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# Predictors of Successful Urinary Stone Treatment by Extracorporeal Shockwave Lithotripsy

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## Abstract

**Background** In spite of the recent advances in the endoscopic treatment of urinary stones, extracorporeal shock wave lithotripsy (ESWL) is still the treatment of choice for most renal and upper ureteric stones; however the outcome depends on multiple factors.

**Objective** To investigate the effects of stone density, as measured by Hounsfield Units (HU) by non-contrasted computerized tomography (CT), stone size and stone location on ESWL treatment outcome of urinary calculi.

**Methods** A prospective study that included 65 patients. Data collection and patient evaluation were performed in Al-Salam Teaching Hospital in Mosul, in the period from March 2012 to December 2012. Patients were submitted to clinical, biochemical and radiological assessments followed by ESWL treatment. Statistical analyses using chi-square, analysis of variance (ANOVA), correlation, regression were performed for statistical significance between ESWL treatment, stone fragmentation and stone density, size and location in the renal pelvicalyseal system.

***Results*** ESWL success rate was high (92%) for low density stones (< 500 HU). ESWL treatment outcome and stone size were inversely related. CT stone densities of 700 HU or less were almost always successfully treated by ESWL. CT stone density and stone size combined account for nearly 74% of the variation in the number of shock waves required to attain fragmentation. Stones located in lower calyceal area had less success rates.

**Conclusion** Stone density measurement is helpful to predict the success of ESWL for urinary stones, stones with higher density, large size and lower location may better be managed by percutaneous nephrolithotomy or endoscopic procedures.

**Key words** CT stone density, ESWL, none contrasted CT scan (NCCT).

## Introduction

In spite of the recent advances in the endoscopic treatment of urinary stones, extracorporeal shock wave lithotripsy (ESWL) is still the first mode of treatment for most renal and upper ureteric stones especially those with size range of 10-20 mm [(1)]. The success rate of this treatment modality is in the range of 60-90% in various series [(2-5)]. Different techniques have been used to determine the chemical composition of urinary calculi *in vivo* as it is considered a valuable factor determining the outcome of ESWL [(6)]. However, the outcome of ESWL treatment depends on many factors including; stone size, site, composition and the presence of obstruction or infection [(7)]. Nowadays, Non-Contrasted Computerized Tomography (NCCT) is the best diagnostic modality to evaluate renal colic, to distinguish radiolucent urinary stones from tumors or blood clots and to diagnose renal calculi with high sensitivity and specificity of over 90% [8-13]. The ability of NCCT to detect density differences as low as 0.5% has been used to determine the composition and fragility of urinary stones, and hence the outcome of ESWL [14]. In previous studies, the NCCT attenuation value of urinary calculi has been investigated as a method to predict the outcome of ESWL for two main purposes: avoiding the extra medical costs associated with nonproductive exposure of renal tissue to ESWL sessions, and seeking alternative patient management strategies [15-17].

The objective of this study was to investigate the effects of stone density ((as measured by Hounsfield Units (HU) on NCCT)), stone size, and stone location on ESWL outcome and stone fragmentation of urinary calculi.

## Methods

This is a prospective study that included 75 patients initially, however 10 patients were excluded due to elevated creatinine levels (more than 2 mg/dL), bleeding diathesis or obstructed kidney. Thus, the analyses, results and conclusions of this study were based on 65 patients who were prospectively followed at Al-Salam Teaching Hospital in Mosul from March 2012 to December 2012.

All 65 patients had initially undergone clinical, biochemical and radiological assessments before ESWL treatment sessions. Of the 65 patients, 38 were males (58%) and 27 were females (42%), mean age of 42 ± 17 years (17-76).

Urinary stone sizes ranged between 5-25 mm; of which 8 were located in the upper calyx, 9 in the mid calyx, 17 in the lower calyx, 24 in the renal pelvis and seven in the upper ureter. Fifteen patients had stone sizes less than or equal 10 mm, thirty patients had stone sizes of 11-20 mm, while the rest (20 patients) had stone sizes of 21-30 mm.

The maximal linear diameter of the stone was measured by NCCT scan. NCCT scan using contiguous three-millimeter section slices through the stone was performed and viewed on soft tissue setting (window width 350; window level 150 HU). Siemens Somatom Plus 4 scanner, at 120 kV and 206 mA, was used at a scan rate of one second per image. A pixel map of the largest region of interest within the stone was performed and consisted of 100 attenuation values in a 10 x 10 matrix; with each value on the pixel map representing the attenuation value for four pixels. The lowest, highest and most common attenuation values were recorded and the mean stone attenuation value was then calculated.

ESWLs of all patients were undertaken by the same staff using Siemens Electromagnetic Lithostar Multiline Lithotripter with fragmentation performed under fluoroscopic or ultrasonographic guidance.

A maximum of 2800 shock waves were delivered in each treatment session with maximum energy level of four. ESWL treatment was terminated if satisfactory fragmentation was noted earlier before delivering the maximum number of shocks (i.e., 2800) and before reaching the maximum number of ESWL sessions (i.e.,) 4 sessions.

Patients underwent plain x-ray or ultrasound 3 weeks after each ESWL session to determine if there is no stone fragmentation or if there are significant residual fragments (≥ 5 mm) which warrants another ESWL session.

The maximum number of ESWL sessions was 4 and the maximum duration of follow up was 12 weeks after which there is either complete stone clearance or failure of ESWL signifying failure of stone fragmentation or the presence of significant residual fragments (≥ 5 mm).

This failure of ESWL treatment indicates the need for another treatment option. Patients who achieved complete stone clearance underwent plain x-ray or ultrasound 6 weeks after treatment completion for final assessment of outcome.

In 16 patients with stones larger than 20 mm, or lower calyx stones larger than 15 mm, J.J. stent was inserted prior to ESWL. Thus the 65 patients were divided into two groups according to the outcomes of ESWLs.

The "success group" comprised patients who had successful stone fragmentation and subsequent stone clearance. The "failure group" comprised patients who failed to clear the stone because fragmentation either did not occur at all or did occur, but, with significant residual fragments (5 mm or larger in size).

Statistical analyses including chi-square, analysis of variance (ANOVA), correlation, regression and 95% confidence intervals were performed on the data to test the statistical significance of the various relationships between ESWL outcome and stone fragmentation on one side, stone density, size and location on the other side.

## Results

The characteristics of both groups are shown in Table 1. The mean stone diameter of the failure group was marginally larger though statistically insignificant *($P$ =* 0.577). The mean stone density, of the failure group was nearly 60% larger than that of the success group; 1075 HU compared to 675 *($P$* = 0.000). On average, the failure group had received 2.6 ESWL treatment sessions compared to only 1.4 sessions in the success group; a difference of nearly 86%. On average, nearly 7200 shock waves were delivered to the failure group compared to only nearly 4000 in the success group (both $P$-values = 0.000).

**Table 1. Characteristics of ESWL treatment outcome groups**

| Variable | Variable mean and (standard deviation) | | | P Value |
|---|---|---|---|---|
| | Success group N = 46 | Failure group N = 19 | Both groups N = 65 | |
| Age (years) | 42.7 (17.4) | 42.0 (17.3) | 42.5 (17.2) | 0.770 |
| Stone diameter (mm) | 18.3 (6.6) | 18.8 (6.8) | 18.4 (6.7) | 0.577 |
| CT Stone Density (Hounsfield units) | 675 (285) | 1075 (255) | 785 (332) | <0.001 |
| Number of ESWL treatment sessions | 1.4 (0.7) | 2.6 (0.9) | 1.8 (0.9) | <0.001 |
| No. of shock waves until fragmentation | 4015 (1830) | 7218 (2525) | 4950 (2510) | <0.001 |

**Stone Density**

The patients were further analyzed by dividing them into three groups according to stone density. The "low density group" comprised all patients with stone densities of less than 500 HU, the "medium density group" comprised all patients with stone densities of 500-1000, while, the "high density group" comprised all patients with stone densities of more than 1000. ESWL treatment outcomes, according to stone density levels are shown in Table 2 showing high success rate in low density group (94% ), A chi-square test analysis revealed statistically significant association between ESWL treatment outcome and stone density (chi-square = 12.4, df = 2, $P$ = 0.002).

**Table 2. ESWL treatment outcome according to CT stone density**

| CT stone density level (Hounsfield units) | Number of Patients (and %) with | | |
|---|---|---|---|
| | Stone clearance (Success) | Non-stone clearance (Failure) | Total number |
| Low density group (< 500) | 15 (94%) | 1 (6%) | 16 (100%) |
| Medium density group (500-1000) | 22 (73%) | 8 (27%) | 30 (100%) |
| High density group (> 1000) | 6 (32%) | 13 (68%) | 19 (100%) |
| Total | 43 (66%) | 22 (34%) | 65 (100%) |

### Stone Size

The patients were also analyzed by dividing them into three groups according to stone diameter. The "low diameter group": stone diameters of 10 mm or less, the "medium diameter group": 11-20 mm, while, the "high diameter group": 21-30 mm. The ESWL treatment outcomes, in terms of success or failure of stone clearance, according to these three stone diameter levels are shown in Table 3. The success rates achieved were 93%, 73% and 45% for lower, medium and larger size groups respectively (chi-square = 6.8, df = 2, *P* = 0.032). A positive correlation between the stone diameter in millimeters and the number of shock waves delivered was noted r = 0.32, (*P* = 0.008).

**Table 3. ESWL treatment outcome according to stone size**

| Stone diameter (Millimeters) | Number of Patients (and %) with | | |
|---|---|---|---|
| | Stone clearance (Success) | Non-stone clearance (Failure) | Total number |
| Low diameter group (0-10 mm) | 14 (93%) | 1 (7%) | 15 (100%) |
| Medium diameter group (11-20 mm) | 22 (73%) | 8 (27%) | 30 (100%) |
| High diameter group (21-30) | 9 (45%) | 11 (55%) | 20(100%) |
| Total | 45 (69%) | 20 (31%) | 65 (100%) |

### Stone Site

Patients were stratified into two groups according to stone site; "lower calyceal group" included all patients with lower calyceal stones, and "other group" included the rest of patients. The ESWL treatment outcomes, in terms of success or failure of stone clearance, according to these two stone sites ("lower calyceal" or "other") are shown in Table 4. The success of ESWL treatment was only 35% in the lower calyceal stone site group compared to 75% in the case of other stone sites (chi-square = 6.3, df=1, P-value = 0.011). Regression analysis was also performed & it revealed that stone density alone accounts for nearly 70% of the variation in the number of shock waves required to attain fragmentation, while both, stone density and stone size combined, account for nearly 74% of the variation.

**Table 4. ESWL treatment outcome according to stone site**

| Stone site | Number of Patients (and %) with | | |
|---|---|---|---|
| | Stone clearance (Success) | Non-stone clearance (Failure) | Total number |
| Lower calyceal | 6 (35%) | 11 (65%) | 17 (100%) |
| Other | 36 (75%) | 12 (25%) | 48 (100%) |
| Total | 42 (65%) | 23 (35%) | 65 (100%) |

Our data also indicate that stone density in the success group is nearly 700 HU; indicating successful treatment by ESWL below this level and failure above 900 HU. The successful outcome was also observed with stone size of nearly 15.5 mm or less, with 1.7 maximum numbers of sessions and up to 4600 shock waves (Table 5).

**Table 5. Means and 95% Probability Confidence Intervals**

| Variable | | Mean | 95% Confidence Interval | |
|---|---|---|---|---|
| | | | Lower bound | Upper bound |
| Stone density (Hounsfield units) | Success group | 675 | 570 | 710 |
| | Failure group | 1075 | 905 | 1202 |
| Stone Size (Diameter in millimeters) | Success group | 18.3 | 15.6 | 20.2 |
| | Failure group | 18.8 | 15.7 | 22.5 |
| Number of treatment sessions | Success group | 1.4 | 1.2 | 1.7 |
| | Failure group | 2.6 | 2.2 | 2.9 |
| Number of shock waves | Success group | 4015 | 3412 | 4620 |
| | Failure group | 7218 | 6270 | 8160 |

## Discussion

ESWL is still considered the best treatment for calculi less than 20 mm. The success rate is in the range of 60-90% in various series but the outcome of this therapy depends on different factors including stone composition, stone location, pelvicalyceal anatomy and stone size [15,17,18]. The success rate of ESWL for renal and upper ureteral calculi in Iraqi patients has been evaluated in some studies and is comparable to the other series, ranging between 60-85% and it is inversely related to stone size [3-5]. These studies described the effect of stone size on the success rate of ESWL but they didn't consider other factors as stone density and stone location in the urinary tract, therefore, further studies are needed to assess the effect of these factors on the success rate of ESWL in Iraqi patients. Stone composition seems to play the most important role in the outcome of treatment, however, still it cannot be known accurately before stone retrieval and analysis. The crystals excreted in urine after ESWL can give an idea about stone composition.

Plain x-ray has been used to predict the outcome of ESWL treatment by comparing stone density with bone density. However, this method has some disadvantages since the stone diameter and appearance might not be measured accurately, especially in the presence of bowel gas interference or neighboring bony structures and the density measurement is subjective [2]. In this study, we used plain CT scan which is a non invasive technique and provides greater density discrimination than plain x-ray. CT scan is more accurate in the evaluation of urinary stones [19]. It can distinguish density differences as low as 0.5% compared to only 5% discrimination using plain x-ray [2,7]. Recently, it is reported that the use of dual-energy multidetector CT can improve the detection of renal stone composition [20]. Joseph et al [2] suggested that stones with CT attenuation value of greater than 950 HU and stones required 7500 shockwaves failed to achieve fragmentation. Gupta et al [21] showed that the worst outcome of ESWL was in patients with calculus densities of more than 750 HU and diameters of more than 1.1 cm, and their clearance rate were only 60%. In our study, the success of ESWL treatment is almost always guaranteed when the CT attenuation value is less than 700 HU, while, at the same time, treatment failure is almost certain when the CT attenuation value exceeds 900. This is comparable to the results of recent studies [17,22,23]. Stone densities in the range of 700-900 HU may, or may not, respond successfully to ESWL treatment. Unlike Gupta et al [21], this study found that stone densities of more than 700 HU may fail to respond successfully to ESWL treatment. In addition, contrary to Gupta et al [21], this study revealed that stone diameters of up to 20 mm may still (depending on stone density) respond successfully to ESWL treatment. Contrary to Joseph et al [2], the results of this study clearly reveal that stones with densities exceeding 900 HU are difficult to fragment. However, unlike Joseph et al [2], up to

4600 shock waves may be attempted before seeking other types of treatment (i. e., percutaneous nephrolithotomy). Even though the results of this study have identified both stone density and size as significant contributors to ESWL treatment success rate, it also revealed that stone density is the determinant factor of treatment success for stone sizes of 20 mm or smaller.

To date, few clinical studies have compared the stone density with the outcome of ESWL *in vivo*. In a study of 65 patients, Joseph et al [2] showed that stones with densities less than 500 HU have 94% clearance rate and required a median of 2800 shockwaves, patients with stone densities of 500-1000 HU have 76% clearance rate and required a median of 3700 shockwaves, and patients with stone densities more than 1000 HU have 42% clearance rate and required a median of 7800 shockwaves.

Pareek et al [24] correlated calculus density with stone clearance in their study of 100 patients. They concluded that patients with residual calculi had a mean calculus density of more than 900 HU. However; Pareek et al [24] did not correlate the calculus density with fragmentation. The results of our study concurs with Pareek et al results in that stone clearance is unlikely when stone density exceeds 900 HU

The results of this study supports those of Joseph et al [2] in that stone density has an inverse relation with the ESWL success rate, and CT stone density has a positive correlation with the number of shockwaves needed for fragmentation. Also, the results of this study concurs with the results of previous studies [25-27] in that stone location has a significant effect on fragmentation success and clearance with lower calyceal stones have less success rates compared to other locations.

This study has some limitations including the limited number of the patients; therefore, larger number of patients is needed to achieve more significant results in the future studies. The other parameter was the study of stone chemical composition which can be predicted by measuring the density of urinary calculi using the dual–energy multidetector CT scan. This parameter was not assessed in our study because such types of CT scan are not yet widely available.

In this study, we recommend using non contrast CT (NCCT) scan as an initial diagnostic test to evaluate acute flank pain. Also it can be used to assess urinary stones prior to ESWL especially in patients with recurrent urinary stones as it is helpful to determine stone size and location and more importantly, stone density. This is valuable to choose the appropriate treatment option and to predict the success of ESWL to avoid unnecessary nonproductive ESWL.

In conclusion, ESWL treatment outcome is strongly, but inversely, dependent on stone density. Stones with CT densities of 700 HU or less undergo successful treatment requiring lesser number of shock waves and sessions, contrary to stones with CT densities more than 900 HU Large stones more than 2 cm and stones with lower calyceal location are resistant to ESWL.

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