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Treatment of Renal Stones by Extracorporeal Shockwave Lithotripsy

An Update

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Key Words

Kidney calculi · Lithotripsy · Clinically insignificant fragments · Residual fragments

Abstract

Aim: Despite the extensive experience with minimal invasive stone therapy, there are still different views on the ideal management of renal stones.

Materials and Methods: Analysis of the literature includes more than 14,000 patients. We have compared these data with long-term results of two major stone centers in Germany. The results have been compared concerning the anatomical kidney situation, stone size, stone localization and observation time.

Results: According to the importance of residual fragments following extracorporeal shock wave lithotripsy (ESWL), we have to distinguish between clinically insignificant residual fragments and clinically significant residual fragments (CIRF). 24 months following ESWL stone passage occurs as a continous process, and if there are no clinical symptoms, any endoscopic procedure should be considered as overtreatment. According to these results, stone-free rates of patients increase in longer follow-up periods. Newer ESWL technology has increased the percentage of CIRF.

Conclusion: We consider ESWL in most patients with renal calculi as first-line treatment, except in patients with renal calculi bigger than 30 mm in diameter.

Introduction

Management of renal calculi has changed dramatically during the past 20 years. Minimally invasive techniques, especially the development and introduction of extracorporeal shock wave lithotripsy (ESWL), virtually have replaced open surgical stone removal. Even large and complex renal calculi may be treated effectively with these minimally invasive techniques. Surgical removal of renal stones had been reserved for those patients with persistent symptoms or recurrent urinary tract infections associated with the presence of the stone. Except for patients with

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Table 1. Lithotriptors used in thist study

	Generator +focusing	Localization	Focus aperture		Clinical introduction
			mm	cm	
Siemens Lithostar Plus	electromagnetic acoustic lens	coaxial US 2 X-ray tubes	80×6	12	1989
Storz Modulith SL 20	electromagnetic Paraboloid	coaxial US integrated X-ray	28×6	40	1989
Siemens Multiline	electromagnetic	in line X-ray	80×5	16	1994

complete staghorn calculi, in most of these patients a combined percutaneous nephrolithotomy (PCNL) and ESWL should be recommended as the first-line treatment [1]. Although open surgical stone removal is performed infrequently, a clear understanding of the subtle renal anatomy aids the urologist in more effectively treating patients with renal calculi and in limiting surgical complications.

Most discussion is about the treatment of calyceal calculi. 20 years ago the term nonobstructive calyceal stone was introduced to justify the conservative management of asymptomatic calculi [2, 3]. With the advent of PCNL, the approach to calyceal calculi has become more liberal. Endourological techniques were developed to remove stones from calyces and calyceal diverticula [4, 5]. ESWL has further simplified the treatment of calyceal calculi, so that the majority have become eligible for treatment [5–9]. However, the results of ESWL were not as satisfactory as for renal pelvic stones, particularly in cases of concrements in the inferior calyces or in calyceal diverticula which are associated with infundibular stenosis [10, 11]. Based on a review of the literature, Lingeman et al. [12] recently advocated PCNL for the majority of lower-pole calculi as primary approach. On the other hand, Ilker et al. [13] recently concluded, that ‘in spite of its lower stone-free rates, ESWL, with its lower morbidity, may still be considered as an acceptable treatment modality, especially when there is a patient desire for conservative treatment’. Based on an extensive review of the literature and our own clinical experiences, we try here to define guidelines for the management of renal stones with special emphasis on a wide clinical acceptance by urologists and patients.

Materials and Methods

Analysis of the Literature

An analysis concerning more than 14,000 patients from the literature worldwide presented in 105 articles was elaborated with special emphasise on long-term results of ESWL of renal calculi. Herein, the treatment of calyceal calculi by ESWL mainly concerns three aspects: (1) the rationale of ESWL for small asymptomatic calculi; (2) the limits of ESWL monotherapy of calyceal calculi in case of associated anatomical disorders (i.e. calyceal infundibular stenosis, horseshoe kidneys), and (3) the overall efficacy of ESWL for calyceal calculi, depending on stone size and localization. Additionally, we were focusing on the specific anatomical situation of the collecting system. In patients with normal renal anatomy, the efficacy of ESWL with respect to stone size, observation time and stone localization was examined. Based on these results, a definition of clinically insignificant residual fragments was worked out in contrast to significant residual fragments resulting in an algorithm for the management of renal calculi.

Comparison of Our Own Clinical Results

The above-mentioned study of the literature was supplemented by the analysis of 2,642 patients treated from 1995 to 1997 at two German institutions (Department of Urology, Klinikum Heilbronn, Teaching Hospital of the University of Heidelberg/Department of Urology, Stadtkrankenhaus Harlaching, Teaching Hospital of the University of Munich). Between 1995 and 1997, ESWL was performed in both institutions either by the Siemens Multiline lithotripter, the Siemens Lithostar Plus or the Storz Modulith lithotripter. All three lithotripters have electronic shockwave elements and belong to the third-generation machines. The technical details are summarized in table 1.

Results

In the following, the results of the review of the literature are presented and compared with the extensive experience of both German stone centers. Moreover, they are discussed on the basis of the current literature worldwide.

ESWL for Small Asymptomatic Calyceal Calculi

ESWL has revolutionized the treatment strategy of urolithiasis worldwide [14, 15]. In Germany, there has been a decreasing use of ESWL for larger pelvic stones and an increasing use for smaller calyceal and ureteral calculi [16]. In the US Cooperative Study published in 1986, 36% of the stones were smaller than 10 mm [7], whereas in recently presented studies in more than 50% of the patients calculi

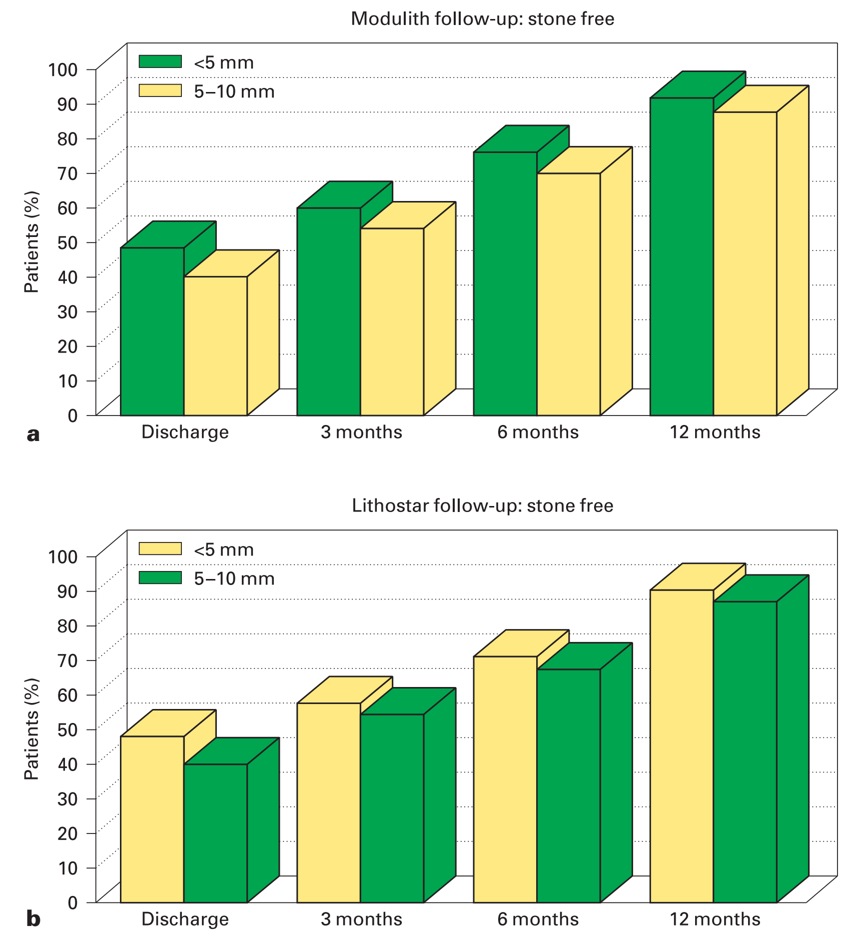

Fig. 1. Stone-free rates after ESWL of small caliceal calculi using the Modulith SL 20 (**a**) and Siemens Lithostar Plus (**b**), n = 445.

were less than 10 mm in diameter [16–18]. These data demonstrate that there is a trend for treating small calyceal calculi.

Before the ESWL era, the urologic dogma was strongly opposed to the removal of nonobstructing calyceal calculi. Most patients were appropriately reassured that the calculus was not causing renal damage nor was it the direct cause of flank discomfort [4]. In 1985, Hübner et al. [19] presented a follow-up study on patients with untreated nonobstructive small calyceal calculi prior to the ESWL era with an observation time ranging from 1 to 21 years: in 68% of these patients calculi were associated with urinary tract infections, and 51% of these patients suffered from renal colic. Interestingly, 40% of the patients ultimately required an intervention, and only in 16% of these patients did the stones pass spontaneously.

In 1986, Brannen et al. [4] reported 95% resolution of preoperative pain after PCNL. They intensively advocated minimally invasive stone removal for small symptomatic calyceal calculi, if possible with even less traumatic ESWL. In 1988, Mee and Thüroff [20] presented the data of 22 patients with small nonobstructive calyceal stones treated by ESWL. 84% of these patients were rendered stone-free and 91% achieved complete or significant relief of pain. In 1991, Hendrikx et al. [21] studied the efficacy of ESWL with small symptomatic calyceal stones in 37 patients: in 84% of the patients the stone could be successfully disintegrated, but the 3-month stone-free rate was only 50% and depended on stone localization (75%) for upper vs. 42% for lower pole stones). 52% of the patients were symptom free, and 32% both stone and symptom free after 3 months. Our own recent study [16] with 445 calculi less than 10 mm treated with two third-generation lithotriptors (Siemens Lithostar Plus, Modulith SL 20) showed 84% and 90% stone-free rates 12 months after ESWL for stones smaller than 5 mm and calculi less than 10 mm, respectively (fig. 1). Only 2% of the patients required auxiliary measures after ESWL [16].

Table 2. Efficacy of ESWL for calyceal diverticula calculi

Author	n	Follow-up months	Stone-free %	Symptom-free %
Wilbert et al. [27]	16	3	20	n.a.
Psihramis and Dretler [31]	10	6	20	70
Ritchie et al. [32]	20	4	25	75
Kriegmair et al. [30]	10	6	10	50
Jones et al. [29]	26	3	4	36
Hendrikx et al. [28]	15	3	13	60
Streem and Yost [26]	19	24	58	86
Total (mean)	129	3–4	17	60

Table 3. Efficacy of ESWL for horseshoe kidneys

Author	n	Stone-free	Lithotripter
Semerci et al. [42]	18	9	Dornier MLP 9000
Alkibay et al. [37]	22	16	Siemens Lithostar Plus
Baltaci et al. [38]	7	5	Dornier MLP 9000
Knopf et al. [39]	18	9	Dornier HM-3

Table 4. Clinically insignificant fragments (CIRF) – definition

4 mm or less residual fragments after ESWL
Calcium oxalate/phosphate calculi
Normal anatomy of the upper urinary tract
No urinary tract infection
No symptoms after ESWL
No adjuvant therapy

Table 5. Distribution of calyceal stones according to size and localization (according to Moon et al. [47] n = 573)

Site	<10 mm	10–19 mm	20–29 mm	>30 mm
Upper calix	10	7	2	0.5
Middle calix	10	5	0.5	–
Lower calix	35	24	5	1
Total	55	36	7.5	1.5

In summary, most of these data confirm the overall efficacy of ESWL for small nonobstructive stones. These results led to a significant expansion of the indications for ESWL as compared with early series [6, 7]. The question remains whether small nonobstructive asymptomatic stones (<5 mm) should be treated primarily with ESWL. We know that about 50% of these stones will become ureteric calculi [19]. The rationale for early treatment with ESWL is that it will prevent any serious problems if stones pass down the ureter. A recent report supporting the opposing view to the aforementioned early retreatment shows that the morbidity of ESWL at 12 months of follow-up is negligible [16]. Such stones might be considered as ideal for outpatient ESWL treatment, with success rates of 90% [16]. Therefore, this option should be discussed individually with each patient.

Overall Efficacy of ESWL for Calculi with Normal Renal Anatomy (table 2, 3)

In patients with normal anatomy, stone disintegration is not the foremost problem, but rather passage of the debris (in contrast to the in situ treatment of ureteral calculi). The treatment goal for any calculus is to render the patient free of symptoms and stones and to preserve renal function. The choice of an appropriate treatment strategy for calyceal calculi depends on many distinct elements. Among these factors are stone size, location and composition as well as the anatomy of the urinary tract and the patient's overall medical condition [25]. Many patients, however, may benefit from stone disintegration that results in minor residual fragments, so-called 'clinically insignificant residual fragments' (CIRF) (table 4). Changing the therapeutic end points would have a major impact on treatment strategies for calyceal stones.

Approximately 40–50% of all treated single urinary calculi are located within the calyces, and most of these are found in the lower calyx [8, 17, 34, 46–48] (table 5). This distribution has not changed during the last decades [89]. The overall results of ESWL for the management of calyceal calculi depend significantly on the localization and size of the stone [8, 13, 49–51] (tables 6–8). During the last decade, the main importance of ESWL treatment was to achieve a complete stone-free status, ignoring the fact that more and more patients benefit from successful stone disintegration but with minor residual fragments, the so-called CIRF (table 9). Of course, the acceptance of this change of therapeutic end points would have a major impact on treatment strategies for all calyceal stones [90, 91].

Stone Size. However, the indication for ESWL monotherapy in the management of calyceal calculi should also consider the stone size (table 7): The results of ESWL for stones up to 10 mm in diameter are satisfactory independent

Table 6. ESWL for calyceal calculi – stone distribution in large series of solitary stones

Status	Graff et al. [64]	Tolon et al. [48]	Moon et al. [47]	Rassweiler et al. [16]	Cass [46]
Patients, n	617	1,160	826	765	7,022
Patients with caliceal stones, n	342	304	573	357	2,537
Year of publication	1988	1991	1993	1995	1995
Localization, %					
Upper calix	16	4	14	10	5
Middle calix	17	6	11	14	7
Lower calix	23	16	44	22	24
Total	56	26	69	46	36

Table 7. ESWL for calyceal calculi – Stone-free rates depending on stone size

Patients	n	Observation time months	Stone-free, %			
			<10 mm	10–19 mm	20–29 mm	>30 mm
Newmann et al. [49]	972	3	80	71	57	n.a.
Ilker et al. [13]	386	12	82	59	59	13
Rassweiler et al. [16]	359	12	87	72	65	17
Lingeman et al. [12][a]	439	3	80	58	33	n.a.
Chen and Streem [52][a]	206	24	63	46	46	13
Küpeli et al. [82][a]	165	3	62	48	28[b]	
Pacik et al. [83][a]	310	3	71	46	31[b]	

[a] Only lower pole stones; [b] ≥21 mm.

Table 8. ESWL for calyceal calculi – stone-free rates depending on the localization and observation time

Status	Newman et al. [49]	Ilker et al. [13]	Petterson and Tiselius [50]	Graff et al. [64]	Zanetti et al. [51]
Patients, n	972	386	187	342	129
Observation time, months	3	12	12	19	12
Stone-free, %					
Upper calix	75	64	85	78	70
Middle calix	71	77	65	75	59
Lower calix	59	59	78	58	39

of the localization in the kidney, whereas the stone-free rates for stones between 10 and 20 mm in diameter are decreasing, particularily for lower-pole stones [12, 13, 51, 52, 77]. On the other hand, there is no study showing satisfactory results for ESWL monotherapy of stones larger than 30 mm in diameter. The fact that the majority (about 75%) of larger stones (>20 mm) are found in the lower calyx (table 5) may have affected significantly the unsatisfactory overall results for lower-pole stones [47]. Nevertheless, there is an increasing consensus in the literature that lower-pole stones larger than 30 mm shoule be preferably treated by PCNL [10–12]. However, it must be emphasized that this concerns

Table 9. Distribution of residual fragments and site of recurrent stone formation (according to Petterson and Tiselius [50] and Kamihara et al. [60]

Location	Residual fragments (%) after			Recurrent stone (%) after 22 months
	1 month	6 months	12 months	
Upper calix	8	7	10	20
Middle calix	10	15	14	13
Lower calix	56	69	72	60
Pelvis	6	3	2	2
Ureter	20	6	2	5

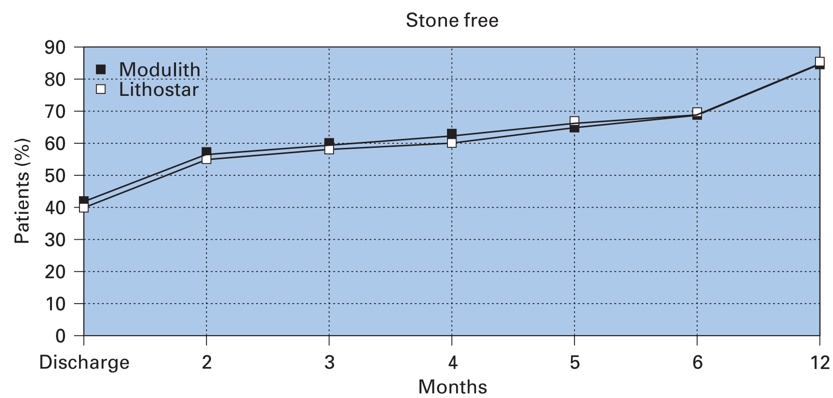

Fig. 2. Kinetics of ESWL results using two electromagnetic lithotripters (Storz Modulith SL 20, Siemens Lithostar Plus). Percentage of stone-free patients within 12 months after treatment.

Table 10. Long-term results of ESWL for lower pole stones

Status	Zanetti et al. [51]	Graff et al. [64]	Ilker et al. [13]	Lingeman et al. [12]	Chen and Streem [51]
Patients, n	49	141	219	439	206
Observation time, years	3	2	1	2	2
Stone-free, %	41	58	59	73	54
Stable/decreased, %	4	13	n.a.	9	41
Recurrence/regrowth, %	55	29	n.a.	18	5
Asymptomatic, %	n.a.	84	91	n.a.	87
Symptomatic episodes, %	n.a.	16	n.a.	n.a.	13
Intervention (ESWL, URS, PCNL), %	n.a.	4	9	10	9

only a minority (about 7–9%) of patients suffering from renal calculi [16, 47, 48, 50].

In recent times, a new treatment modality, the so-called sandwich therapy, for patients with major stone burden, especially with staghorn calculi, was described in many studies [53–56]. Sandwich therapy was developed as a planned endourologic approach to manage large, extensively branched or otherwise complex calculi. Specifically, it was designed to allow safe and effective application of minimally invasive technology to patients who might otherwise require open operative intervention or to those who would not predictably benefit from PCNL or ESWL alone [55]. Because the risk of bleeding and sepsis with percutaneous monotherapy is at least to some extent proportional to the number of percutaneous tracts used, and because the potential toxicity of repeated high-dose shockwave lithotripsy is unknown, sandwich therapy has been designed specifically to minimize the risk of bleeding and septic complications and to decrease the number of shockwaves otherwise required. A further goal of this treatment is to decrease the need for prolonged nephrostomy drainage that had been a part of earlier approaches to combined endourologic management [53].

Observation Time. Interestingly, a review of the literature suggests that the duration of follow-up (3 vs. 19 months) does not significantly influence the stone-free rates obtained with ESWL for calyceal calculi [34, 52]. Some series, however, with a longer follow-up period, indicate the continuous clearance of fragments for at least 24 months following ESWL [57, 58] (fig. 2). These differences may be explained by various diganostic methods for determination of complete passage of fragments (plain films versus plain films plus ultrasound) as well as the fact that particularly in cases of small upper and middle calyceal stones, most of the debris will pass during the first 3 months [59] or migrate to the lower calyceal group (table 9). Finally, long-term studies always have to deal with the problem of stone recurrence which is about 8% per 12 months [49, 59–62].

Our own clinical experience, comparable to the results of other European centers (Vienna, Stuttgart, Mannheim), clearly indicates that the passage of stone fragments does not end after 3 months, but occurs as a continuous process for at least 24 months (fig. 2). It must be emphasized that stone clearance occurs asymptomatically in most of the patients (table 10; fig. 3) and, therefore, rarely requires any auxiliary procedures (table 11). During this period, any endoscopic procedure aimed at total stone clearance of asymptomatic fragments (CIRF) should be considered as overtreatment without any additional benefit for the patient.

Stone Localization. Although stone-free and residual fragment rates were similar in pelvic, upper and middle calyces, patients with lower calyceal and pelvicalyceal stones had high residual fragment rates and lower stone-free rates. Patients with stones in the lower calyces or pelvicalyces had high recurrence and regrowth rates [92]. Stone recurrence occurs predominantly in the lower pole [60]. The most important reason for the relatively low stone-free rate in the lower calyx observed in a long-term analysis of Zanetti et al. [51], in fact, may be a bias caused by parallel recurrent stone formation. The success of ESWL is affected by stone location, since lower pole calyceal stones have a lower clearance rate than other calyceal or renal pelvic stones of similar size and composition. While Politis and Griffith [85] reported a 69% stone-free rate with the HM3 lithotriptor, McDougall et al. [77] described only a 57% stone-free rate after ESWL for lower pole calculi.

Considering stones of similar composition, stone-free rates following SWL are not solely dependent on the size of the calculi, but rather on size together with stone location. Stone-free rates are generally the highest for upper and middle calyceal calculi and significantly lower for lower calyceal stones. For upper and middle calyceal calculi, one should expect stone-free rates ranging from 70 to 90%, whereas those for such calculi located in the lower calyces range between 50 and 70% [7, 8, 10, 34, 48, 50, 51, 61, 63–70]. The presence of residual fragments following ESWL, necessitating multiple or adjunct procedures, is more commonly found in association with larger stones and lower calyceal calculi [12, 48]. There is no doubt that ESWL represents the preferred method of treatment in this group of patients (table 12).

The management of lower calyceal stones still remains controversial [12]. Another option for minimally invasive treatment of lower calyceal stones is percutaneous lithotripsy. Although it is associated with a higher stone-free rate (85%), because of its higher morbidity most urologists reserve this procedure for lower-pole calculi larger than 2 cm [93]. However, this cutoff point has been recently contested. In a prospective randomized study of 1- to 2-cm lower-pole calculi, Elbahnasy et al. [71] recently noted that the stone-free rate of ESWL versus percutaneous lithotripsy was 29 vs. 86%. The poor clearance of fragments after ESWL is the greatest deterrent to its use. The reasons for lower clearance of the fragments from the lower pole following ESWL are unclear. It is most commonly though that the gravitiy-dependent position of the lower-pole calyx precludes efficient stone passage [58].

Thus, to improve stone clearance after ESWL, others have suggested various regimens, such as positioning the patient head down, ureteral stenting and flushing the lower pole with saline during ESWL or transcutaneous needle flushing of the lower calyx [72–74, 76, 78]. The outcome of these procedures has been favorable. Stone-free rates have improved up to 88% after inversion therapy. A recent study shows that successful ESWL is highly sensitive to lower-pole anatomy. An infundibulopelvic angle of 90° or greater, or a short, wide infundibulum regardless of infundibulopelvic angle is invariably associated with a successful

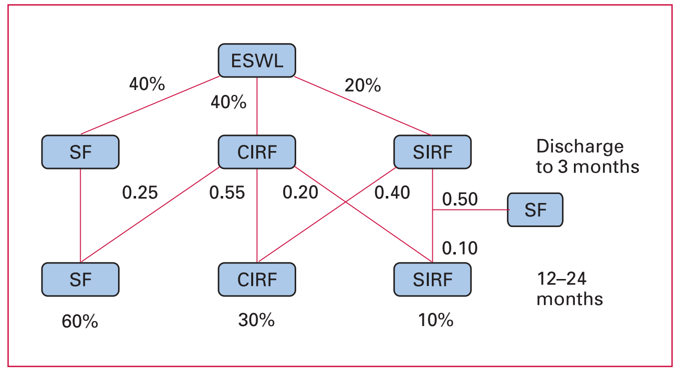

Fig. 3. Algorithm about the fate of residual fragments after ESWL. SF = Stone free; CIRF = clinically insignificant fragments; SIRF = significant fragments; percentages = rate of all patients; decimals = rate of the different subgroups. Data averaged from the studies cited in the reference list (tables 7–10).

Table 11. Auxiliary procedures after ESWL (Department of Urology, München-Harlaching, Siemens Multiline)

Auxiliary procedure	All stones %	Renal stones %	Lower calyx %
Percutaneous nephrostomy	2.5	2.0	0.8
Double J-stent	1.9	1.8	1.1
PCNL	0.1	0.1	0.0
Ureteroscopy	1.4	1.4	1.1
Total	5.9	5.3	3.0

Table 12. Treatment recommendations for calyceal calculi

Stone characteristics	ESWL	PCNL
Normal anatomy		
Stone size <20 mm	first approach	after failure of ESWL
Stone size 20–30 mm	first approach	after failure of ESWL
– Upper/middle calix		
– Lower calix	if PCNL is contraindicated	first approach
Stone size >30 mm	if PCNL is contraindicated	first approach
Caliceal diverticulum		
Stone size >10 mm	first approach (‘diagnostic’ ESWL)	after failure of ESWL
Stone size >10 mm		
– Patent neck	if PCNL is contraindicated	first approach
– Obstructed neck	contraindicated	if symptomatic

outcome for calculi 15 mm or less in the lower-pole calyx. On the other hand, a combination of unfavorable factors, such as infundibulopelvic angle less than 90°, infundibular lenght greater than 3 cm and infundibular width 5 mm or less, is a poor indication with only 17% ESWL success in these patients [71]. Based on a review of the literature with significantly greater efficacy of PCNL, particularly for stones larger than 10 mm in diameter, Lingeman et al. [12] advocated a wide use of PCNL in the management of lower-pole stones to achieve higher stone-free rates and thus a lower recurrence rate. Moreover, anatomical studies showing an angle <90° between the lower infundibulum and the renal pelvis in 26% and the length of the lower infudibulum exceeding 4 mm in 60% (as signs of a gravity-unfavorable situation) supported this strategy [58]. The long-term stone-free rate of ESWL monotherapy for lower pole stones ranging from 41 to 73% with 59% on average (table 10).

These results have mainly be produced using the Dornier HM3 spark gap technology which required general or epidural anesthesia. Therefore, the retreatment rate was kept as minimal as possible. One of the main advantages of newer lithotripter technology represents the avoidance of anesthesia. This resulted in a wider acceptance of repeat ESWL to improve the pulverization of the fragments and thereby stone clearance, i.e. ‘stir up ESWL’ [75] or ‘booster technique’ [15]. Conclusively, this strategy also increases the percentage of clinically insignificant fragments [76–81]. Even before this era, the majority of the residual fragments could be classified as clinically insignificant (CIRF): 75–87% of the patients remained asymptomatic and only 4–25% required a secondary intervention which mostly consisted of a repeat ESWL [8, 13, 16, 52]. Considering recent experiences with third-generation electromagnetic lithotripters (i.e. Storz Modulith, Siemens Multiline) the complication rate and the need for post-ESWL auxiliary

Table 13. Complications after ESWL treatment (Department of Urology, München-Harlaching, Siemens Multiline)

Complications	All stones (n = 1,917) %	Renal stones (n = 1,153) %	Lower calyx (n = 374) %
Renal hematoma	1.3	1.9	1.6
Infected hydronephrosis	5.2	4.5	4.3
Total	6.5	6.4	5.9

procedures could be further reduced, ranging between 3.0 and 6.5% (table 11, 13).

Adding this figure to the rate of stone-free patients, we estimate that less than one third of patients with residual fragments will present with any clinical problems; only 10% may require percutaneous clearance of fragments (fig. 3). Based on this analysis, we suggest that PCNL as a primary approach for lower-pole calculi represents overtreatment. We share this opinion with the majority of European stone centers [94, 95].

Calculi with Associated Anatomic Anomalies

Anatomic abnormalities such as infundibular stenosis, horseshoe and malrotated kidneys, and nephrocalcinosis of medullary sponge kidney limit the efficacy of ESWL monotherapy in patients with calyceal calculi.

Infundibular Stenosis. The symptomatic and functional relevance of infudibular stenosis of a calyceal diverticulum remains unclear [22]. Calyceal diverticulae are urine-filled cavities connected to the normal collecting system by a narrow isthmus. The cavity is lined with nonsecretory transitional epithelium and fills with urine in a retrograde fashion. These diverticulae are generally detected incidentally on routine intravenous pyelograms and have an incidence of less than 1% [23]. The exact cause of these anomalies is controversial, although most agree that they are likely congenital, because the incidence is comparable in children and adults. Although most calyceal diverticula remain asymptomatic, flank pain, hematuria or recurrent infection may alert one to their presence. The incidence of calculi within calyceal diverticulae has been reported to range from 10 to 50% [22]. These calculi often cause a localized inflammatory reaction that can lead to fibrosis of the diverticular wall and possible stenosis or obliteration of the connecting isthmus [24]. These stones rarely pass spontaneously, yet require intervention if they become symptomatic. The most common indication for treatment of calyceal diverticular calculi is ipsilateral flank pain; others include recurrent infection and persistent gross hematuria [25].

Early studies with a short follow-up (3–6 months) revealed stone-free rates ranging from 4 to 58% (table 2). Streem and Yost [26] reported that 11 of 19 patients were stone free and 86% of patients remained symptom free after 2 years of follow-up. Only 1 patient developed stone recurrence during follow-up. They concluded that 'ESWL for selected patients with calculi in calyceal diverticula can achieve a relatively high initial stone-free rate and that recurrent stones may not be inevitable.' These authors suggest that criteria of selection should include the size of the stones (maximal 10 mm) and 'perhaps more importantly', the radiographically documented patent diverticular neck [26].

Furthermore, the length of the infundibular stenosis (maximal 10 mm) could influence the results [27]. Otherwise, Streem and Yost [26] showed that anatomical classification (i.e. communication to a minor calyx, infundibulum or renal pelvis) had no impact on patient outcome. Many studies demonstrated that 63% of the patients (36–86%) remained symptom free after ESWL [26–33] (table 2). These data sustain the concept of a 'diagnostic' ESWL [5, 34] as the primary approach for most of the calyceal diverticulum stones. More invasive procedures like percutaneous or retrograde nephrolithotripsy may be reserved for special cases with persisting stones and symptoms [26, 32, 34]. It must be mentioned, however, that several authors reported a 77–100% stone-fee rate and a 69–100% symptom-free rate with PCNL as the primary approach [30, 35, 36, 98]. If economic restraints play a major role in the future, primary PCNL might be more advantageous for managing a stone-containing diverticulum [12]. However, it should be remembered that particularly for this indication, PCNL is a technically difficult procedure requiring extensive endourologic expertise.

In summary, it appears that ESWL monotherapy for calculi in calyceal diverticula may be beneficial in selected patients and as symptomatic treatment alone. However, in those patients with recurrent infections, in whom a stone-free result is important, or in situations where ablation of the diverticulum is necessary, other treatment modalities should be used.

Horseshoe and Malrotated Kidneys. Stone-bearing horseshoe kidney present a challenge for ESWL. The medial and extremely medial location of the lower calyx makes stone localization difficult. Passage of fragments through the frequently high ureteropelvic junction can also be arduous. Nevertheless, surprisingly high stone-free rates ranging from 50 and 85% have been reported [37–43, 79, 88] following ESWL. Lampel et al. [40], however, emphasized the relatively high recurrence rate of 29% after 2 years of follow-up, exceeding the normal range by a factor 1.5–2 Schmidt et al. [41] had to perform additional percutaneous stone removal in 28% of their patients after performing ESWL by two lithotripters with different localization systems (fluoroscopy or ultrasound). This represents a technically demanding procedure. Concerning these studies, many authors conclude that ESWL represents the treatment of choice in horseshoe and malrotated kidneys with small calyceal calculi ($<$20 mm) – similar to a normal anatomic situation [34, 38, 42] (table 3). The more anterior position of these kidneys results in a great distance between flank and kidney with difficulties in proper positioning of the calculus in the focal point (F2) in the standard fashion, depending on the body habitus. Additionally, the high insertion of the ureter with its anterior course over the isthmus may probably prevent the fragment passage after ESWL; ESWL treatment in the prone positioning of such patients may be effective [44]. The presence of anatomic obstruction will necessitate open surgery for urolithiasis in patients with horseshoe kidney; however, in patients with normal urinary drainage PCNL or ESWL can be considered, either singly or as a part of combination therapy. When management is tailored to the individual patient's needs, results of stone treatment can be equivalent to those in normal kidneys.

Nephrocalcinosis of Medullary Sponge Kidneys. ESWL is ideal for treating stone-related obstruction and infection in medullary sponge kidneys. The main advantage of ESWL in these patients is the reproducibility and pain-free application [15, 17, 34]. Considering the special anatomy and high recurrence rate of stone-bearing medullary sponge kidneys, the therapeutic pursued goal is the reduction of the stone burden within the collecting system with improved renal function and symptoms rather than achieving a stone-free status. It must be noted that ESWL represents only one part of the treatment of this disease [45]. The stone clearance rate in patients with lithiasis in medullary sponge kidneys (MSK) is not similar to that of non-MSK patients but there is a great reduction in the frequency of renal colic and urinary tract infection.

Discussion

It is difficult to define general guidelines. Different philosophies exist concerning Anglo-American countries in contrast to European and Eastern countries in treating renal stones, especially staghorn calculi. Mattelaer et al. [95] recently reported in a long-term follow-up for more than 6 years that primary ESWL monotherapy of staghorn calculi is justified because of the comparable results with open surgery and PCNL. Prognostic good factors are small stone mass with most of the stone mass in the upper and middle calices, the absence of dilatation and the absence of anatomical anomalies. Ashida et al. [94] from Japan reported on 97 patients with staghorn calculi treated by ESWL monotherapy using a Lithostar Lithotriptor (Siemens) with a stone-free rate of 63.2% after 5 years. Lingeman [96] advocated in a review that staghorn stones are usually best managed initially with percutaneous nephrolithotomy followed by the addition of ESWL, if necessary. Generally, agreement exists about ESWL as first-line treatment in lower pole calculi less than 2 cm in diameter. Cass [97] reported that although the stone-free rate with PCNL is higher than with SWL, the lower complication rate, lower repeat treatment, secondary procedure rate, the shorter hospital stay and the similar recurrent stone rate with ESWL make ESWL more clinically effective as the primary therapy for lower pole calculi. Concerning the efficacy and cost-effectiveness of ESWL for solitary lower pole renal calculi, the Dornier HM3 shoud be considered the initial treatment choice for most lower pole stones of less than 2 cm [99]. In summary, ESWL is a safe procedure with a lower morbidity than open surgery or PCN [100, 101]. The number, location and type of the stones are factors that influence the success of SWL [51, 101, 102]. As mentioned before, the observation time influences the stone-free rates [51]. The management of staghorn calculi is one of the more demanding tasks in urology. An extensive literature review produced a summary of the world's experience with the treatment of staghorn calculi (table 14) [103].

The problem for metaanalysis of results and comparison and discussion of the literature is that a clear definition of stone-free rates rarely exists. Does this mean CIRF or no fragments shown by X-ray or ultrasound? Another problem is the use of different lithotriptors. General agreement exists about the importance of the effective quotient:

$$EQ1 = \frac{\text{number of stone-free patients\%}}{100\% + \text{Re-ESWL\%} + \text{auxilliary methods post-ESWL\%}}$$

first described by Preminger and Clayman [104] for calculating the success rate of ESWL. The disadvantage of the EQ1 is that not all auxilliary methods are involved, only the post-ESWL, but in our days there is a trend for more auxilliary methods pre-ESWL (i.e. JJ stent). For this reason, post-ESWL auxilliary methods are decreasing. Therefore, Rassweiler et al. [105] developed a new modified formula which included the kind of auxilliary management, adjuvant as well as curative:

$$EQ2 = \frac{\text{stone-free patients\%} - \text{curative auxilliary methods\%}}{100\% + \text{Re-ESWL\%} + \text{\% auxilliary methods pre- and post-ESWL}}$$

However, beside this, we strongly feel that the literature as well as our own extensive experience supports the less-invasive approach favoring ESWL for the majority of calculi (table 12).

Table 14. Treatment of staghorn renal calculi [103]

	SWL	PNL	PNL+ SWL	Open surgery
Stone-free rate, %				
Median	50	73	81	82
95% confidence interval	26–74	–	68–91	57–96
Complication rate, %				
Median	31	7	25	12
95% confidence interval	2–82	0–32	4–61	1–47
Procedures/patients (n)				
Primary	2.1	1.5	2.8	1
Second	0.4	<0.1	<0.1	<0.1

[a] Includes: hydronephrosis, pneumonia, vascular injury, urinoma, secondary unplanned intervention, sepsis and loss of kidney.

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