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INVITED REVIEW

Aspects on how extracorporeal shockwave lithotripsy should be carried out in order to be maximally effective

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Abstract The present review summarizes the most important considerations and steps for an optimal result of extracorporeal shockwave lithotripsy. The relationship between shockwave path, geometry and anatomical conditions is of utmost importance. Selection of appropriate treatment variables in terms of shockwave number, power and frequency, is an important prerequisite for proper disintegration and prevention of complications. Several supportive measures such as inversion therapy, citrate therapy, high diuresis, α-receptor antagonists, chemolysis and recurrence preventive measures are important parts of the management of this group of patients in order to avoid problems with residual fragments and new stone formation. Proper understanding of these factors as well as of the physics of shockwaves is necessary for a successful application of this non-invasive technology treatment concept.

Keywords Extracorporeal shockwave lithotripsy · SWL · Auxiliary procedures · Residual fragments · Shockwave power · Shockwave number · Complications · Recurrence prevention

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Introduction

How best stones should be removed from the urinary tract has been a matter of constant debate ever since the introduction of extracorporeal shockwave lithotripsy (SWL) in 1980 [1, 2]. Despite the successful achievements with SWL there is presently a trend towards the preferred use of invasive endoscopic procedures rather than a non-invasive approach by means of SWL [3–10]. This development is an effect of a considerable variation of SWL results. Literature data give stone-free rates for renal and ureteral stones in the range of 32–90 % [11] and 43–98 % [10, 12, 13], respectively and a similar variation in terms of successful stone disintegration. There are indeed several explanations for this variation. Following the tremendous success with the original lithotripter HM3, a number of lithotripters were marketed, some with inferior disintegrating capacity. Moreover, since SWL was considered an easy-to-handle technology and by many urologists a boring part of urology, it was either put in the hands of young colleagues without or with only limited treatment instructions or given to nurses with similarly poor education. In other cases, technicians often without any medical education and poorly trained were made responsible for the treatment. In some cases these arrangements worked out satisfactorily, in others obviously less so. This unfortunate situation undoubtedly explains the variable success reported for SWL.

When late SWL results are reviewed in the literature, it is usually concluded that they never or very seldom come up to those obtained with the Dornier HM3 device. Accordingly, this lithotripter is still very often referred to as the “gold standard” [14, 15]. The question that thereby emerges is why the reported results are not better with the modern and more powerful lithotripters.

For an analysis of this problem and for further discussion it is necessary to look at the features of the original HM3 lithotripter. Of great importance is that the patient was immersed in the same water compartment as the shockwave source and the shockwave transmission from the ellipsoid reflector was without obstacles until entering the body. The geometry of the shockwave system resulted in a large focal volume, albeit with a much lower energy density than in later generation lithotripters. A two-plane fluoroscopy system facilitated stone positioning. Moreover, the patients were initially treated under either general or regional anaesthesia or later with analgesics and sedatives. ECG-gated shockwave generation also resulted in a shockwave frequency usually in the range of 60–90/min.

There is no doubt that recent generations of lithotripters are more user-friendly and they all enable treatment with only small doses of analgesics/sedatives [14, 16–21]. Shockwaves are in most modern lithotripters generated electromagnetically and it was noted that ECG-gating was no longer necessary. Accordingly, the option to use a shockwave frequency of 120 (2 Hz) or more was a feature that satisfied the urologists' and patients' desire to complete the treatment quickly. The transmission of the shockwave was not as straightforward as in the HM3 device, because the new design, without a water tub, required shockwave passage over one or several membranes and transmission media. The altered geometry of the shockwave source generally resulted in focal volumes that were much smaller than that in the HM3 lithotripter, but the power density should be higher when appropriately used [21, 22].

The bottom-line is that the use of modern lithotripters requires a number of factors to be taken into account by the operator in order to get a satisfactory stone disintegration and treatment outcome. The problem of shockwave transmission, the small focal volume and the relationship between shockwave geometry and anatomy are probably the major explanations for poor treatment results. Below is a discussion on how SWL can be improved and a non-invasive treatment approach with good results be maintained. Appropriate management of the lithotripter is definitely not that easy that the success follows an effort that only requires "pressing a button" as emphasized by some colleagues.

Some aspects on shockwave physics

The proper application of SWL also requires a basic understanding of shockwave physics [21, 23]. Since the properties differ slightly from one lithotripter to another, it is necessary to be familiar with the specific features of the lithotripter that you are working with. An appropriate understanding of what the various physical terms stand for is certainly also of great importance when decisions are made for the purchase or leasing of a lithotripter.

Whichever device is used its main function is based on the concentration of shockwave power to an ellipsoid volume along the line of the shockwave path. This volume has its centre at the point F2. When an electrode was used such as in the Dornier HM3 lithotripter the spark gap was at F1, but in later lithotripters the origin of the shockwave cannot always be precisely defined in the same way. For a certain power level there is a peak pressure generated and the focal volume is defined as that comprising shockwave energy down to 50 % of the peak pressure. The technical solution for focusing shockwave power is to use a reflector of some kind or an acoustic lens and the geometric properties determine the focal size. It thus follows that with a large reflector diameter the focal volume will be small and vice versa.

For the clinical work it is not necessary to understand all different factors that contribute to stone disintegration. However, there might be one important exception: because recent physical studies have shown that the two most effective explanations for stone disintegration might be (dynamic shearing with quasi-static squeezing) a combination of squeezing and spalling effects [21]. Thereby, a focal volume with a diameter exceeding the stone diameter should be a favourable factor. Accordingly, the possible conclusion from recent experiments has been that a large focal volume with a relatively low-pressure focus might have better disintegrating properties than a small focus with a high pressure. Although a certain threshold energy level needs to be exceeded, this might explain why the HM3 lithotripter was so effective despite the large low-pressure focus.

The shockwave focus

Most lithotripters that are used today have a shockwave geometry which is characterized by wide body entrance angle and a small focal volume. It thereby should be understood that the focal volume is defined as the volume in which the shockwave power is at least 50 % of the peak power value. With a wide entrance angle it is assumed that the pain, at least at the skin surface, can be reduced [24]. The small focal volume as the consequence of such a technical solution provides a higher density of shockwave power and thus a better disintegration should be expected compared to the larger HM3-focus. The requirement for optimal benefit of the high power is, however, a very precise positioning of the stone in focus. Otherwise, the stone will be hit by shockwaves with a very low power, because even at short distances from the focal point the shockwave power subsides rapidly. Appropriate focusing is, however, a difficult undertaking because the kidney and ureter can move significantly with respiration and the patients might also move as a reaction to pain. Even in lithotripters that have been equipped with variable focal volumes, accurate and careful stone positioning is mandatory.

There are several methods that can be used to achieve a good and reasonable hit-rate of the shockwave. First of all, it is essential to give the patient a satisfactory analgesia during the procedure, but with the exception for children there is usually no need for general or regional anaesthesia. Almost all treatments can be completed under analgo-sedation [13, 25–27]. Pre-treatment with an NSAID agent have proven useful to reduce the need for further administration of analgesic and sedative drugs [28, 29]. It has been the routine in the authors' hands to use small intermittent doses of alfentanil with or without propofol [30, 31]. An extensive experience of this form of analgesia/sedation has shown that such a regimen is without risk, provided ECG and oxygen saturation are monitored during treatment and that 2 L/min of O_2 is applied through the nose or with an oxygen mask. The literature shows that there are also other alternatives that can be applied [30, 32–35]. A satisfactory pain relief is necessary for enabling treatment at appropriate power levels. It has to be emphasized that efficient SWL is not pain-free—even with modern devices—and that stone characteristics and properties should determine the choice of treatment variables and not insufficient administration of analgesics.

The basic rule in positioning of the stone is to place it within the focus during the expiratory phase. Thereby, also with pronounced respiratory movements, the stone will come into focus during the longest period of time. In order to reduce the range of stone movement, a belt applied over the abdomen (or lower back) is very helpful [36–38]. This should be a routine procedure! An additional advantage of this device is to maintain good contact between the patient's body and the membrane of the shockwave source. Patients who feel uncomfortable because of the shockwave administration tend to reduce the discomfort by elevating the body. Thereby, no shockwave transmission occurs and the treatment will fail. The belt is best placed in the upper part of the abdomen, but should not be applied over the chest which can impair respiration.

With the modern lithotripter technology there is no or very low risk of ventricular extra beats (VES) during shockwave generation and the previous use of ECG-gated shockwave generation is not necessary. Nevertheless, if VES are observed ECG-triggered mode of treatment should be applied. It is of note, however, that VES also occurs during periods of bradycardia as an effect of analgesic treatment. For those patients an intravenous dose of atropine (0.5–1.0 mg) usually solves the problem.

Stone localization

Stones in the urinary tract can be demonstrated either with ultrasound technique or with fluoroscopy. The advantage of ultrasound is that X-ray exposure is avoided and also radiolucent stones can be found. The successful use of ultrasound requires considerable experience of the operator, and because of interference with skeletal structures not all stones in the collecting system can be identified. It is also difficult to judge the degree of disintegration during treatment. This is the reason why presently most SWL treatments are carried out under fluoroscopic guidance. It is thereby necessary to apply strict discipline to avoid unnecessary radiation exposure of the patients and of the personnel in the room. Once the stone has been identified the collimators should be used to give a fluoroscopic window as small as possible, usually a square with a side of 5–7 cm. By making this adjustment the X-ray load will be approximately 20 times lower than with a full screen window!

There are presently lithotripters with an auto-positioning system that can contribute to a further reduction of the X-ray load. In the further positioning process intermittent fluoroscopy is recommended and the operator should learn how much the table moves with a certain button-press. Thereby, continuous fluoroscopy during the primary positioning procedure or position correction should and can be avoided. Restricting the fluoroscopic exposure is particularly important for this group of patients who repeatedly might be exposed to considerable radiation as a result of repeated CT examinations [39].

As guide to the radiation exposure it is of value to calculate the quotient between total dose (expressed in cGy cm^2) and the fluoroscopy time in minutes multiplied by 100. A quotient of around 1 or lower is a good indicator that the collimators have been used appropriately.

The stone is placed in focus always first in the horizontal plane and then in the vertical plane. Thereby it is of note that for a stone precisely positioned in the horizontal plane, during the vertical adjustment the stone should only be moved up or down along the vertical line of the focus indicator. Repeated fluoroscopic control should be carried out as frequently as necessary to check the stone position and to follow stone disintegration. It is important to realize that stones sometimes can move to other parts of the collecting system during the treatment. In some situations it is observed that the shockwaves cause stones to move by kinetic energy: "jumping stones". In those cases a reduction of the shockwave power is recommended.

Steps to ascertain the appropriate transmission of shockwaves

When the water tub in the HM3 lithotripter was abandoned, the optimal transmission of the shockwave from its source into the body and to the stone became a problem. Thereby the shockwave has to pass one or several membranes, each comprising an obstacle that reduces the shockwave power. One of the most important responsibilities by the operator is to make sure that the shockwave is transmitted to the stone with as little loss of energy as possible.

Following shockwave generation in a water compartment, the further shockwave path in most lithotripters goes over a membrane that is covered by an ultrasound gel. It is highly important that this gel medium is completely free of air bubbles. The authors have seen numerous examples when ultrasound gel full of air has been applied to the shockwave head. Such a situation will seriously reduce the shockwave power and jeopardize the treatment outcome. Whatever transmission medium is used it is absolutely necessary that it is both free of air and applied in a way and in an amount that will result in a complete coverage of the transmission space [40–42]. There should be *no* air pockets in these spaces. It is essential to develop a technique applicable to the individual lithotripter in order to avoid such obstacles. Maybe an integrated camera control system can help to solve this problem [43]. Once the therapy head is in place it is not possible to see how well the transmission medium has been applied. Ultrasound can be used to check the homogeneity in case of uncertainty [42]. When water is part of the transmission path it is recommended that the water is degasified. The need of carefully paying attention to these factors cannot be overemphasized.

Since the patient's position usually changes when the shockwave head is placed in treatment position, it is necessary to adjust the stone (patient) position before starting the treatment.

Recognition of the problem with cavitation bubbles

When shockwaves are transmitted through water and tissues cavitation bubbles may occur. These are small liquid-free spaces in water, stone and tissues [44]. Such entities only exist during a short period of time, after which they implode. Their disappearance is associated with a local jet-stream. Interestingly, cavitation bubbles have a dual role in SWL. Collapse of these bubbles within the stone contributes to stone disintegration by the jet-stream that is formed, and moreover, each bubble also constitutes a reflection surface. This mechanism might contribute to the fragmentation of the stone. On the other hand, cavitation bubbles present in the shockwave path and at the surface of the stone will attenuate the disintegrating power. A more problematic part is, however, that the implosion of cavitation bubbles gives rise to tissue damage and before the implosion of the bubbles, reflection of a new shockwave might cause additional trauma.

Although all cavitation bubbles spontaneously disappear this process requires some time (~0.3–0.7 s) [45, 46]. This is the main reason why necessary attention has to be paid to the frequency of shockwave administration. Experiments have shown that when the treatment is carried out with a frequency of 120 SW/min (2 Hz), the interval between two shockwaves (0.5 s) is insufficient to allow complete disappearance of cavitation bubbles [47, 48]. Accordingly, the recommendation has been to deliver shockwaves with a frequency of 60–90/min (1–1.5 Hz) and recent experience speaks in favour of 60/min (1 Hz) [48–54]. There are also studies in which an even lower rate (30/min; 0.5 Hz) has been proposed [55, 56]. However, most lithotripters do not have this possibility. It has been clinically demonstrated that the low rate of shockwave generation results in both: less tissue trauma and better stone disintegration than a high rate [55, 57, 58]. The relative drawback of a low shockwave frequency is, however, that the duration of the treatment is prolonged, provided the low rate is not associated with such an improvement in stone disintegration that the total number of shockwaves can be accordingly reduced. Unfortunately it is difficult to accurately assess stone disintegration during the SWL session and due to the lack of studies on this problem most operators stick to the total number of shockwaves that has been the routine during the past decades. When longer treatment periods might be necessary this is demanding for both patients and operators.

Choosing the appropriate shockwave energy level

It is not possible to give precise recommendations which shockwave power is optimal because the delivered energy differs significantly between individual lithotripters. It is, however, obvious that renal tissue and vessels are more sensitive to shockwave power than tissues along the ureter [59]. The basic rule is to avoid a higher shockwave power level than that resulting in appropriate stone disintegration [59]. Thereby the upper power level should always be lower when shockwaves hit the kidney. Choosing a low shockwave power is particularly important when treating children, in patients with reduced renal function or in other risk patients. It is of note that a high power level will give rise to larger fragments and smaller fragments at low shockwave power, provided a sufficient disintegration threshold has been passed.

From experimental studies it has been concluded that a vasoconstriction can be accomplished if the SWL-treatment starts with a series of low-power shockwaves, before the energy is increased [60]. Such a regimen resulted in a reduced risk of bleeding complications. It is therefore recommended, that when renal tissue can be expected to be within the focus of the shockwave (that is for treatment of stones in the kidney or proximal ureter), the treatment should be started with 100–200 shockwaves at low power level. Subsequently, the shockwave power should be increased stepwise (ramping) until a level at which disintegration can be observed [58, 61, 62]. Introducing a short (2–3 min) pause after the first series of shockwaves might be of value in order to allow for a maximal vasoconstriction, and such a step seems particularly important for patients with an increased risk of bleeding. Inasmuch as it might be difficult to see if a stone is disintegrated it has proven useful to identify the early appearance of hematuria. Clinical experiences have shown that with a bladder catheter and high diuresis, early appearing macroscopic hematuria clearly reflects stone disintegration. The absence of this finding in the vast majority of cases means that either the shockwave power is too low or the stone is not in focus. For inexperienced colleagues it is very helpful to use a catheter/diuresis regimen of this kind despite the slightly higher grade of invasiveness.

Whereas shockwave ramping is recommended for stones in the kidney, such a process is not necessary for ureteral stones. On the other hand, it is necessary to slowly increase the power for better patient's acceptance and for enabling determination at which power level stone disintegration occurs.

It is well recognized that the stone composition is an important determinant of disintegration. Based on conclusions from a large number of SWL treatments hardness factors were derived [63] (Fig. 1). These factors can be used as a guide when the stone composition either is known from the previous history or can be reasonably well anticipated. Although even hard stones of reasonable size (diameter <20 mm; stone surface area <300 mm^2) can be disintegrated with SWL, relatively higher energy levels are necessary to disintegrate stones composed of brushite, COM and cystine [64]. But none of these stones is completely resistant to shockwaves. Generally, the more reflection surfaces the stone contains, the easier is the disintegration. Accordingly, a stone with a dense structure and a smooth surface provides the greatest resistance to shock waves.

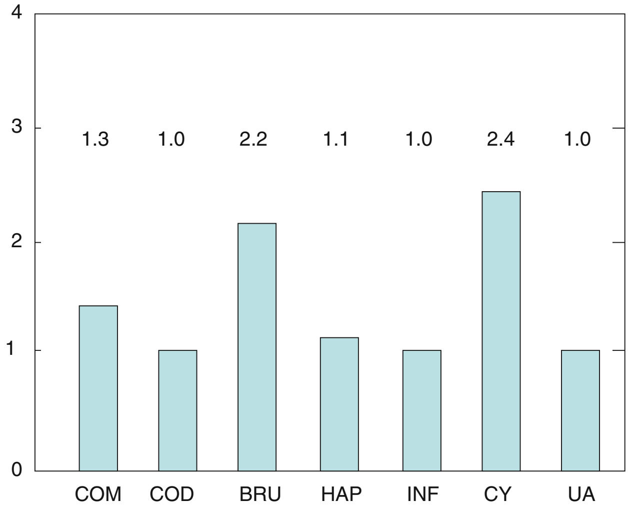

Fig. 1 Hardness factor for stones composed of calcium oxalate monohydrate (*COM*), calcium oxalate dihydrate (*COD*), brushite (*BRU*), hydroxyapatite (*HAP*), magnesium ammonium phosphate + carbonate apatite (*INF*), cystine (*CY*) and uric acid (*UA*) [63]

Factors that attenuate the shockwave power

The most important explanation for treatment failures or insufficient stone disintegration is that only a fraction of the generated shockwave power hits the stone. The main factor is absorption of power by skeletal structures or intestinal gas. Moreover, even soft tissues such as skin, fat and muscles contribute to the loss of shockwave power. Analysis of treatment results has disclosed that a long skin-to-stone distance is an unfavourable factor [65, 66].

An appropriate interpretation of these effects requires understanding of both shockwave geometry and anatomy. As shown in the examples below the distance between the upper level of the shockwave head and the skeleton and the depth of the stone both play an important role. It needs to be emphasized that with larger reflector diameters the risk of power reduction is more pronounced than with a small diameter reflector. Figure 2 shows the difference between small and large diameter reflectors and Fig. 3 between a reflector at some distance from the skeleton and one close to the skeleton. Figure 4 shows the considerable reduction of shockwave power caused by interference with pelvic bones and spine. In this case the problem is illustrated by a shockwave entrance perpendicular to the body. Similar problems are, however, encountered also with other directions of the shockwave. The solution to these

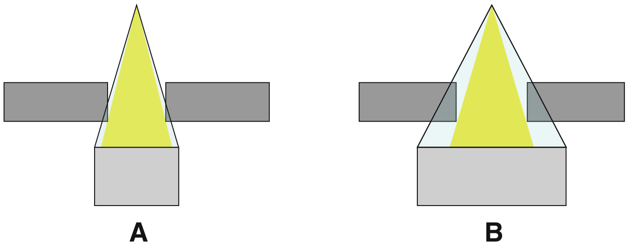

Fig. 2 Comparison of shockwave path from reflectors with small (**a**) and large (**b**) diameters. Note that with the larger reflector at the same distance from the obstructing structures (*dark grey rectangles*, a great part of the shockwave power will be lost

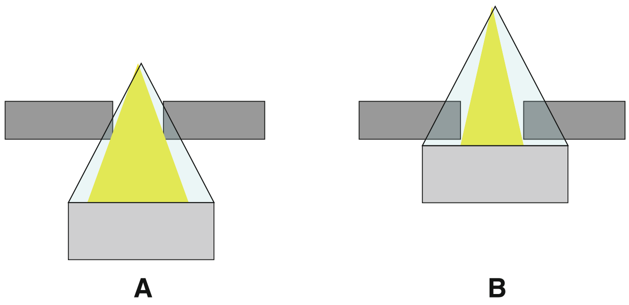

Fig. 3 This schematic drawing shows the difference in shockwave path when the reflector is at a large distance from the obstructing structures (**a**) and close to these structures (**b**). It should be noted that in case **b** a large part of the generated power is lost by absorption by the obstructing elements (*grey rectangles*)

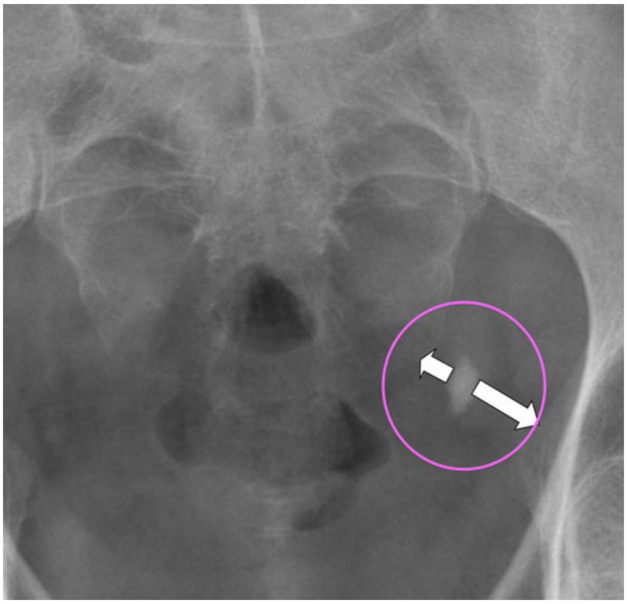

Fig. 5 Stone in the distal left ureter. It is essential when shockwaves are administered from the back that the stone is located midway between the sacrum bone and the lateral skeleton. Even small deviations from that position might lead to complete skeletal shielding of the stone

problems is either to deliver shockwaves from the abdominal side of the body for the patient as in Fig. 4 or by tilting the patient to the left as in Fig. 5, so that the shockwave enters the pelvic cavity and hits the stone between the sacrum and the lateral skeleton (spina ischiadica and iliac bone).

If a satisfactorily free shockwave path cannot be obtained with shockwaves from the back an alternative direction should be considered. Whenever shockwaves are administrated from the abdominal side, intestinal gas might be a problem and if gas covers the stone SWL-treatment should be postponed until the gas has been eliminated. Intestinal gas in the sigmoid part of the colon or elsewhere in the left colon or rectum can be eliminated with enema. It is of note, however, that when treating stones in the urinary bladder, the rectum gas is behind the stones. Pre-treatment with dimeticon during a period of 5 days preceding the SWL session might be helpful for the patient in whom anterior direction of shockwaves can be expected. Intake of macrogol (Laxabon®) is a theoretically attractive alternative but, unfortunately, associated with a considerable ingestion of air. We have avoided a fasting period and routine laxatives, because with both routines the intestinal gas content was increased.

The skeletal structures observed as potential obstacles to shockwave transmission are indicated in Fig. 6.

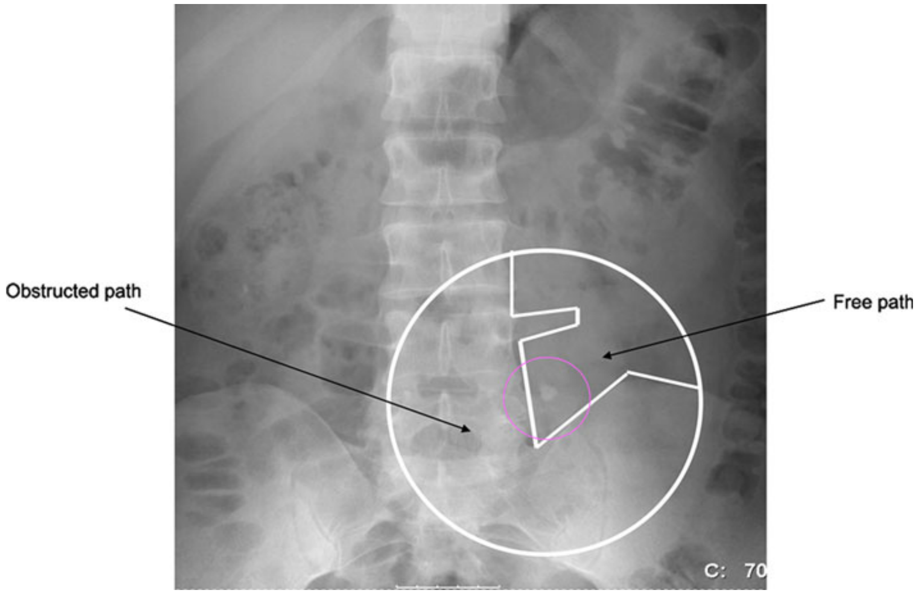

Fig. 4 This is an example of a patient with a stone in the ureter at a position in the area between the spine and the sacroiliac joint. The *circle* indicates the surface of the shockwave cone. All parts of the shockwave to the patient's right side is obviously absorbed by the skeleton and only approximately one-third of the original shockwave power will hit the stone

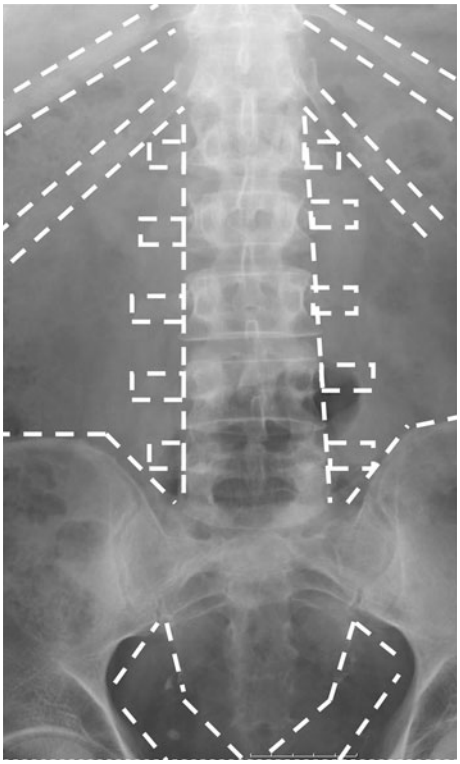

Fig. 6 An overview of skeletal structures to consider when shockwaves are administered from the back of the patient. Ribs, spine, transverse processes, sacroiliac skeleton and other pelvic bone structures always need attention. The position of the patient always should allow the shockwave to pass with as little interference as possible

Auxiliary procedures

There are certain assisting procedures that might be necessary for avoiding complications and for improving treatment results. Counteraction to the formation of a steinstrasse is accomplished by a stent that should be inserted before treating stones with a surface area exceeding 300 mm^2 or a largest diameter $\geq$20 mm [36, 67, 68]. Thereby, obstruction caused by fragment accumulation is avoided. There is also an indication for ureteral stenting in case of smaller stones in patients with simultaneous bacteriuria or a history of urinary tract infection [32, 68]. Obstruction by fragments without the possibility to pass a stent sometimes requires a percutaneous nephrostomy catheter.

Facilitated fragment clearance after SWL of stones in the kidney or ureter can be accomplished by administration of α-receptor antagonists [69–73]. It might also be of value to speed up the elimination of fragments by a diuretic regimen, but there are no studies supporting such a recommendation.

Identification and localization of radiolucent stones can be made with ultrasonography or by contrast medium administrated through a ureteral catheter or percutaneously [74]. Also intravenous contrast is sometimes helpful, provided no diuretic has been given. Following disintegration of *uric acid* stones oral treatment with alkali should be used to dissolve the fragments [75]. This process is usually quite fast because of the enlarged surface area of the fragments and in many patients it is not at all necessary to proceed to active stone removal.

Although we were unable to demonstrate an advantage of high diuresis during primary treatment of ureteral stones, it can be recommended for re-treatments [76]. Early clinical experience also showed that high diuresis during treatment of stones in the kidney was associated with a better disintegration [77, 78]. Fluid injection through a ureteral catheter in case of impacted stones can open up the space between the stone and the ureteral wall and improve uptake of shockwave power.

All procedures described above can be carried out without regional or general anaesthesia. Therefore, ureteroscopic or percutaneous surgical procedures are considered as alternative endoscopic techniques and not as auxiliary procedures.

Complications and their prevention

The two most feared complications seen after SWL are subcapsular hematoma and septicemia. Although these consequences cannot completely be eliminated, a lot can be done to significantly reduce the risk. Several risk factors associated with an increased risk of bleeding complications from the kidney have been identified (Table 1) [22, 79, 80].

It is essential always to measure the blood pressure before proceeding to SWL. For treatments during which the shockwaves hit the renal tissue there is always a potential risk of vessel rupture and bleeding and it has been a routine not to carry out SWL when the blood pressure is above 160/100 mmHg. This rule is not that important for treatment of ureteral stones, but it should be observed that direction of shockwaves toward the proximal part of the ureter also hits the lower part of the kidney.

Treatment with salicylates (aspirin) should be stopped 7–10 days before the treatment in order to allow new

Table 1 Risk-factors for subcapsular hematoma

Coagulation disorders
Treatment with anticoagulants (salicylates, warfarin)
Hypertension
History of hypertension
Diabetes mellitus
High age (>65–70)

thrombocytes to form [68]. When an emergency treatment is unavoidable pre-treatment with desmopressin (Octosim®) is an option that occasionally can be used [0.3 μg/kg] [81]. Patients under warfarin (and other similar agents) medication can only be treated with SWL if the treatment is temporarily discontinued and replaced by low-molecular heparin in daily doses between 2,500 and 5,000 Units. If and how anticoagulation can be stopped varies according to the reason for this form of treatment and has to respect the patient's interest. Details of how the anticoagulation should be managed have been thoroughly discussed in a recent review article [82]. Experience has shown, however, that if daily doses of heparin above 5,000 Units cannot be avoided an alternative endoscopic approach is safer than SWL.

For patients with coagulation disorders SWL is possible following appropriate medical corrections. Coagulation experts always should be consulted in those cases.

In all patients with risk factors of bleeding a shockwave frequency of 60 (or lower) should be used and ramping carried out slowly so that the lowest power level at which disintegration occurs can be defined. It is important to avoid over-treatment in terms of shockwave power and number [59, 83] and also to make a pause after the first set of shockwaves.

Inasmuch as contusion of renal tissue occurs during SWL, it is important not to repeat shockwave sessions to the kidney with too short intervals. There is no consensus on the minimal interval, but experimental studies have shown that it is wise to allow at least 14 days to pass between successive sessions for stones in the kidney. Although shorter intervals were reported with the HM3-device, this was with a much lower energy density than that in modern lithotripters. For ureteral stones long intervals are not necessary and repeated SWL can be carried out within a few days, but it is often of value to wait until fragments from the previous treatment have passed.

It has also been shown that anti-oxidative agents (e.g. verapamil, allopurinol) can protect the renal tissue from damage [84–86]. This kind of treatment is recommended in case of an expected large number of SWL sessions or in patients with reduced renal function. For the latter group of patients the same careful treatment principles should be applied as those for patients with increased risk of bleeding.

SWL in patients with urinary tract infection is contraindicated because of the obvious risk of a septic complication. In every patient with a positive reaction for bacteriuria or a history of urinary tract infections pretreatment with antibiotics is necessary. Intravenous administration of an antibiotic agent according to the sensitivity pattern should be made 1 h before starting SWL. If no urine culture has been made, a single dose of gensumycin 120–150 mg or ceftazidim 1–2 g has proven effective. For patients with bacteriuria this regimen should be followed by a longer period of oral or intravenous treatment. When there is risk of obstruction following SWL in the presence of bacteria and/or infection, it is a good rule always to insert an internal ureteral stent.

Episodes of ureteral colic during passage of fragments and stones are common. These complications can be counteracted by prescription of diclofenac 50 mg × 2 during the first 5–7 days following the treatment [87].

Residuals

Following satisfactory disintegration of stones in the ureter, the fragments usually pass without problems, albeit repeated treatment sessions are occasionally required. Treatment of ureteral stones might result in stone-free rate exceeding 95 % [12, 31]. Small, smooth and very hard stones can be difficult to break and unless spontaneous passage of such stones occurs, endoscopic stone removal should be considered. Pharmacological facilitation of fragments passage can be accomplished by administration of α-adrenergic receptor antagonists. Tamsulosin is the most commonly used compound [88], but other α-blocking agents appear to be similarly effective.

It was previously suggested that impacted ureteral stones should be pushed up to the kidney with a ureteral catheter for easier disintegration. Apart from the fact that pushing a ureteral stone to the kidney with a ureteral catheter is successful only in some patients, stone disintegration in the kidney might give rise to residual fragments in the kidney. It is therefore generally recommended that stones located in all parts of the ureter are disintegrated in situ.

In contrast to the very high stone-free rates achieved with SWL of ureteral stones, a substantial number of patients treated for stones in the kidney have residual fragments [89, 90]. These findings might comprise isolated minute fragments or accumulation of well-disintegrated fragments of various sizes. Inasmuch as such fragments in most cases are without symptoms, they have been referred to as clinically insignificant residual fragments (CIRFs) or asymptomatic residual fragments (ARFs). This is an annoying finding that has driven urologists to extensive additional endoscopic procedures (RIRS or PNL) in order to improve the outcome and to get a complete stone clearance. Whether a fast intervention in these cases is of the same high interest for the patient as it is for statistics is still under discussion. The fraction of patients with residual fragments after SWL varies according to the size of the stone, intrarenal anatomy and pelvico-caliceal physiology (contraction power). Reported percentage of residual fragments ($\leq$4 mm) after treatment of stones in the kidney is, however, in the range of 30–40 %. How these patients should be treated best is a matter of debate.

It is well recognized that residual infection stone fragments or fragments associated with bacteria need to be eliminated to avoid fast new stone development or chronic urinary tract infection. For such patients an auxiliary endoscopic approach is frequently necessary. It is of note, however, that pure infection stone fragments can be dissolved by percutaneous chemolysis with Renacidin or Suby's solutions [75, 91]. This is a method that should be considered in all patients with a percutaneous nephrostomy catheter or in patients for who endoscopic stone removal means an increased risk.

The recurrence rate in cystine stone forming patients is very high and careful clearance is recommended. For this patient group percutaneous chemolysis with THAM and acetylcysteine solutions is an alternative [75, 92].

Uric acid stone fragments (and even uric acid stones) can advantageously be dissolved by oral chemolytic treatment with alkali such as sodium bicarbonate, sodium potassium citrate or potassium citrate [75]. In the absence of obstruction there is no absolute need for SWL other than to facilitate dissolution by increasing the contact surface area between the fragments and the alkaline urine. To avoid secondary obstruction during oral chemolysis, an internal ureteral stent is sometimes of value. In cases with a nephrostomy catheter, percutaneous irrigation with a THAM solution usually results in a very fast dissolution. The only problems that can be encountered are patients with ammonium urate stones (sometimes seen together with uric acid stones). This stone component reflects infection with urease producing microorganisms. This finding might call for endoscopic fragment removal, but it has been demonstrated that in case of well-disintegrated stones, long-term treatment with antibiotics might results in sterilization of the fragments.

For all patients with infection, cystine and uric acid stones lifelong recurrence preventive measures are necessary and the analytical procedures for such treatment is an obligate part of the management of patients with stones [93–96].

The stone composition is not always obvious and to determine early what kind of stone the patients has formed the following steps are helpful. Demonstration of typical struvite or cystine crystals after urinary sediment examination is diagnostic [97]. In vitro dissolution test of passed fragments in tubes with Renacidin or THAM is also very useful. The measurements of stone densities (expressed in terms of Hounsfield units) on CT images [98–102] as well as comparison with plain film images are other helpful guides. Needless to say, a stone analysis should be carried out in all patients [68]!

The management of patients with residuals after SWL of calcium oxalate and calcium phosphate stones is a more complicated and diverse issue. The course of calcium stone residuals cannot be easily predicted. Some of these fragments might grow and result in new therapy requiring stones, whereas others remain silent and stationary. Literature results on the course of residuals are shown in Fig. 7. In a recent review of close to 150 patients the need for repeated SWL session during a follow-up period of 7 years was recorded in 20 %. Unchanged, passed or minimally changed fragments were observed in 60 % of the patients during a mean follow-up of 5 years (recent personal experience).

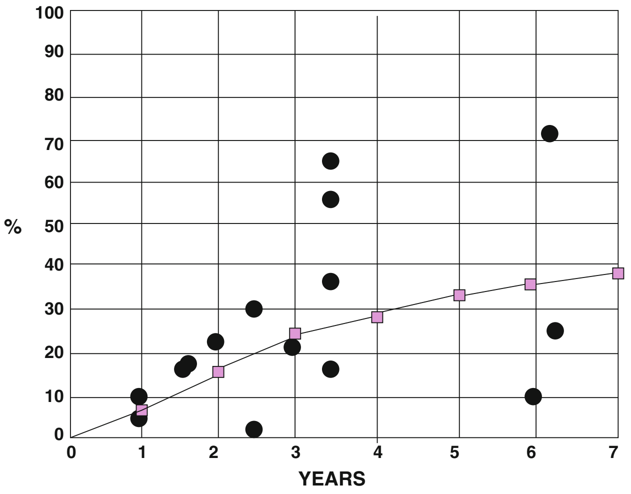

Fig. 7 Course of residual fragments reported in the literature. The *curve* indicated in the diagram represents expected new stone formation in patients rendered stone-free

When endoscopic stone removal is undertaken to clear the collecting system from stone material and "to definitely solve the problem…" it is important to know that also in completely stone-free patients the recurrence rate after 5 years amounts to about 30 % [103]. Moreover, neither PNL nor RIRS are without residual fragments/stones [104]. Stone disease is a chronic abnormality and prevention of recurrent stone formation requires identification of risk factors and appropriate medical advice and/or pharmacological treatment [105–109]. It has been shown that the recurrence rate for residual fragments after PNL could be significantly counteracted by pharmacological treatment [104]. Therefore, it is recommended to collect urine for risk analysis in all patients with residual fragments and to add recurrence preventive measures particularly when the presence of residual fragments is combined with a metabolic risk.

Fragments tend to remain in the kidney due to gravity. Most fragments are found in the lower calyx, but the majority of treated stones are also found in that location [103]. Various more or less complicated geometrical description of the lower calyx anatomy has been presented in order to explain why fragments reside [110–118], but

Table 2 Recommendations for the management of patients with residual fragments

Stone composition	Asymptomatic residual fragments	Symptomatic residual fragments
Calcium oxalate/ calcium phosphate	Follow-up Recurrence prevention	Additional stone Removing procedure
Brushite	Additional stone removing procedure Recurrence prevention	Additional stone removing procedure Recurrence prevention
Uric acid	Oral chemolysis Recurrence prevention	SWL + oral chemolysis Recurrence prevention
Infection stone	Additional stone removing procedure Urine acidification + antibiotics	Additional stone removing procedure Percutaneous chemolysis Urine acidification + antibiotics
Cystine	Additional stone removing procedure Recurrence prevention	Additional stone removing procedure Recurrence prevention

none of them can be used to accurately predict the risk of residual fragments. Such anatomical findings might, however, be useful for selecting those patients who will benefit from non-surgical fragment elimination procedures. Thereby, the inversion/vibration treatment deserves to be mentioned [119, 120]. This is a procedure during which the lower calyx is elevated by inverting the patient. Administration of alkaline citrate has shown increased fragment elimination, but the results are inconsistent [119]. Simultaneous vibration over the kidney during high diuresis has in some studies proved very successful [120]. This is a non-invasive treatment that can improve stone-free rates after SWL. Interestingly, recent animal experiments have indicated that focused ultrasound might be useful for elimination of residual fragments [121].

Another factor that deserves future research is to which extent the contractile power of the renal collecting system influences fragment elimination. It is well recognized that the very powerful system of children results in a surprisingly complete fragment passage [122]. This power obviously fades with increasing age and there are at least indirect signs that large stones residing in calices might further reduce the contractile power of the calyx. It would indeed be desirable to have some pharmacological tools to enforce such properties.

When patients are left with residual fragments in the kidney, an appropriate follow-up programme is mandatory and an important part of modern urology. The interval of repeated imaging that in most cases can be carried out with plain X-ray films (KUB) should be individualized. Thereby conclusions should be drawn on the need of repeated SWL sessions, inversion therapy, recurrence preventive measures, chemolysis or alternative endoscopic stone removal. It stands to reason that the appropriate care of patients with urinary tract stone disease—in order to be maximally low-invasive—requires considerable understanding not only of stone removing procedures, but also of the epidemiology, aetiology and medical treatment of this large group of stone formers. Only in this way can complications of stone disease, emergency visits and cost be kept low.

A summary of how to deal with residual fragments is given in Table 2. For selection of appropriate medical recurrence prevention the readers are referred to other sources [93, 95, 106, 123].

Conclusion

Although endoscopic and invasive procedures such as PNL, URS and RIRS are associated with fewer re-treatments and a higher stone-free rate than that recorded for SWL, it is important to be aware of the price that has to be paid for these minor advantages. The cost of endoscopic procedures is usually higher, anaesthesia and an operating theatre is necessary and the complication rate is higher. Therefore, SWL still turns out to be an excellent first line treatment for the majority of patients with urinary tract concernments provided the technique is appropriately applied. It is important to note, however, that without properly educated and trained operators the success of SWL cannot be ensured.

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