Usefulness of hounsfield unit and density in the assessment and treatment of urinary stones

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Abstract

Computed tomography (CT) is widely used to examine stones in the urinary system. In addition to the size and location of the stone and the overall health of the kidney, CT can also assess the density of the stone in Hounsfield units (HU). The HU, or Hounsfield density, measured by CT, is related to the density of the tissue or stone. A number of studies have assessed the use of HU in urology. HUs have been used to predict the type of stone during diagnosis, and the efficacy has been assessed using methods including extracorporeal shock wave lithotripsy (ESWL), percutaneous nephrolithotomy (PCNL), ureterorenoscopic ureterolithotripsy (URSL), and medical expulsive treatment (MET). Previous studies have focused on the success rate of HU for predicting the type of stone and of ESWL treatment. Understanding the composition of the stone plays a key role in determining the most appropriate treatment modality. The most recent reports have suggested that the HU value and its variants facilitate prediction of stone composition. However, the inclusion of data regarding urine, such as pH and presence of crystals, increases the predictive accuracy. HUs, which now form part of the clinical guidelines, allow us to predict the success of ESWL; therefore, they should be taken into account when ESWL is considered as a treatment option. However, there are currently insufficient data available regarding the value of HU for assessing the efficacy of PCNL, URSL, and MET. Studies performed to date suggest that these values would make a significant contribution to the diagnosis and treatment of urinary system stones. However, more data are required to assess this further.

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Key words: Hounsfield unit; Urinary stones

Core tip: Hounsfield units provide information not only for the diagnosis of urinary system tumors but also regarding a number of properties of urinary stones. Computed tomography is currently used most commonly to predict the type of stone and assess the potential efficacy of extracorporeal shock wave lithotripsy treatment. However, it might also assist urologists to decide which of percutaneous nephrolithotomy, ureterorenoscopic ureterolithotripsy, and medical expulsive treatment should be used to treat a patient.

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INTRODUCTION

In recent years, the use of helical non-contrast computed tomography (CT) in patients with urinary system stones has increased. Hounsfield units (HU), a parameter generated from standard CT, are related to the density of the stone or structure of interest.

Sir Godfrey Newbold Hounsfield first introduced...
the principle to quantify the amount of X-rays that pass through or are absorbed by tissues, and developed the resulting radiodensity scale. CT images are made up of pixels, each of which has a gray scale value from 1 (black) to 256 (white). This value corresponds to the amount of X-rays that pass through the structure, and can be measured and expressed in Hounsfeld units (HU). HU have since been used to evaluate and quantify tissues and fluids. When the radiodensity of water is defined as 0, fat has a negative HU, and blood and other tissues have a positive HU. Using this method it is possible to differentiate 256 shades of gray that are indistinguishable to the naked eye\(^3\).

HU can also be used to assess the CT density of urinary system stones. In recent years, this has become an important diagnostic tool, not only for predicting the type of stone but also for determining the appropriate mode of treatment. The aim of this review is to assess the various areas in which HU is used to diagnose and treat urinary system stones (Table 1).

### THE ROLE OF HU IN PREDICTING THE TYPE OF STONE

Understanding the composition of urinary system stones is critical for determining the optimal mode of treatment. Urine pH, the presence of crystals, urease-positive bacteria in urine, plain radiographs, and a history of urinary stones have long been used to predict the composition of stones; recently, HU also was used for this purpose\(^2\). Mostafavi et al\(^3\) performed an in vivo study and reported that stone composition could be predicted with high accuracy using HU. Motley et al\(^4\) attempted to determine stone composition using HU density, calculated by dividing HU by the greatest transverse diameter of the stone (in mm), and suggested that HU density was more effective than HU alone. However, the authors also reported that neither HU value nor density was sufficient for determining stone composition in vivo\(^4\).

Patel et al\(^5\) investigated whether HU values could be used for differentiating among subtypes of calcium stones, and reported they were particularly useful for diagnosing calcium oxalate monohydrate and dihydrate stones. In a similar study, the authors reported that calcium stones could be identified with high accuracy using HU values, but that there was an overlap between the HU values of cystine and uric acid stones, making it difficult to differentiate these types of stones\(^6\).

Spettel et al\(^7\) designed an in vivo study to predict uric acid stones using urine pH and HU, and argued that using the two parameters together were more effective for predicting uric acid stones than either one alone. Specifically, for a stone > 4 mm a HU ≤ 500 and pH ≤ 5.5 had a positive predictive value of 90% for uric acid composition\(^7\). To elucidate whether the composition of struvite stones could be predicted using HU values, Marchini et al\(^8\) reported that the HU values of pure and mixed struvite stones overlapped, and concluded that struvite stone composition could not be accurately predicted by HU.

Recent studies suggested that HU and their variants are useful for predicting the composition of stones. However, they were insufficient for certain types of stone; the use of urinary parameters improved the accuracy in such cases.

### THE ROLE OF HU IN PREDICTING RADIO-OPACITY

Knowing the radio-opacity of urinary system stones affords significant information to urologists for selecting the appropriate treatment and imaging modality to use during follow-up. Nevertheless, the relationship between the range/threshold of the HU values of stones measured using CT and radio-opacity is poorly understood.

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**Table 1** Some critical hounsfield unit values in recent literature

| Ref. | Year | Hounsfield units | Affected parameters |
|------|------|------------------|---------------------|
| Prediction of stones | Motley et al\(^4\) | 2001 | Density < 76 / mm | Non-calcium stone |
| Patel et al\(^5\) | 2009 | Mean, 879 ± 230 | Calcium oxalate monohydrate stone |
| | | Mean, 844 ± 346 | Apatite stone |
| | | Mean, 550 ± 74 | Cystine stone |
| Spettel et al\(^7\) | 2013 | < 500 | Uric acid stone |
| Prediction of Radio-opacity | Chua et al\(^6\) | 2012 | > 498.5 | Radio-opaque stone |
| Huang et al\(^8\) | 2009 | > 800 (ureteral stones) | Radio-opaque |
| | | > 200 | Radiolucent |
| Predicting the success of ESWL | Hamed et al\(^9\) | 2013 | > 1350 | Low ESWL success |
| El-Assmy et al\(^10\) | 2011 | > 1000 | Low ESWL success |
| El-Assmy et al\(^11\) | 2013 | ≤ 600 and stone length ≤ 12 mm (in children) | High ESWL success |
| Ouzaid et al\(^12\) | 2013 | > 970 | Low ESWL success |
| Foda et al\(^13\) | 2013 | > 934 | Low ESWL success |
| Use in PNL | Gücük et al\(^14\) | 2012 | < 677.5 | Low PNL success |
| Gücük et al\(^15\) | 2013 | ≤ 677.5 | Increases success with flexible nephroscope use |
| Use in URS | Kim et al\(^16\) | 2014 | Any | No effect |
| Medical expulsive treatment | Erturan et al\(^17\) | 2013 | Any | No effect |

ESWL: Extracorporeal shock wave lithotripsy.
Identifying radiolucent stones using CT has the advantage of preventing unnecessary radiographies during follow-up, preventing exposure to radiation, lowering anxiety, and reducing costs. Chua et al.\(^\text{[9]}\) also assessed the predictive potential of the radio-opacity of stones identified using plain radiographs and HU values. They examined 184 cases, and calculated that 498.5 HU was the appropriate cut-off value for determining if a stone > 4 mm was radio-opaque or radiolucent, with 89.3% sensitivity and 87.3% specificity.\(^\text{[9]}\) Huang et al.\(^\text{[10]}\) performed a study that also included ureteral stones, and reported that stones of HU > 800 were visible on plain radiographic images, whereas those with a density < 200 HU were not. Taken together, data assessing the relationship between HU values and radio-opacity suggested that the follow-up of certain groups of patients could be performed adequately using plain radiographs rather than repeated CT examinations, reducing the time, cost, and exposure to ionizing radiation.

**THE ROLE OF HU IN PREDICTING THE SUCCESS OF EXTRACORPOREAL SHOCK WAVE LITHOTRIPSY TREATMENT**

Extracorporeal shock wave lithotripsy (ESWL) can successfully eliminate approximately 90% of renal stones in adults.\(^\text{[11]}\) Successful ESWL depends on the type of lithotripter, and the localization, size, and hardness of the stone. Many previous studies have investigated the relationship between CT parameters and successful ESWL. Data revealed that the energy of the shock wave needed for fragmentation was related to stone density, and that the higher the stone density, the stronger the shock wave energy needed to achieve fragmentation.\(^\text{[12]}\)

Hameed et al.\(^\text{[13]}\) reported that successful fragmentation using ESWL was decreased in stones with HU > 1350, which required application of more shock waves. El-Assmy et al.\(^\text{[14]}\) used the Hounsfield value of the stones to predict stone composition and density, and the fragmentation success using ESWL, and selected HU > 1000 as their cut off value. Another study of pediatric patients by the same group revealed that stones ≤ 600 HU and ≤ 12 mm in length were significant independent predictors of SWL success in children.\(^\text{[15]}\)

Ouzaid et al.\(^\text{[16]}\) performed a prospective study on 50 patients, and reported that a HU threshold of 970 was predictive of successful ESWL. Specifically, the stone-free rate was 96% and 38% with HU < 970 and > 970, respectively.\(^\text{[16]}\) Foda et al.\(^\text{[17]}\) demonstrated that stone disintegration failed if the stone density was > 934 HU; therefore, they did not recommend ESWL in this group of patients.

Taken together, the available data suggest that the HU value, a parameter that is incorporated into clinical guidelines and enables prediction of successful ESWL, should be considered when making decisions regarding the use of ESWL.

**THE ROLE OF HU IN PERCUTANEOUS NEPHROLITHOTOMY**

Fluoroscopic imaging has been widely used during percutaneous nephrolithotomy (PCNL) operations to facilitate access to the collector system and renal anatomy, determine the placement of surgical tools, and identify and extract residual stones. The accurate assessment of post-operative residual stones significantly reduces morbidity. However, identifying residual stones using fluoroscopy depends largely on the size and opacity of the stone. In contrast, CT is an effective imaging tool for identifying all but indinavir stones. In addition, it allows the opacity of the stones to be quantified using HU. The HU value of stones affects the outcome of PCNL operations. Gücük et al.\(^\text{[20]}\) investigated the effects of certain parameters, including HU, on the outcome of 179 PCNL patients, and concluded that the HU value was an independent factor that affected the success of PCNL. Specifically, an HU value < 677.5 reduced the success of PCNL by 2.65-fold. The authors also reported a positive relationship between HU value and hemorrhage, and explained that this was associated with an increased frequency of endoscopic manipulation to extract residual stones.

The identification of residual stones became easier with increasing HU value, and a higher HU value was also associated with increased renal trauma as a result of the higher energy required to breakdown stones\(^\text{[20]}\). The same group assessed the efficacy of routine flexible nephroscopic examination for identification and treatment of residual stones during PCNL operations, and reported that flexible nephroscopy was more effective in stones with low compared with high HU values. They suggested that this might be because flexible nephroscopy is used more commonly than fluoroscopy because stones with a low HU cannot be identified using fluoroscopy.\(^\text{[21]}\)

Although limited data are available regarding the association between HU and percutaneous nephrolithotomy, we conclude that consideration of HU values in patients scheduled for PCNL might assist selection of the appropriate treatment procedures and improve success rates.

**THE ROLE OF HU IN URETEROSCOPIC LITHOTRIPSY**

Ureteroscopic lithotripsy (URSL) is an important treatment modality for ureteral stones that is currently used for stones of all sizes present in any location within the ureter. The size and location of the stone are the prime factors that determine the success of URS L. However, it remains unclear whether HU is a determinant of URSL success. The only previous study of the relationship between HU value and URSL success was performed by Kim et al.\(^\text{[22]}\). They examined the size, location, impaction, and HU value of stones using CT, as well as the effect of
these parameters on the success of URSL. Their results revealed that the HU value did not affect the success of treatment using URSL. However, this study failed to assess several important parameters, such as the duration of the operation and of lithotripsy. As with ESWL, more energy might be needed and/or the procedure might be prolonged to fragment stones with a high HU using URSL. Therefore, further studies are required to elucidate whether higher energy and/or prolonged treatment are needed to successfully fragment stones with high HU values, and to identify any associated complications.

THE ROLE OF HU IN MEDICAL EXPULSIVE TREATMENT

Medical expulsive treatment (MET) is commonly used to facilitate the passage of ureteral stones in the absence of severe renal colic, infection, and obstruction. The spontaneous passage ratio can be as high as 98%, particularly in stones smaller than 5 mm. The most important factors that affect spontaneous passage are the size and location of the stone. Erturhan et al. assessed the effect of HU value on the success of MET. This study, the only current report assessing this relationship, demonstrated that stones with a high HU would pass through the ureter slowly and with difficulty because of their compact structure. They compared two groups of stones with mean HU values of 625 and 507, and concluded that HU could not be used to predict the likelihood of spontaneous passage ratio can be as high as 98%, particularly in stones smaller than 5 mm. The most important factors that affect spontaneous passage are the size and location of the stone.

CONCLUSION

Previous studies have revealed the benefit of HU values, parameters obtained from CT scans, on ESWL treatment and predicting the composition of urinary system stones. HU measurements now form part of the clinical guidelines because of the lower success rate of ESWL treatment of high HU stones. Although HU is currently used most commonly during ESWL treatment and for prediction of stone composition, current data suggest that it could be used in other treatment modalities as our knowledge increases.

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