis in men (1).

The Hounsfield unit scale (HU) is a measurement of radio density used by radiologists to determine the physical properties of the tissue scanned based on their capacity for absorption or attenuation of the x-ray beams emitted by the computer tomograph machine. Considering the density of distilled water to be arbitrarily defined as zero HU, for example, we have upper values above 1000

Received: 09.04.2022

Accepted: 10.06.2022

HU for bones or 3000 HU for metals and negative values of -1000HU for air. Based on these values, radiologists can predict the type of tissue scanned including the characteristics of urinary calculi (2-5).

Regarding urinary lithiasis, we can try to classify the most common encountered stones based on their composition as follows: calcium oxalate 70-80%, calcium phosphate 5-7 % (apatite is the most common type of calcium phosphate calculus and brushite is much less common), struvite - 2 to 15%, uric acid - 5 to 8 %, cystine - 1 to 2 %, others <1%. These values are approximate values, and in the authors' opinion they are the closest to most of the mean values described in the literature so far (6-9).

Calcium phosphate stones, although less frequent than calcium oxalate, can be subdivided into three categories: hydroxyapatite, calcium carbonate phosphate and brushite. Brushite is a precursor phase of hydroxyapatite, and the lack of conversion will lead to brushite forming calculi. The most common type of calcium phosphate stones are composed of hydroxyapatite and about a quarter of calcium phosphate stones are composed of brushite (10,11).

Ringden et al published a paper in which the authors quantified urinary stone hardness by the number of ESWL (Extracorporeal Shock Wave Lithotripsy) sessions, the number of shock waves applied during sessions and the energy index necessary for shockwave lithotripsy in 2100 patients with urinary lithiasis. Comparing with the stone fragments composition, the authors have elaborated a hardness index, resulting in the following classification (*table 1*).

The authors also noted that the most frequently encountered stones were calcium oxalate monohydrate, calcium oxalate dihydrate and hydroxyapatite (12).

Cystine, calcium oxalate (monohydrate) and brushite based stones are, the hardest stones that we can encounter in the urinary tract. Their reduced fragility makes them resistant to ESWL, and knowing in advance the urinary stone composition can help urologists avoid

pointless ESWL sessions and the complications associated to it (renal hemorrhage and fibrosis) (13).

On the other hand, uric acid stones are more fragile and can be treated with medication that alkalizes the urine (13).

Regarding stone radiodensity, except medication related stones (e.g. indinavir) and pure matrix stones which can be undetectable even on CT scans, almost 99% percent of urinary calculi are hyperdense (visible) on CT scans.

One classification can be made given the HU characteristics of urinary stones as follows: calcium (oxalate $\pm$ phosphate) about 400-600 HU, struvite (variable in density, most often opaque, but not as dense as calcium stones), uric acid stones: 100-200 HU, cystine: opaque but not as dense as calcium stones. Theoretically, based on this classification, we can distinguish struvite, cystine and uric acid lithiasis from calcium containing stones (14-17).

Dual-energy CT (DECT) may better characterize stone composition. DECT utilizes scanners that emit two separate radiograph energy sets to differentiate the attenuation properties of matter. However, DECT is rarely used clinically to determine stone composition (17). The aim of this review is to determine whether Hounsfield units (HU) measuring scale on CT scans can predict urinary stone composition, density, and overall stone hardness.

MATERIAL AND METHODS

Based on our literary review we encountered a series of studies that present new elements based on the Hounsfield computed tomography (CT) measurement scale that can aid the urologist in improving diagnosis and treatment.

We conducted a literature search in PubMed and UpToDate databases aiming to discover the latest publications that address computed tomography in urological pathology using the key words: Hounsfield units, urinary stone composition, density and hardness.

As a time-span criteria, we selected papers published after the year 2000.

RESULTS

Regarding the predictive value of stone composition, density and overall hardness based on Hounsfield CT scale, a few studies emerged addressing this issue.

Motley et al, studied 100 pure stones of the patients using the HU values measured by two radiologists. Moreover, using the stones largest diameter for each

Table 1 - Hardness factor of stone

calcium oxalate dihydrate	
uric acid	
magnesium ammonium phosphate	
mixed infection stones	1.0
hydroxyapatite	1.1
calcium oxalate monohydrate	1.3
brushite	2.2
cystine	2.4

adapted from Ida Ringdén & Hans-Göran Tiselius (2007) Composition and clinically determined hardness of urinary tract stones, Scandinavian Journal of Urology and Nephrology, 41:4, 316-323, DOI: 10.1080/00365590601154551

stone, the authors measured the HU density of the stones in order to exclude stone size from interfering with the results. The authors concluded that calcium containing stones had similar HU and could not be distinguished between each other, and that non-calcium stones (uric acid, struvite, cystine) could not be clearly differentiated from calcium stones. However, when using the HU density measuring tool, the authors concluded that no non-calcium containing stone had a HU density greater than 76 HU/mm and that significant differences were noted between uric acid (50 ± 24) and calcium stone (105 ± 43) density. In conclusion, the authors noted that HU values and HU density could not identify stone composition in vivo (18).

Studying the CT attenuation values of 119 patients who underwent PCNL (percutaneous nephrolithotomy), Silva et al, came to the following conclusion: values equal or above 1548 HU represented the cut-off point for calcium oxalate monohydrate, and values below 1131 HU were registered only for uric acid containing stones. The authors also mention that in four cases, brushite containing stones could not be identified using their method of diagnosis (13).

Measuring the HUC (HU of the center of the urinary stone), Gallioli et al noted a cut off value of 825 HU in differentiating low-dense stones (uric acid, cystine) and medium-high dense stones (calcium, struvite). More than that, by using HUD (ratio between HU mean value and stones largest diameter in the axial plane) the authors could differentiate calcium from struvite stones at a cut-off value of 35 HU/mm with lower values noted for the latter (19).

Other authors have reported a wide range of HU attenuation values for different stone composition, as follows: for calcium oxalate dihydrate: 1853-2536, 1416-1938 and 324-1015. For calcium oxalate monohydrate: 1707-1925, 496-1865 and 507-1639. For struvite: 549-869, 862-944 and 790-2143. For uric acid stones: 67-769, 566-632 and 347-512.

Plata et al when comparing their results with the previous results mentioned above, discovered similar attenuation values. For calcium containing stones: calcium oxalate monohydrate (783-1010 HU), calcium oxalate dihydrate (873-1218) and apatite (835-1034), the authors concluded that these calculi had similar attenuation values.

Furthermore, attenuation values for uric acid (367-556) and struvite (540-693) were similar with literature results and thus can be helpful in differentiation from other stones. The authors conclude that they could differentiate uric acid, struvite and COM stones, but they also report that no pure renal stone was analyzed

and that heterogeneity of stone composition is one factor for biased results (20-23).

Regarding stone overall hardness, Zarse et al conducted a study following the CT composition of 47 calcium oxalate monohydrate stones and their susceptibility to shockwaves. The stones included in the study ranged between 0,4 and 1 cm in diameter and they were analyzed using micro-CT scanning to check for heterogeneity in the stones (presence of apatite inclusions, voids and lobulation) and also helical CT scanning after immersion in water. After fragmenting the stones on a mesh using a lithotripter, the SW were counted. After fragmentation the authors discovered that homogenous COM stones required almost twice as many shockwaves per stone gram ($1,874 \pm 821$ SW/g) than did heterogenous stones (912 ± 678 SW/g) when micro-CT was used, and that similar findings were discovered when helical CT was used. More than that, stone fragility did not correlate with HU and the authors concluded that it is the stone morphology (inhomogeneity due to internal structural features) rather than HU attenuation values that correlates to overall stone fragility (22).

Gupta et al also tried to determine if CT can predict ESWL outcome. The study included 112 renal and upper ureteric calculi with a diameter between 0,5 and 2 cm using a SW regime of maximum 3.0 kv. The results showed good outcomes for stone values < 750 HU and stone diameter < 1.1 cm (less than three sessions of ESWL with clearance rate of 90%) and worst outcome for stone diameter > 1.1 cm and stone attenuation values > 750 HU (three or more ESWL sessions with 60% clearance rate). So, based on their study, stone density and stone size were predictive of stone susceptibility for SW, with stone density being more useful than the latter (23).

Another study using 180 near pure and pure urinary stones showed that calcium stones had an HU value more than 448 and H/u density greater than 50HU/mm and that no other non-calcium stone had higher values than that. The study could not differentiate between the types of calcium containing stones and cystine, uric acid and struvite could not be accurately detected, thus contradicting the current findings in the former studies presented (24).

DISCUSSION

Regarding stone radiodensity, the results published in the literature describe lower attenuation values for uric acid and cystine stones (mostly below 700-800 HU) and for calcium containing stones values above this

number. Having noted the wide range of HU values registered in calcium containing stones, most of the studies could not accurately differentiate between the subtypes of calcium stones.

Regarding stone hardness of the calcium stones, COM (calcium oxalate monohydrate) stones seem to have less attenuation values than COD (calcium oxalate dihydrate) but the results are inconclusive. Moreover, other studies reported missing brushite containing stones from interpretation.

Cystine, the hardest known calculus existing in the urinary tract, was found to be in the same attenuation range of uric acid stones, a calculus much more fragile.

Studies noted the cut-off value for stone overall hardness, measured by ESWL resistance, to be around 750 HU and stone size of about 1.1 cm. Above these values, the number of sessions doubles and the results are less favorable.

CONCLUSION

To answer the question if radiodensity on CT scan is a criteria for stone hardness, based on what we know so far, the most dense calculi on CT scans are calcium containing stones, but we should be aware that only a percentage of calcium containing stones (e.g. calcium oxalate monohydrate) or brushite (1/4 of calcium phosphate stones) are truly hard stones.

The attenuation values for truly hard stones (COM, brushite and cystine) were overlapping with other types of more fragile calculi and thus, for now, we cannot certainly predict stone composition, stone hardness or ESWL susceptibility.

More than that, when trying to predict stone density and hardness, we must take into consideration the following factors: heterogeneity or homogeneity of stones on CT scans, the pureness of the calculi (pure vs. mixed stones) and stone diameter.

In conclusion, since there is not a consensus to clearly guide current clinical practice, further prospective studies should be conducted, but the information already provided by the researchers is showing great promise and common elements discovered can already be implemented in daily practice.

Acknowledgements

The authors acknowledge the initiative and innovation of all the authors mentioned in this review and consider their work to be of great importance and praiseworthy.

Conflict of interest

The authors declare no conflicts of interests.

Ethics of approval

Ethical approval was not needed for this retrospective study.

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