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ORIGINAL PAPER

# Is the gravity effect of radiographic anatomic features enough to justify stone clearance or fragments retention following extracorporeal shock wave lithotripsy (SWL)

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**Abstract** We determined whether the gravity effect of radiographic anatomic features on the preoperative urography (IVP) are enough to predict fragments clearance after shock wave lithotripsy (SWL). A Total of 282 patients with mean age 45.8 ± 13.2 years (189 male, 93 female), who underwent SWL due to renal calculi between October 2005 and August 2009 were enrolled. The mean calculi load was 155.72 ± 127.66 mm$^2$. The patients were stratified into three groups: patients with pelvis calculi (group 1); patients with upper or middle pole calculi (group 2) and patients with lower pole calculi (group 3). Three angles on the pretreatment IVP were measured: the inner angle between the axis of the lower pole infundibular and ureteropelvic axis (angle I); the inner angle between the lower pole infundibular axis and main axis of pelvis-ureteropelvic (UP) junction point (angle II) and the inner angle between the lower pole infundibular axis and perpendicular line (angle III). Multivariate analysis was used to define the significant predictors of stone clearance. The overall success rate was 85.81%. All angles, sessions number, shock waves number and stone burden were significant predictors of success in patients in group 1. However, in group 2 only angle II and in group 3 angles I and II had significant effect on stone clearance. Radiographic anatomic features have significant role in determining the stone-free rate following satisfactory fragmentation of renal stones with SWL. The measurement of infundibulopelvic angle in different manner helps to predict the stone-free status in patients with renal calculi located not only in lower pole, but also in renal pelvis and upper or middle pole. Gravity effect is not enough to justify the significant influence of the radiographic anatomic features on the stone clearance and fragments retention after SWL.

**Keywords** Urolithiasis · SWL · Renal anatomic features · Gravity

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## Introduction

Urolithiasis is a common disorder affecting 2–3% of the population in the developed countries [1]. In the guidelines of American Urology Association (AUA) and European Association of Urology (EUA) for renal calculi, shock wave lithotripsy (SWL) recommended as the first line treatment option when the largest diameter of the stone is <20 mm [1, 2]. It is well established that there are many factors which significantly influence the efficacy of SWL. The key factor is the satisfactory fragmentation of calculi that can then pass spontaneously. The clearance rate of lower pole caliceal calculi has been uniformly low compared to that of calculi elsewhere. This low clearance rate is more a problem of retention of the fragments rather than stone disintegration. Therefore, the reason for fragments retention in the lower pole after SWL became an area of interest. Caliceal anatomy of the lower pole and its possible impact on stone clearance with SWL were first described by Sampaio and Aragao [3, 4]. Elbahnasy et al. [5] measured radiographic anatomical features in a well-defined manner to establish the significance of its influence on the clearance of inferior caliceal calculi following SWL or ureteroscopy. In this retrospective study, we determined the gravity-related radiographic anatomic features of both; lower pole and renal pelvis, and defined how these factors influence renal calculi clearance after lithotripsy.

## Materials and methods

Between October 2005 and August 2009, the clinical records of consecutive patients who underwent SWL due to solitary renal calculi were retrospectively evaluated. Complete data were available on 282 patients (189 male, 93 female), with the mean age of 45.8 ± 13.2 years. The mean stones area was 155.72 ± 127.66 mm$^2$. Area was calculated by multiplying the maximum diameter (length) with the next maximum width dimension perpendicular to the maximum diameters as seen on the plain abdominal X-ray. The study group was divided into three subgroups based on calculi location: patients with renal pelvis calculi (group 1, 160 patients), patients with middle or upper pole calculi (group 2, 89 patients), and patients with lower pole calculi (group 3, 33 patients) (Table 1). All groups were homogenous in terms of ages, angles, stones area, total number of shock waves, sessions number and the presence of hydronephrosis ($p > 0.05$) (Table 1). Hydronephrosis degree (mild, moderate, severe) was defined on IVP and no case with severe hydronephrosis was present. The inclusion criteria: primary cases with radio-opaque renal stone, satisfactory disintegration of the stone, normal renal function, no stenting, no previous renal surgery and no major renal abnormalities. Satisfactory disintegration was defined as complete fragmentations of the stone on fluoroscopy at the last session of SWL that then can pass spontaneously. The patients were treated with hydraulic lithotripter (ELMED, Turkey) on an outpatient basis. No anesthesia was given, however non-steroidal analgesics were administered when necessary. Patients were evaluated by plain film of the kidney, ureters and bladder (KUB), IVP, urine analysis, urine culture, serum biochemistry and coagulation test before the procedure. Treatment was initiated with 13 kv, and the energy was gradually increased up to 19 kv. Therapy was terminated when complete fragmentation of the stone was noted on fluoroscopy. All patients were evaluated after 3 months of the last session. The success was defined as complete absence of the fragments more than 4 mm at the plain abdominal X-rays. Three angles on the pretreatment IVP were measured (Fig. 1). The first angle was measured as an inner angle between the central axis of the lower pole infundibulum and ureteropelvic axis (angle 1) defined by Elbahnasy et al. [5], angle II was the inner angle between lower pole infundibular axis and main axis of pelvis-UP junction point and angle III was the inner angle between lower pole infundibular axis and perpendicular line (Fig. 1). Data retrospectively analyzed included stone area, session number, shock waves number, presence of hydronephrosis and renal anatomy. Significant predictors of stone clearance were determined for each group. Factors found to be significant using the Chi-square test were further analyzed using multivariate regression analysis.

### Statistical analysis

Comparison between the parameters of subgroups was calculated by Student's $t$ test, 1 and 2-way analysis of variance (ANOVA), and Chi-square tests. Multivariate analysis was used to determine the predictor factor of success rate. ROC curve and Youden index were used for calculating optimal cutoff values for angles. SPSS for windows 10.0 statistical packet was used in statistical analysis. $p$ values more than 0.05 were accepted as insignificant.

## Results

Out of the study group, 242 patients became stone free 85.81%. The stone-free rate for groups 1, 2 and 3 was (140/160, 87.5%), (77/89, 86.51%) and (25/33, 75.75%), respectively. In overall patients, angles I, II, and III, stone area, sessions number and total number of shock waves were significant predictors of success ($p < 0.05$). However, age, sex and presence of hydronephrosis were not ($p > 0.05$). The predictors of success showed variations in the subgroups. In group 1, except for angle III ($p = 0.053$), angles I and II as well as stone area, sessions number and number of shockwaves had significant influence on success ($p < 0.05$). However, in group 2 only angle II and in group 3 angle I and angle II were of determinant influence at stone clearance after lithotripsy ($p < 0.05$). ROC curve and Youden index were used for calculating optimal cutoff values for angles. The cutoff values for angles I, II and III were 64, 103 and 42°, respectively (Table 2). The mean value of angle 1 for successes was 69.6°compared to 60.6° for failures ($p < 0.001$). Similarly, the mean value of angle II was 112.9° for successes and 96.7°for failures ($p < 0.001$). Angle III showed a little difference between the mean values of successes and failures; 44.39°and 40.9°, respectively ($p = 0.046$). Complete comparison between the mean values of the parameters for stone-free patients and those with residual fragments are shown in Table 3. There were significant differences between all predictors of success in patients in the success and failure groups; stone burden, angle 1, angle 2, angle 3, sessions number and mean values of total shock waves number. About three sessions were needed for the majority of patients (242 patients, 85.81%) to be stone free. Age and presence of

**Table 1** The mean values of the demographic characteristic of the patients

| | *N* | Age | Sex (m/f) | Session (*n*) | Angle (1) | Angle (2) | Angle (3) | Total number of shockwaves | Area (mm) | Presence of hydronephrosis (*n*) |
|---|---|---|---|---|---|---|---|---|---|---|
| Group (1) | 160 | 46.4 | 107/53 | 3.78 | 64.5 | 104.60 | 42.40 | 10021 | 160.60 | 87 (54.37) |
| Group (2) | 89 | 45.5 | 56/33 | 4.33 | 65.98 | 104.60 | 41.8 | 10684 | 147.76 | 44 (49.43) |
| Group (3) | 33 | 39.4 | 26/7 | 3.59 | 67.00 | 108.59 | 46.59 | 9346 | 144.94 | 12 (36.36) |
| *P* | | 0.07 | 0.56 | 0.79 | 0.61 | 0.48 | 0.24 | 0.71 | 0.77 | 0.34 |

ANOVA test used for comparison of age, session, angles 1, 2, and 3, number of shockwaves and area of stone

Chi-square test was used for comparison of sex and hydronephrosis

*n* Number of patients, *m/f* male/female

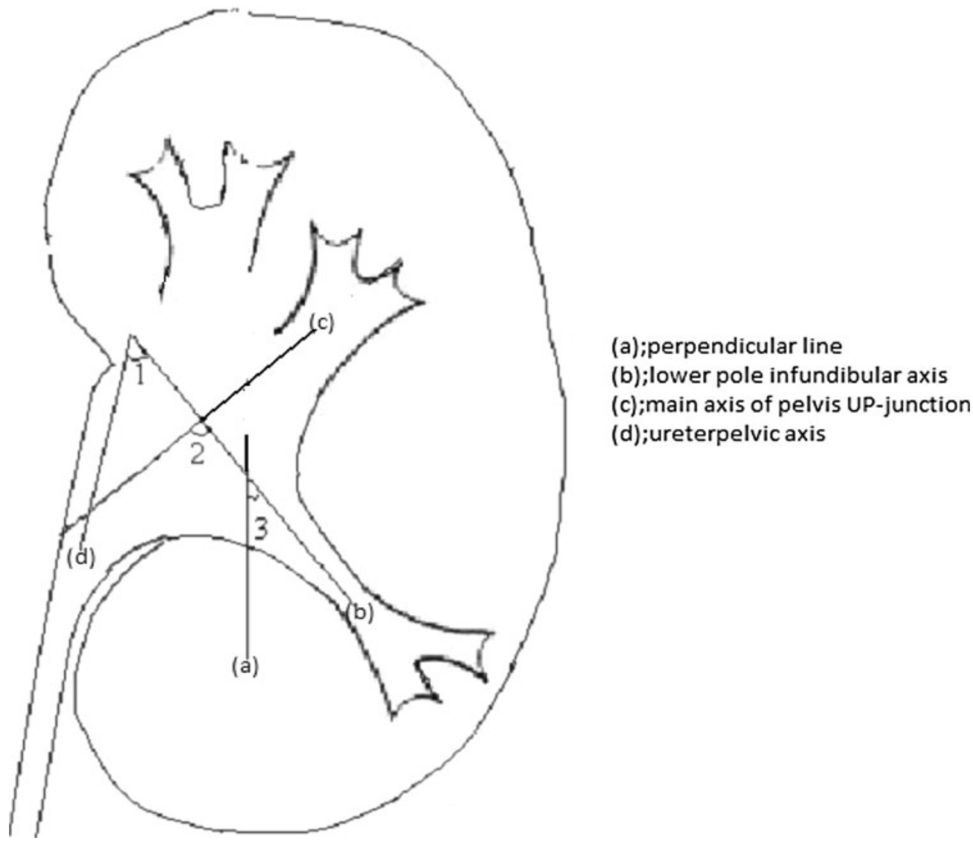


**Fig. 1** Method of measuring angles, Angle 1: between the axis of the lower pole infundibulum (*b*) and ureteropelvic axis (*d*); angle 2: between lower pole infundibular axis (*b*) and main axis of pelvis-UP junction point (*c*); angle 3: between lower pole infundibular axis (*b*) and perpendicular line (*a*)

hydronephrosis had no significant impact on stone clearance, thus they were similar in both groups of success and failure (Table 3).

## Discussion

Since the first clinical application of SWL by Chausy et al. [6], SWL has been established as the preferred treatment modality for the majority of the upper urinary tract stone diseases. Treatment outcome after lithotripsy depends on several factors. The type of lithotripter, stone characteristics such as size, location, number and composition, renal anatomy and renal function are the important factors for determining treatment characteristics and outcomes. The majority of the studies which reported the effect of anatomic features on the lower pole stone clearance after lithotripsy investigated the impact of lower caliceal anatomy, e.g. infundibular length, width and infundibulopelvic angle [4, 7]. Elbahnasy et al. [5] were the first to report the significant influence of radiographic anatomic feature on the stone clearance after SWL or ureteroscopy. Subsequently, others described the effect of the anatomic features of the lower calics on the stone clearance of the lower pole stones [7–10]. Herein, we determined the gravity-related radiographic features of lower pole and renal pelvis and investigated the probable effect of these features on the stone clearance not only in patients with lower pole stones

**Table 2** The cutoff values for the three angles and the success rates

| Cutoff values (angle, degree) | Clearance | | Failure | | Q-square | $p$ |
|---|---|---|---|---|---|---|
| | ($n$) | % | ($n$) | % | | |
| Angle 1 | | | | | | |
| ≤64 | 36 | 27.3 | 96 | 72.7 | | |
| >64 | 108 | 72.0 | 42 | 28.0 | 28.1 | <0.001 |
| Angle 2 | | | | | | |
| ≤103 | 22 | 16.6 | 110 | 83.3 | | |
| >103 | 122 | 81.3 | 28 | 18.6 | 58.74 | <0.001 |
| Angle 3 | | | | | | |
| ≤42 | 62 | 42.5 | 84 | 57.5 | | |
| >42 | 82 | 60.3 | 54 | 39.7 | 4.4 | 0.034 |

ROC curve and Youden index were used for calculating optimal cutoff values for angles

Chi-square test was used to calculate the significant difference between the success rates for patients located below and above the cutoff value of each angle

*n* Number of patients

**Table 3** Comparison between the variables of stone-free patients and those with residual fragments

| Variables | Clearance Mean ± SD | Failure Mean ± SD | $p$ |
|---|---|---|---|
| Age (year) | 45.58 ± 13.35 | 46.1 ± 12.96 | 0.826* |
| Area ($mm^2$) | 115.1 ± 105.44 | 198.12 ± 135.55 | <0.001* |
| Angle 1 (°) | 69.6 ± 11.12 | 60.68 ± 9.6 | <0.001* |
| Angle 2 (°) | 112.9 + 10.83 | 96.72 ± 9.47 | <0.001* |
| Angle 3 (°) | 44.39 ± 11.53 | 40.96 ± 8.43 | 0.046* |
| Sessions number ($n$) | 3.00 ± 2.12 | 4.93 ± 1.75 | <0.001* |
| Mean value of shock waves number ($n$) | 7461.11 ± 5454.34 | 12952.77 ± 5229.88 | <0.001* |
| Presence of hydronephrosis ($n$) | 74 | 69 | 0.802** |

* T-test and Chi-square test** were used for statistical evaluation

*SD* Standard deviation

but also in patients with renal calculi located in renal pelvis or in other poles of the kidney. Angle 1 was first defined and used by Elbahnasy et al. [5] and the stone clearance has been shown to be a poorer for an actually angled than an obtusely angled inferior calics. This can be justified by the high gravity effect on the retention of the fragments in case of acute angle. Similarly, in our study, the more acute angle the less success; the mean values of the angle for successes and failures were 69.6° and 60.6°, respectively ($p < 0.001$) (Table 2). The cutoff value for angle 1 was 64°. Out of 150 patients who have angle 1 more than 64°, 108 patients (72%) became stone free. The angle between lower pole infundibular central axis and main axis of pelvis-UP junction point (angle II) was noticeably different from others. The reason for this discrepancy in some reports was due to the difference in methodology of measurement of the angle [5, 11]. There are three different methods reported for determining infundibulopelvic angle, but in most of the studies the infundibulopelvic angle was the angle subtended by the lower pole infundibular axis and renal pelvis axes, similar to that of Elbahnasy et al. [5]. However, Gupta et al. [7] defined infundibulopelvic angle as the inner angle between lower pole infundibular axis and ureteropelvic axis. In our study, we aimed from this discrepancy in the measurement of infundibulopelvic angle (angle II) to define the relation of renal pelvis with lower pole and UP junction. We believe that UP junction is important as that as infundibulum of lower pole, because after successful fragmentation of renal stone the fragments either pass to ureter via UP junction or go back to lower pole via infundibulum. The mean values of angle II for success were 112.9° and 96.7° for failure ($p < 0.001$) and the cutoff values of angle II was 103° e.g. 150 patients had values more than 103° and 122 of them (81.3%) became stone free. Up to our knowledge we are the first who reported the measurement of the second angle and its influence on the stone clearance in patients with various locations of renal stones.

Angle III was weak predictor of success after lithotripsy. The mean values of angle for successes and failures were 44.39° and 40.9°, respectively ($p = 0.046$). The cutoff value was 42°, e.g. the success rate for patients with angle more than 42° was 60.3%, and the success rate for those with values <42° was 42.5% ($p = 0.034$). Angle III measured the perpendicularity of the lower pole thus it is expected to reflect the gravity effect on retention of the fragments in the lower pole. So as angle III was of low influence of the stone clearance it is difficult to only justify the retention of the fragments in lower pole by the gravity. Sampaio [10] reported that some special anatomical findings suggest that retention of what are considered to be 'passable stone fragments' (4 mm in diameter or less) in the inferior pole might be a consequence not only of the gravity-dependent position of lower calices, but also of particular anatomical features of the inferior pole collecting system.

Lingeman et al. [12] performed a meta-analysis in 13 published studies on the management of lower calculi with extracorporeal. They reported short-term stone-free rates ranging between 25 and 85%. In our study, the success rate for patients with lower pole stones was 75.75% which is identical to the reported rates. On multivariate analysis, the three angles were found to have significant effect on the stone clearance in overall patients. Thus, the renal morphologies are the important factors in predicting the success rate of SWL not only for patients with lower calics stone, but also for patients with renal stones located in renal pelvis, middle and upper pole. Similarly, this findings correlate with the published date in literature Abdel-Khalek et al. [9] mentioned that radiological renal features are prognostic factors determining stone clearance after SWL of renal calculi and he reported accuracy of 87% of predicting the success after lithotripsy using multivariate regression analysis. Al-Ansari et al. investigated 10 prognostic factors for the success of SWL and he concluded that the success rate of SWL for the treatment of renal stones could be predicted by stone size, location, radiological renal features and congenital renal anomalies. However age, sex, nationality, and ureteric stenting had no such significant impact [13]. Similarly, Tan et al. [14] reported that increased stone burden, multiple stones, staghorn calculi, narrow lower infundibulopelvic angle and longer lower infundibulum are factors that adversely affect the clearance rate.

When evaluating the subgroups separately, variations were found in the factors which influence the success. In group 1, except for angle III ($p = 0.053$), angles I and II, as well as sessions number, total shock waves and stone burden were significant predictor for success ($p < 0.05$). However, in group 2 only angle II and in group 3 angles I and II had significant influence on stone clearance. Angle II defines the relation of renal pelvis with lower pole and UP junction point and it had significant influence on stone clearance in all groups. This means that pelvis anatomy is of crucial effect in fragment elimination, as the renal pelvis forms the passage of all fragments for any renal calculi after SWL. Angle III is of low significant influence for patients with renal pelvis stone, however in patients with lower, upper or middle pole it had not impact on the stone clearance. This means that the perpendicularity or the gravity effect of the lower pole is not the only mechanism which standing behind the retention of the fragments after lithotripsy. This may be why there are some authors like El-Assmmy et al. and Sameh WM et al. who deny the influence of radiographic anatomic features on the stone clearance [15, 16]. If the infundibulopelvic angle reflects only the gravity effect this may not be enough to justify the significant influence of renal anatomy. We believe that beside the gravity effect, there are some factors which affect the elimination of the fragments like urine stream direction toward UP junction which may propel the fragments and peristaltic movement of the muscular layer of the ureter which may have suction effect on the fragments. These factors may be altered by the degree of the angulation of infundibulopelvic angle thus the radiographic features significantly influence the stone clearance.

Although the exact mechanism by which these anatomic features work is not clear, we recommend the measurement of these angles prior to SWL application especially angle II which was a significant predictor of success in all subgroups. To maximize the effect of the gravity on the fragments clearance after SWL therapy, we advise position of standing more than setting or supine position during the day. Angle III which directly measures the gravity effect, fails to explain the retention of fragment in group III. Therefore, further studies should be carried out to define the mechanism that overcomes the gravity effect which can explain the retention of the fragments in the lower pole [10].

## Conclusion

Gravity-related radiographic anatomic features have significant role in determining the stone-free rate following satisfactory fragmentation of renal stone with SWL. However, the gravity alone is not enough to explain the significant influence of radiographic features on the stone clearance or fragments retention following SWL. Using these radiographic parameters, ESWL can be selected as a treatment modality for predictably favourable outcomes in individual cases.

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