Predictive Factors of Lower Calyceal Stone Clearance After Extracorporeal Shockwave Lithotripsy (ESWL): The Impact of Radiological Anatomy

Chih-Chieh Lin[1], Yen-Shen Hsu[1,2]*, Kuang-Kuo Chen[1,2]

[1]*Division of Urology, Department of Surgery, Taipei Veterans General Hospital, and*
[2]*Department of Urology, National Yang-Ming University School of Medicine, Taipei, Taiwan, R.O.C.*

Background: This study was carried out to determine whether or not there is a significant relationship between the radiologic anatomy of the lower calyx, as seen on preoperative intravenous urography (IVU), and the outcome of stone clearance after extracorporeal shockwave lithotripsy (ESWL) for lower renal calyceal stones.

Methods: Between June 1998 and April 2007, 112 patients with a solitary lower renal calyceal stone measuring 20 mm or less in size were enrolled in this retrospective study. Pretreatment IVU was reviewed for measuring the anatomical predictors, such as lower pole infundibular length, infundibular width (IW) and infundibulopelvic angle, while the stone location and size were determined on plain abdominal X-ray. All patients were treated with ESWL using a Siemens Lithostar Plus lithotriptor and were followed-up for the outcome of stone clearance 3 months after ESWL with plain abdominal X-ray films and ultrasonography.

Results: Three months after ESWL, only 49 (43.7%) patients were stone-free. Under multivariate analysis with logistic regression, smaller stone size (10 mm or less, $p=0.005$) and greater IW (4 mm or more, $p=0.029$) were significant favorable predictors for better stone clearance.

Conclusion: In addition to the influence of stone size, lower pole anatomy, especially IW, has a significant impact on stone clearance for lower calyceal stone after ESWL. [*J Chin Med Assoc* 2008;71(10):496–501]

Key Words: extracorporeal shockwave lithotripsy, infundibulopelvic angle, kidney, stone clearance, urolithiasis

Introduction

It is broadly accepted that extracorporeal shockwave lithotripsy (ESWL) is the treatment of choice for renal stones with a maximal length of 2 cm or less.[1] The clearance rate of renal calculi varies, ranging from 45% to 95%.[2] The outcome of stone clearance after ESWL is strongly related to stone disintegration and clearance of the fragments.[3] Stone disintegration is affected by several factors, including stone factors (burden, number, composition), patient factors (obesity, body habitus), operator experience, and machine factor (type of lithotriptor, shock wave number, shock wave energy).[4–7] In addition, the clearance rate of stone fragments is influenced by stone location and patterns of intrarenal collecting system drainage and urinary transport.[8,9] Hence, in 1992, Sampaio and Aragao studied the correlation of lower pole collecting system anatomy and ESWL from cadavers.[10] Lingeman et al demonstrated that the clearance rate of stone fragments was worse over the lower calyces than over the middle or upper calyces.[9] Accordingly, after the measurement of lower calyceal anatomy in intravenous urography (IVU) initially demonstrated by Elbahnasy et al,[11] many authors raised different viewpoints about the measurement of the lower calyceal anatomy. Consequently, the aim of this present study was to comprehensively investigate the influence of spatial anatomical factors of the lower calyx on stone clearance rate.

*Correspondence to: Dr Yen-Shen Hsu, Division of Urology, Department of Surgery, Taipei Veterans General Hospital, 201, Section 2, Shih-Pai Road, Taipei 112, Taiwan, R.O.C.
E-mail: hsuys@vghtpe.gov.tw • Received: August 7, 2008 • Accepted: September 2, 2008

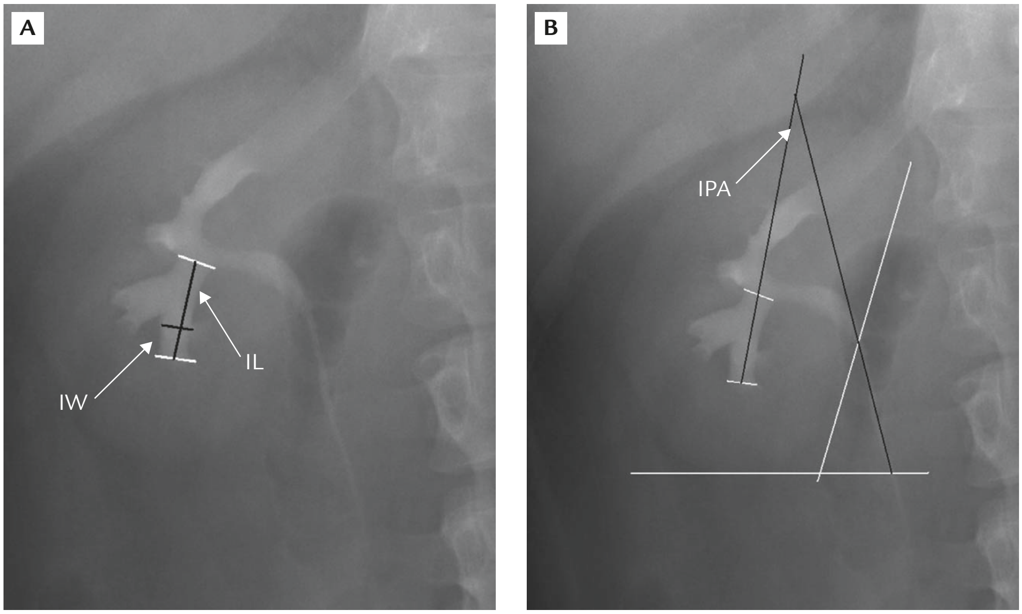

Figure 1. Measurement of lower pole calyceal anatomy. (A) Infundibular width (IW): the narrowest point of the lower calyx; infundibular length (IL): the length of the most distal point of the lower calyx to the midpoint of the opening of the lower calyx into the renal pelvis. (B) Infundibulopelvic angle (IPA). The ureteropelvic axis (black line on right) is derived from the 2 white lines. The black line on the left is the central axis of the lower pole infundibulum.

Methods

From June 1998 to April 2007, a total of 112 patients with a solitary lower calyceal renal stone 20 mm or less in size were enrolled in this retrospective study. Exclusion criteria were horseshoe kidney, severe hydronephrosis, multiple stone location, multiple or branched calyx, stone size larger than 2 cm, acute urinary tract infection, coagulopathy, pregnancy, and follow-up period less than 3 months. In addition, all patients had received pretreatment IVU and had been evaluated by medical history, physical examination, ultrasonography of the urinary tract, and IVU. The stone size and location were reviewed and determined on anteroposterior abdominal plain X-ray of IVU series by Y.S. Hsu. Stone size was defined as the largest diameter of the stone under bi-dimensional film and measured with computer software (*Digital Imaging and Communication in Medicine* [DICOM], third version, American College of Radiology and National Electrical Manufacturers Association).

Also, the spatial anatomic factors of the lower pole of the kidney, such as infundibular length (IL), infundibular width (IW) and infundibulopelvic angle (IPA), were measured in pretreatment IVU with DICOM. Elbahnasy et al proposed the method for measuring these anatomic factors of the lower pole,[11] derived from the concept initially demonstrated by Bagley and Rittenberg in 1987.[12] It was adopted in our study, as shown in Figure 1. IL was defined as the length from the most distal point of the lower calyx, where the targeted stone is located, to the midpoint of both sides of the opening of the lower calyx into the renal pelvis. IW was determined from the narrowest point of the lower calyx. It was defined that the lower pole IPA was the inner angle created by the intersection of 2 lines. The first line, the central axis of the lower pole infundibulum, was drawn by connecting 2 midpoints, the distal part of the lower infundibulum and the opening of the infundibulum into the renal pelvis. The other line, the ureteropelvic axis, was created by connecting the midpoint of the renal pelvis opposite the margins of the superior and inferior renal sinus to the midpoint of the ureter opposite the inferior border of the lower pole of the kidney.

All patients received treatment with ESWL using a Siemens Lithostar Plus lithotriptor (Siemens AG, Berlin and Munich, Germany) under intravenous analgesic sedation with fentanyl. The maximal number of shock waves was estimated to be no more than 3,200, and the targeted stone was noted to be disintegrated into fragments by the operator under fluoroscopic imaging during treatment. The treatment outcome of stone clearance was determined and evaluated with plain abdominal X-ray films and ultrasonography within 3 months after ESWL. Residual stone status was defined as persistent stone fragments larger than 2 mm on plain abdominal X-ray films.

Table 1. Comparison between the stone-free and residual stone groups*

	Total no. of patients	Independent sample t test		
		Stone-free group	Residual stone group	p
Age (yr)	54.0 ± 13.1	48.0 ± 12.2	56.4 ± 14.3	0.201
Stone size (cm)	1.00 ± 0.29	0.89 ± 0.23	1.18 ± 0.39	< 0.001
Infundibular length (mm)	32.5 ± 6.0	31.2 ± 4.2	33.5 ± 6.8	0.044
Infundibular width (mm)	4.2 ± 0.6	4.3 ± 1.2	4.0 ± 0.7	0.053
Infundibulopelvic angle (°)	41.6 ± 5.5	42.4 ± 6.2	41.0 ± 4.7	0.182

Data presented as mean ± standard deviation.

All statistical analyses were performed with SPSS version 12.0.1 (SPSS Inc., Chicago, IL, USA) for Windows. Statistical significance of all stone sizes and anatomical factors, such as IL, IW, IPA, and the ratio of IL and IW, was further compared between the stone-free group and residual stone group by using independent sample t test. Univariate and multivariate analyses of the correlation between success rate of stone clearance and all influencing factors were carried out with χ^2 test or logistic regression model.

Results

The mean age of the 112 patients (84 males, 28 females) was 54 years (range, 23–75 years). Mean stone size over the lower calyx (75 in left kidney, 37 in right kidney) was 1.00 ± 0.29 cm (range, 0.50–1.80 cm). The overall stone clearance rate of these 112 patients was 43.7% (n = 49). The results showed that stone size in the stone-free group (mean, 0.89 cm) was significantly smaller than that in the residual stone group (mean, 1.18 cm; p < 0.001). Regarding the spatial anatomy of the lower poles of the kidney measured in the study, mean IL was 32.5 ± 6.0 mm (range, 2.7–46.1 mm), mean IW was 4.2 ± 0.6 mm (range, 2.6–5.6 mm), and mean IPA was 41.6 ± 5.5° (range, 29–60°). Between the stone-free and residual stone groups, there was no statistically significant difference in IW (p = 0.053) and IPA (p = 0.182), but the IL of the stone-free group (31.2 mm) was significantly shorter than that of the residual stone group (33.5 mm; p = 0.044) (Table 1).

Cut-offs, applied in this study, were created from the mean value of the measured data in the series and then statistically checked by sensitivity test. Consequently, the exact values of the cut-offs were determined and adopted in this series for differentiating between favorable and unfavorable predictors of outcome of stone clearance. Univariate analysis with Pearson's χ^2 test revealed that stone clearance rate in the patients with smaller stone size (< 1 cm; p = 0.01) and widening IW (≥ 4 mm; p = 0.011) were significantly better (Table 2). We further assessed the favorable and unfavorable predictors for success rate of stone clearance with a logistic regression model of multivariate analysis (Table 3). Larger stone size (1–2 cm) showed significantly worse stone clearance rate than smaller stone size (< 1 cm; OR = 0.237, p = 0.005). In addition, under the aspect of lower pole anatomical factors, patients with IW of 4 mm or wider revealed better stone clearance rate than those with IW less than 4 mm (OR = 2.592, p = 0.029). There was no statistically significant influence on stone clearance rate between other predictors, such as patient's gender, stone laterality, IL, and IPA (Table 3).

Discussion

As treatment options for kidney stones have evolved in recent decades, less invasive treatment choices such as percutaneous nephrolithotomy (PCNL) and ESWL have taken the place of traditional open surgical methods.[13] However, the treatment of lower pole calculi, especially for stones larger than 1 cm in size, remains controversial.[9,14,15] The comparison of stone clearance rate between ESWL and more invasive treatments such as PCNL or ureteroscopy was also done by many authors.[16–18] Stone clearance rates of lower pole calculi after ESWL were reported to range from 37% to 96%.[3,16,18–22] Although the overall stone clearance rate was 43.7% in our study, the stone-free rate for the patients with stones smaller than 1 cm was 55.0%.

To improve stone clearance rate after ESWL and further predict the outcome of stone clearance, Sampaio and Aragao proposed the measurement of anatomic features of the lower pole calyx, e.g. the infundibular diameter or width and angle between the lower infundibula and renal pelvis, from 3-dimensional polyester resin endocasts obtained from 73 adult cadavers.[10] They demonstrated that 74% of 146 kidneys had a measured angle greater than 90°, and these anatomic pyelocalyceal features play an important role in stone

Table 2. Patients' demographic data

	Total patients, *n*	Stone-free, *n* (%)	*p*
Gender			0.441
Male	84	35 (41.7)	
Female	28	14 (50.0)	
Stone laterality			0.742
Left	75	32 (42.7)	
Right	37	17 (45.9)	
Stone size (cm)			0.010
< 1	60	33 (55.0)	
1–2	52	16 (30.8)	
Infundibular length (mm)			0.536
< 30	54	22 (40.7)	
≥ 30	58	27 (46.6)	
Infundibular width (mm)			0.011
< 4	47	14 (29.8)	
≥ 4	65	35 (53.8)	
Infundibulopelvic angle (°)			0.943
< 40	59	26 (44.1)	
≥ 40	53	23 (43.4)	

Table 3. Multivariate analysis of variables in stone clearance of inferior calyx after extracorporeal shockwave lithotripsy

Variables	OR	95% CI	*p**
Gender (female *vs.* male)	0.358	0.063–2.205	0.245
Stone laterality (right *vs.* left)	0.918	0.181–4.661	0.917
Stone size (< 1 cm *vs.* 1–2 cm)	0.237	0.087–0.644	0.005
IL (< 30 mm *vs.* ≥ 30 mm)	0.896	0.377–2.129	0.804
IW (< 4 mm *vs.* ≥ 4 mm)	2.592	1.100–6.110	0.029
IPA (< 40° *vs.* ≥ 40°)	0.823	0.349–1.939	0.656

**Logistic regression model. OR = odds ratio; CI = confidence interval; IL = infundibular length; IW = infundibular width; IPA = infundibulopelvic angle.*

clearance rate. However, there existed some problems in measuring the angle in patients. The methods of measurement of IL, IW, and IPA by interpreting IVU as proposed by Elbahnasy et al[11] were applied by many subsequent authors. In addition, they demonstrated the cut-off value of IPA to be 70°. Sorensen and Chandhoke showed that IPA is not a significant predictor of stone clearance after ESWL, and no more than 5 patients had IPA larger than 70°.[20] In our study, the mean IPA was 41.6° (range, 29–60°), and no patients had IPA above 70°. Consequently, we agree with other investigators[16,20,22–26] that IPA is not a statistically significant predictor of the outcome of stone clearance.

Although many investigators, such as Ruggera et al,[3] Sumio et al[19] and Ghoneim et al,[21] believe that there is a positive correlation between lower pole IPA and stone clearance, there are some doubts and errors existing in the measurement of IPA. First, most of these studies were done under 2-dimensional view, such as plain X-ray or IVU, and might be influenced by variations in kidney axis in different patients. Sengupta et al demonstrated that position change between supine and prone made a statistically significant difference in the angulation of the kidney to the median plane of vertebral body.[27] In addition, the mean angulations of anterior and posterior calyces to the renal plane were around 30–40° and, therefore, the angulation between anterior and posterior calyces was estimated to be around 60°. When interpreting and measuring the IPA, some errors could exist in the occasion of projection of calyces onto coronal view, like plain film of IVU. Second, variation in angulation, even in the same patient, could occur due to the patient's respiration and hydration condition of the renal pelvis. Change in kidney axis resulting from respiratory movement and hydration have also been reported in previous articles.[21,23] Consequently, more effort is needed to overcome the errors of variation and different measuring methods.

IL was also not a statistically significant predictor of the outcome of stone clearance in multivariate analysis in the present study ($p=0.804$), as also determined in previous investigations.[20,23,24,26,28] In Ghoneim et al's study, IL was found to be a statistically significant factor, with the cut-off at 50 mm.[21] Nevertheless, there was no patient with IL exceeding 50 mm in our study. The mean IL we found was 32.5 mm (range, 2.7–46.1 mm), which is similar to the mean value reported by Albala et al[16] and Elbahnasy et al.[18] Cut-off analysis of IL was also performed in our study, which was determined to be 30 mm. The possible reason for the difference is that measurement of IL in IVU bears the same problem as measurement of angulation. IL might be underestimated from 3-dimensional anatomical structure to 2-dimensional plain films in IVU.

From the measurement of the 3-dimensional anatomic structure of the lower calyces of cadavers, Sampaio and Aragao found that infundibular diameter < 4 mm was a poor prognostic factor for stone clearance.[10] Cut-off analysis for IW in the present study was also 4 mm. Using a logistic regression model for multivariate analysis in our research, IW ≥ 4 mm was a favorable predictor for better outcome of stone clearance (OR = 2.592, $p=0.029$). There were 2 Asian studies, by Sumio et al[19] and Sabnis et al,[29] which reported that infundibular width or diameter was the significant predictor for outcome of stone clearance, and the cut-off value was also noted to be 4 mm. Moreover, in a Western study, different cut-off values, i.e. 5 mm and 6 mm, were previously proposed.[30] The range of IW was from 2.6 mm to 5.6 mm in this study, and thus it might be strictly confined at the values of 5 mm or 6 mm. Previously, Pace et al[31] investigated the variation in the measurement of IW on routine IVU in individual patients and demonstrated that IW changes with different times, i.e. 5 minutes, 10–20 minutes, compression film, and postvoid film. They described that IW was widest during the compression phase and narrowest during the postvoid phase. However, there existed some doubts in their study as some of the measured calyces were partly normal without stones. It would be more convincing if all the measured calyces in their study had stones in them. In the present study, we measured IW on compression film, the reason being that might be the major influencing timing in the outcome of stone fragments expelled out of the calyces into the renal pelvis. Controversial as it remains in the measurement of IW during the dynamic change resulting from peristalsis, it is supposed that the greater the IW measured in the compression film of IVU, the better the prognosis of clearance of stone fragments.

In conclusion, IW was the only statistically significant predictor of better stone clearance in the present study. Though the influence of the lower calyces on stone clearance remains debatable, more precise measurement of the lower calyces and a decrease in interobserver bias would render more compelling evidence for prediction. We also found that stone size was an important predictor of stone clearance. As revealed in previous articles, PCNL or flexible ureteroscopic lithotripsy should be considered as the initial choice of treatment in patients with calculi that are larger than 1 cm.[9,16] For patients with lower calyceal calculi smaller than 1 cm, ESWL would appear to be the better choice from a cost-effectiveness aspect. Furthermore, patients with IW greater than 4 mm have better stone clearance outcome than patients with IW less than 4 mm.

Acknowledgments

The authors thank Ms Hui-Chen Lee for her valuable assistance in the statistical analyses.

References

1. Tiselius HG, Ackermann D, Alken P, Buck C, Conort P, Gallucci M. Guidelines on urolithiasis. In: *Guidelines of the EAU*. Arnhem, The Netherlands: European Association of Urology, 2001.
2. Clayman RV, McClennan BL, Garvin TJ, Denstedt JD. Lithostar: an electromagnetic acoustic shock wave unit for extracorporeal lithotripsy. *J Endourol* 1989;3:307–10.
3. Ruggera L, Beltrami P, Ballario R, Cavalleri S, Cazzoletti L, Artibani W. Impact of anatomical pyelocalyceal topography in the treatment of renal lower calyces stones with extracorporeal shock wave lithotripsy. *Int J Urol* 2005;12:525–32.
4. Dretler SP. Stone fragility: a new therapeutic distinction. *J Urol* 1988;139:1124–7.
5. Gerber R, Studer UE, Danuser H. Is newer always better? A comparative study of 3 lithotriptor generations. *J Urol* 2005; 173:2013–6.
6. Graber SF, Danuser H, Hochreiter WW, Studer UE. A prospective randomized trial comparing 2 lithotriptors for stone disintegration and induced renal trauma. *J Urol* 2003;169:54–7.
7. Portis AJ, Yan Y, Pattaras JG, Andreoni C, Moore R, Clayman RV. Matched pair analysis of shock wave lithotripsy effectiveness for comparison of lithotriptors. *J Urol* 2003;169:58–62.
8. Schulz E, Hengst E, Brundig P, Haerting R, Pirlich W, Gunther H. Disturbed urinary transport in the pelvi-calyceal system in calcium-oxalate stone patients. *Urol Res* 1987;15:109–13.
9. Lingeman JE, Siegel YI, Steele B, Nyhuis AW, Woods JR. Management of lower pole nephrolithiasis: a critical analysis. *J Urol* 1994;151:663–7.
10. Sampaio FJB, Aragao AHM. Inferior pole collecting system anatomy: its probable role in extracorporeal shock wave lithotripsy. *J Urol* 1992;147:322–4.
11. Elbahnasy AM, Clayman RV, Shalhav AL, Hoenig DM, Chandhoke P, Lingeman JE, Denstedt JD, et al. Lower-pole caliceal stone clearance after shockwave lithotripsy, percutaneous nephrostolithotomy, and flexible ureteroscopy: impact of radiographic spatial anatomy. *J Endourol* 1998;12:113–9.

12. Bagley DH, Rittenberg MH. Intrarenal dimensions: guidelines for flexible ureteropyeloscopes. *Surg Endosc* 1987;1:119–21.
13. Paik ML, Wainstein MA, Spirnak JP, Hampel N, Resnick MI. Current indications for open stone surgery in the treatment of renal and ureteral calculi. *J Urol* 1998;159:374–9.
14. Obek C, Onal B, Kantay K, Kalkan M, Yalçin V, Oner A, Solok V, et al. The efficacy of extracorporeal shock wave lithotripsy for isolated lower pole calculi compared with isolated middle and upper caliceal calculi. *J Urol* 2001;166:2081–4.
15. Turna B, Ekren F, Nazli O, Akbay K, Altay B, Ozyurt C, Cikili N. Comparative results of shockwave lithotripsy for renal calculi in upper, middle, and lower calices. *J Endourol* 2007;21:951–6.
16. Albala DM, Assimos DG, Clayman RV, Denstedt JD, Grasso M, Gutierrez-Aceves J, Kahn RI, et al. Lower pole I: a prospective randomized trial of extracorporeal shock wave lithotripsy and percutaneous nephrostolithotomy for lower pole nephrolithiasis—initial results. *J Urol* 2001;166:2072–80.
17. Pearle MS, Lingeman JE, Leveillee R, Kuo R, Preminger GM, Nadler RB, Macaluso J, et al. Prospective, randomized trial comparing shock wave lithotripsy and ureteroscopy for lower pole caliceal calculi 1 cm or less. *J Urol* 2005;173:2005–9.
18. Elbahnasy AM, Shalhav AL, Hoenig DM, Elashry OM, Smith DS, McDougall EM, Clayman RV. Lower caliceal stone clearance after shock wave lithotripsy or ureteroscopy: the impact of lower pole radiographic anatomy. *J Urol* 1998;159:676–82.
19. Sumio Y, Mimata H, Tasaki Y, Ohno H, Hoshino T, Nomura T, Nomura Y. Predictors of lower pole renal stone clearance after extracorporeal shock wave lithotripsy. *J Urol* 2002;168:1344–7.
20. Sorensen CM, Chandhoke PS. Is lower pole caliceal anatomy predictive of extracorporeal shock wave lithotripsy success for primary lower pole kidney stones? *J Urol* 2002;168:2377–82.
21. Ghoneim IA, Ziada AM, Elkatib SE. Predictive factors of lower calyceal stone clearance after extracorporeal shockwave lithotripsy (ESWL): a focus on the infundibulopelvic anatomy. *Eur Urol* 2005;48:296–302.
22. Juan YS, Chuang SM, Wu WJ, Shen JT, Wang CJ, Huang CH. Impact of lower pole anatomy on stone clearance after shock wave lithotripsy. *Kaohsiung J Med Sci* 2005;21:358–64.
23. Madbouly K, Sheir KZ, Elsobky E. Impact of lower pole renal anatomy on stone clearance after shock wave lithotripsy: fact or fiction? *J Urol* 2001;165:1415–8.
24. Danuser H, Müller R, Descoeudres B, Dobry E, Studer UE. Extracorporeal shock wave lithotripsy of lower calyx calculi: how much is treatment outcome influenced by the anatomy of the collecting system? *Eur Urol* 2007;52:539–46.
25. Fong YK, Peh SO, Ho SH, Ng FC, Quek PL, Ng KK. Lower pole ratio: a new and accurate predicator of lower pole stone clearance after shockwave lithotripsy? *Int J Urol* 2004;11:700–3.
26. Srivastava A, Zaman W, Singh V, Mandhani A, Kumar A, Singh U. Efficacy of extracorporeal shock wave lithotripsy for solitary lower calyceal stone: a statistical model. *BJU Int* 2004;93:364–8.
27. Sengupta S, Donnellan S, Vincent JM, Webb DR. CT analysis of caliceal anatomy in the supine and prone positions. *J Endourol* 2000;14:555–7.
28. Gupta NP, Singh DV, Hemal AK, Mandal S. Infundibulopelvic anatomy and clearance of inferior caliceal calculi with shock wave lithotripsy. *J Urol* 2000;163:24–7.
29. Sabnis RB, Naik K, Patel SH, Desai MR, Bapat SD. Extracorporeal shock wave lithotripsy for lower calyceal stones: can clearance be predicted? *Br J Urol* 1997;80:853–7.
30. Tan MÖ, İrkilata L, Şen İ, Onaran M, Küpeli B, Karaoğlan U, Bozkirli I. The impact of radiological anatomy in clearance of lower caliceal stones after shock wave lithotripsy. *Urol Res* 2007;35:143–7.
31. Pace KT, Weir MJ, Harju M, Tariq N, D'A Honey RJ. Individual patient variation and inter-rater reliability of lower calyceal infundibular width on routine intravenous pyelography. *BJU Int* 2003;92:607–9.