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Role of Non-contrast Computed Tomography - Kidney, Ureter, and Bladder in Predicting the Stone Fragility and Extracorporeal Shock Wave Lithotripsy Success Rate

S M Kannan[1], S Mangaiyarkarasi[2], S K Subhakanesh[2], A Larif[2], B Thiruvasagamani[3], Heber Anandan[4]

[1]Professor and Head, Department of Urology, Tirunelveli Medical College, Tirunelveli, Tamil Nadu, India, [2]Assistant Professor, Department of Urology, Tirunelveli Medical College, Tirunelveli, Tamil Nadu, India, [3]Associate Professor, Department of Urology, Tirunelveli Medical College, Tirunelveli, Tamil Nadu, India, [4]Senior Clinical Scientist, Department of Clinical Research, Dr. Agarwal's Healthcare Limited, Tirunelveli, Tamil Nadu, India

Abstract

Introduction: Extracorporeal shock wave lithotripsy (ESWL) has revolutionized the treatment strategy of urolithiasis worldwide and continues to be a major therapeutic modality for treating a majority of upper urinary tract stones.

Aim: The aim is to study the density of renal stone by non-contrast computed tomography (NCCT) scan as measured in Hounsfield unit (HU) and its correlation with susceptibility of fragmentation by ESWL.

Materials and Methods: This is a prospective study conducted in 100 patients of renal stone disease who underwent ESWL treatment at Tirunelveli Medical College Hospital, during January 2016 to March 2107 were included in the study.

Results: The overall success rate of ESWL was 80% in our study. 68/100 patients with <750 HU had 100% stone fragmentation and clearance. 12/100 patients with 750-100 HU had 59% stone fragmentation and clearance in the II sitting and 41% had stone fragmentation and clearance in III sitting (retreatment with ESWL needed). 20/100 patients with HU >1000 had significant residual fragment even after III sitting ESWL (auxiliary procedures needed) (there was a statistically significant difference with $P < 0.001$).

Conclusion: For stones with HU >1000, other modalities of treatment (endoscopic and open stone surgery) are preferable to ESWL. NCCT estimation of stone density by HU predicts the successful outcome of the ESWL therapy.

Key words: Extracorporeal shock wave lithotripsy, Hounsfield unit, Non-contrast computed tomography, Renal stones

INTRODUCTION

Stone disease causes enormous social and economic burden to the society.[1] The lifetime prevalence of kidney stone disease is 1-15% with the probability of having a stone varying according to age, gender, race, and geographic location. Management options for renal calculi has changed dramatically during the past 30 years.[2] Minimally invasive techniques, especially the introduction and development of extracorporeal shock wave lithotripsy (ESWL) have virtually replaced open surgical stone removal.[3] ESWL was introduced by Chaussy *et al*. in 1980.[4] Around 80-85% of simple renal calculi can be treated effectively with ESWL. ESWL is a non-invasive therapy for urinary calculi with good success rates and decreased morbidity, length of hospitalization, and anesthesia requirement.[5] According to the AUA guidelines, ESWL is the preferred modality of treatment for renal stones of 2 cm size. Even large and complex renal calculi can be treated effectively with these minimally invasive techniques. For complete staghorn calculi a combined percutaneous nephrostolithotomy (PCNL) and ESWL (Sandwich) therapy has been recommended as the

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Corresponding Author: S Mangaiyarkarasi, Department of Urology, Tirunelveli Medical College, Tirunelveli, Tamil Nadu, India. Phone: +91-9442450390. E-mail: 19ganesh75@gmail.com

first line of treatment. However, even for the calculi of this size, the stone-free rates (SFRs) vary between 66% and 99%.[6] This variation in stone fragmentation is due to factors such as stone size, location, chemical composition, body mass index, other congenital anatomical anomalies, shock wave generator, and presence of obstruction (or) infection. The renal calyces are the most common location of asymptomatic (or) incidentally discovered urinary calculi. Pelvic calculi, upper calyceal, and middle calyceal stones of <2 cm have been treated with ESWL with SFR of up to 99%.[7] The management of lower calyceal stone is more controversial and in this situation, SFR after ESWL range from 44% to 79%. Lower calyceal stone with favorable infundibula pelvic anatomy have good success rate with ESWL. Stone fragmentation by ESWL is variable. Hence, it is desirable to reduce the number of retreatment (or) limit one definite therapy.[8] In addition to the local effects of ESWL on renal parenchyma, injuries to surrounding organs are also of concern. The long-term prevalence rate of HT and change in renal plasma flow following ESWL treatment constitute a further reason for the surgeon to limit the therapy to one-stage definite treatment. The success of ESWL has been correlated with the radiodensity of the renal stone on plain X-ray kidney, ureter, and bladder (KUB).[9] Overall accuracy of predicting calculi composition from plain radiographs was reported to be only 39%, which is at present insufficient for clinical use. The emergence of non-contrast computed tomography (NCCT) KUB in the assessment of flank pain and the subsequent availability of the attenuation coefficient measurement has resulted in many studies comparing the attenuation value and stone composition *in vitro*. These studies have determined that stone compositions can be predicted on the basis of the attenuation value determined by NCCT.[10] The density of stone measured by NCCT Hounsfield unit (HU) varies with stone composition and determines the fragility of a calculus which ultimately determines the clinical outcome in ESWL. NCCT, because of its easy availability, superb sensitivity, and very high-resolution capability, is a good modality for the measurement of stone density.

Aim

The aim is to study the density of renal stone by NCCT scan as measured in HU and its correlation with susceptibility of fragmentation by ESWL.

MATERIALS AND METHODS

This is a prospective study conducted in 100 patients of renal stone disease who underwent ESWL treatment at Tirunelveli Medical College Hospital, Tirunelveli. Inclusion criteria: Patients with renal stones 8-35 mm in diameter who have not received any previous treatment for the same. All stones were located in a satisfactory functioning, non-obstructed renal unit. Exclusion criteria: Bleeding diathesis, pregnant females, uncontrolled infection, ureteric calculi, distal obstruction, congenital anomalies, patients with cardiac pacemaker, and lower calyceal stone with unfavorable anatomy. 100 patients with renal stones were included in the study. In all patients, history and physical examination were done. Baseline investigations included were complete hemogram, renal function tests, urine C/S, X-ray KUB, ultrasonography (USG) KUB, and CT KUB. NCCT scan was done in 3 mm cuts. Stone density in HU was obtained on the particular cut in which the stone was seen in the greatest diameter. Mean stone density was calculated in some cases. Patients were explained about the study, ESWL procedure and informed consent were obtained. ESWL was done as outpatient procedure. Patients' data were recorded in the pro forma. All treatments were done with Dornier Compact Delta III (Electromagnetic Generator) Machine. Patients were administered sedation intravenous Fortwin (20 mg), 30 min before procedure. In pediatric patients, endotracheal general anesthesia was given by anesthetist. Topical EMLA cream was used in some patients. Calculus was focused using fluoroscopy, USG probe (in radiolucent stones) a maximum of 2500 shocks were given in each sitting. Intensity of shockwaves increased stepwise. Shock frequency was 60/min. Stone fragmentation was monitored fluoroscopically after every 100 shock waves or continuously with USG probe, and the procedure was terminated once adequate fragmentation was observed. Adequate fragmentation was accepted when following were observed: Increase in stone surface area, alteration in configuration, irregularity in outline, obviously separated fragment, and decreased overall density. If the stone size is large (>2.5 cm), pre-procedure 5F DJ stenting was done. After each session of treatment, patients were observed for 4-6 h period and allowed to go home. Patients were explained about the post-treatment hematuria, pain and voiding of fragments. Analgesics were given and patients advised to take around 5-6 L of fluid/day. All patients were instructed to pass urine through sieve (coffee filter) and to collect stone fragments. This was brought and given to us at the time of review for chemical analysis. Patients were followed up at 2 weeks with X-ray KUB, USG KUB, and CT KUB. For those patients with residual fragments, II sitting ESWL was instituted. For those patients who undergone II session of ESWL, follow-up was done at the end of 4 weeks with X-ray KUB, USG KUB, and CT KUB. Those patients with residual fragments, III sitting ESWL was given. After 2 weeks, patients were followed up. Residual calculi by X-ray KUB, USG KUB, and CT KUB <4 mm clinically insignificant residual fragment were considered adequately treated. Residual fragments >4 mm were considered treatment failures.

RESULTS

This study comprised of 100 patients who had satisfied the inclusion and exclusion criteria mentioned earlier and later underwent NCCT KUB for the assessment of stone density in HU followed by ESWL (maximum III sittings 7500 shock waves).

There were 69 male patients and 31 female patients in the study. The age of the patients ranged from adults 97 patients (20-60 years) pediatric age group 3 patients. Majority of patients presented with loin pain (80 out of 100 patients). Other symptoms were dysuria, hematuria, and urinary tract infection. 20 patients were asymptomatic and incidentally detected (Table 1).

It was observed that 65 patients had right-sided stones and 35 patients had left-sided stone. The largest calculus was 35 mm and smallest was 8 mm. In our study, stone of size 8-15 mm were found in 70 patients (70%), 16-25 mm in 17 patients (17%), and 26-35 mm in 13 patients (13%) (Table 2).

58 patients had stone in the renal pelvis, 25 patients had stone in the upper calyx, 10 patients had stone in the middle calyx, and 7 patients had stone in the lower calyx with favorable anatomy (Table 3). Stone size >25 mm were stented, 30 patients were stented and 70 patients were non-stented.

Stone Density in CT Scan

- 68 patients had CT HU= 320-750
- 12 patients had CT HU =750-1000
- 20 patients had >1000 HU.

Out of 100 patients, 68 patients' stone was completely disappeared. 12 patients had good fragmentation and 20 patients had clinically significant residual fragment.

In 68 patients, size of the stones are 58 patients 8-15 mm 16-25 mm in 6 patients, 4 patients had 26-35 mm, even though the size >2.5 cm if HU was <750, stone fragmentation rate was good (Table 4).

12 patients had stone density of 750-1000. Among the 12 patients, 7 patients underwent II sitting ESWL and stone was fragmented. 5 patients underwent III sitting ESWL and stone was completely fragmented. Among 12 patients, 6 patients had stone size 8-15 mm, 4 patients had stone size 16-25 mm, and 2 patients had stone size 26-35 mm. In the II group, re-treatment is needed. 7 patients residual fragments at 2 weeks and underwent II sitting ESWL, 5 patients underwent III sitting ESWL and became stone-free. 20 patients had stone density of >1000 HU and received 7500 shocks. III sitting ESWL patients had clinically significant >4 mm (Table 5). In these groups, axillary procedures PCNL, open surgery, or ureteroscopy is needed. Among 20 patients, 6 patients had stone size 8-15 mm. Even though the stone size is smaller since the HU >1000 stone was not fragmented. 7 patients had stone size 16-25 mm and 7 patients had 26-35 mm. From the above study, it is obvious that size of the stone will not be able to predict the number of shock waves (even though moderate correlation) but stone density in HU will be able to predict the number of shocks needed in a better quantitative way.

The chemical composition of post-ESWL fragments was obtained in 80 patients by chemical dissolution method (qualitative analysis). 20 patients were not able to retrieve

Table 1: Distribution of symptoms

Symptoms	Number of patients (%)
Flank pain	80 (80)
Dysuria	10 (10)
Fever	5 (5)
Asymptomatic incidentally detected	20 (20)

Table 2: Distribution of size

Size (mm)	Number of patients
8-15	70
16-25	17
26-35	13

Table 3: Distribution of location

Location	Number of patients
Pelvis	58
Upper calyx	25
Middle calyx	10
Lower calyx	7

Table 4: Distribution of fragments

Description	Stone free	Fragmented completely	Residual fragments
Number of patients	68	12	20
Stone density	320-750	750-1000	>1000
Number of shocks	800-2200	2500-6000	5000-7500

Table 5: Distribution of mean shock

CT HU	Number of patients	Mean shock	Standard deviation	One-way ANOVA *F*-test
<750	68	1978.99	775.754	*F*=199.8 *P*=0.001 significant
750-1000	12	3690.91	1454.960	
>1000	20	7175.00	1453.444	
Total	100	3206.50	2300.106	

CT: Computed tomography, HU: Hounsfield unit their stones. Uric acid stones were completely disappeared in a single sitting with ESWL (HU 320-350). Struvite stones had HU 400-600, stone fragmented and cleared completely. Mixed stones had varying, HU between 400 and 1600. Stone fragmentation also varies.

DISCUSSION

ESWL has revolutionized the treatment strategy of urolithiasis worldwide and continues to be a major therapeutic modality for treating a majority of upper urinary tract stones. It is non-invasive in nature along with high efficacy has resulted in outstanding patient and surgeon acceptance. ESWL is the preferred modality of treatment for renal stones <2 cm. However, SFR after treatment has never been near 100% and has been in the range of 65-75% (present study 80%). The success rate of ESWL is determined by factors such as stone size, composition, location, presence of obstructive changes, and anatomical anomalies. Stone composition is one hidden factor which decides the fragility of calculus and its susceptibility to ESWL. The number of shocks required for fragmentation is related not only to the size of the stone but also to its hardness (or) brittleness which largely depends on its chemical composition. CT being an easily available modality of investigation and because of its increased sensitivity to density differences has been used to measure stone densities of various types of calculi, and attempts are made to correlate the density with chemical composition.

Hillman *et al*. reported 89% overall accuracy of CT scan to categorize uric acid, calcium oxalate, and struvite calculi.[11] On the contrary, Kuwahara *et al*. reported that there is no correlation between the attenuation value and the chemical composition of renal stone.[12] In our study, we also could not find any correlation between CT density and chemical composition of stone. The predominant stone (Mixed stone) of calcium oxalate, phosphate, and uric acid had stone HU ranging from 400 to 1600 and the values were overlapped for various calculi.

Joseph *et al*. reported overall success rate of 80% for calculus up to 2 cm when they assessed the susceptibility of stone fragmentation by ESWL. According to the HU, they found that the success rate for stone with attenuation value <1000 HU was significantly higher than that for stone with value >1000 HU. In their study, they found a significant correlation between number of shocks required for stone fragmentation and the attenuation value of the stone.[13]

We noted that 80/100 patients with CT density of <1000 HU had significantly successful treatment. In the I sitting ESWL, 68 patients have cleared their stone. 7 patients pulverized their stone in II sitting ESWL and 5 patients undergone III sitting ESWL for complete clearance. 20 patients with CT HU >1000 HU had unsuccessful fragmentation even after 7500 shock waves. Thus, the CT density of the renal stone is inversely proportional to the fragmentation and clearance.

The success rate of ESWL is also related to chemical composition of stone. Uric acid and struvite stones having HU <750 easily fragment. Mixed calcium oxalate and cystine stones have HU <1000, these stones are ESWL resistant because of their greater deformation capability and higher resistance to crack propagation. Ductile stones (smooth cystine calculi) can absorb the energy of cavitation jet impact through plastic deformation thus preventing the cavitation damage produced on the anterior surface of stone.

Size and location of stones are the other variables depending on which success of ESWL fairly correlates.

Joseph *et al*., in study of 30 patients, those with calculi <500 HU had complete clearance in 2500 shocks. Stones with 500-1000 HU had clearance rate of 86% and median number of shock waves 3390. Patients with calculi >1000 HU had clearance rate of 55% requiring a median of >3000 shock waves.[13]

Motley *et al*. concluded that there is no significant difference between density values of calcium oxalate and calcium phosphate calculus.[14]

Pareek *et al*. correlated calculus density with clearance in 50 patients. 36% of patients had residual calculi with their mean density of >900 HU compared to 74% clearance with mean density of 500 HU.[15]

A total of 100 patients with renal calculi measuring between 8 and 35 mm were included in our study. The stone density measured on NCCT and mean density value obtained. All patients were treated with ESWL, and the susceptibility of renal stone to fragmentation was correlated with stone density and its chemical composition.

The overall success rate of ESWL was 80% in our study. 68/100 patients with <750 HU had 100% stone fragmentation and clearance. 12/100 patients with 750-100 HU had 59% stone fragmentation and clearance in the II sitting and 41% had stone fragmentation and clearance in III sitting (retreatment with ESWL needed). 20/100 patients with HU >1000 had significant residual fragment even after III sitting ESWL (auxiliary procedures needed) (there was a statistically significant difference with $P < 0.001$).

Comparing stone size with ESWL fragility, even though stone size >2.5 cm, if the stone density is <750 HU stone fragmentation is 100%.

Even if the stone size <15 mm, a stone density of >1000 HU shows poor fragmentation with ESWL.

On stone composition analysis, uric acid and struvite stones had fragmented completely in the I sitting. The chemical composition of mixed renal stones did not correlate with attenuation value of stone.

CONCLUSION

For stones with HU <750 and stone size even up to 3.5 cm, SFR of 100% can be achieved with ESWL. For stones with 750-1000 HU, patient may need re-treatment (multiple sittings ESWL). For stones with HU >1000, other modalities of treatment (endoscopic and open stone surgery) are preferable to ESWL. NCCT estimation of stone density by HU predicts the successful outcome of ESWL therapy.

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