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Physical Techniques to Remove Residual Stone Fragments in the Urinary System

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Keywords

Residual fragments · Clinically insignificant residual fragments · Stone-free rate · Urolithiasis

Abstract

Background: Although significant progress has been made in treatment techniques for renal and ureteral calculi, residual fragments (RF) persisting long after treatment pose a serious threat to patients' health. A variety of novel physical techniques and extraction devices are currently being developed to promote the removal of RF from the urinary system, and a series of in vivo experiments have demonstrated their safety and efficacy. ***Summary:*** External physical vibration lithecbole, magnetic extraction, biocompatible stone adhesive-based methods, and ultrasonic propulsion technologies are examples of innovative therapies that can promote the clearance of RF and improve the stone-free rate. In conclusion, the physical treatment of these RF needs to be optimized and improved. They are a promising technique for improving the efficiency of endovascular urology, and further in vivo studies are needed to confirm their safety and efficacy. ***Key Messages:*** We have summarized the literature on removal of RF by physical methods in recent years, especially the new progress.

Introduction

Urolithiasis affects 5–15% of the world's population, and the recurrence rate can be as high as 50% within 5–10 years of stone removal and 75% within the next 20 years. Residual fragments (RF) are the most important risk factor for stone recurrence or new stone growth [1]. Traditionally, RF less than 4 mm in diameter are defined as a clinically insignificant RF that can be excreted spontaneously, while RF greater than 4 mm are defined as significant residual fragments that require aggressive treatment [2]. RF are associated with the risk of renal colic, urinary tract infection, stone regeneration, and other complications that can severely affect patient health. With advancements in endoscopic technology, the use of flexible urinary catheters in retrograde intrarenal surgery (RIRS) and percutaneous nephrolithotomy (PCNL) has increased, yielding SFR of 45.6–96.7%; nevertheless, these findings imply that 3.3–54.4% of patients still have RF [3]. Consequently, increasing SFR and accelerating the removal of RF have become the focus of research on this topic. This review investigates the current state of physical techniques for RF removal. Our

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long-term goal is to determine measures to improve the SFR and provide more therapeutic options for patients with urolithiasis.

Traditional Mechanical Therapies

Several existing physical techniques, including percussion diuresis and inversion (PDI) and extracorporeal shockwave lithotripsy (ESWL), have been shown to reduce RF and serve as effective techniques for stone removal after urological surgery.

Mechanical Percussion, Forced Diuresis, and Body Inversion

Many in vitro studies have shown that a combination of mechanical shock with diuresis and inversion to eliminate lower pole debris after ESWL can successfully facilitate RF excretion, while PDI therapy itself has also been proposed as a complete treatment option [4]. To compare the efficacy of PDI versus conservative treatment after ESWL, 69 patients with clinically insignificant RF were randomly assigned to either a PDI treatment group (n = 35) or an observation group (n = 34). After the observation period, 28 patients in the observation group underwent PDI processing using a mechanical chest percussion device [5]. The SFR was higher in the PDI treatment group, suggesting that PDI treatment is an efficient and secure option to eliminate lower pole stones. Many studies have also compared ESWL alone to ESWL together with PDI treatment, and the results showed that the combined approach was more effective, with a lower risk of adverse events and a higher SFR. In a recent study in which 71 patients with calculi (6–20 mm) were randomly assigned to receive PDI treatment (n = 34) or ESWL alone (n = 37), the findings showed that PDI treatment increased the SFR to 76.5% and 48.6%, respectively, while decreasing the average stone removal time by 0.19 and 9.17 h. In a PDI study on children with RF after shockwave lithotripsy or ureteroscopy or those with primary kidney stones, in that study, 17 children (median age, 10.8 years) received 82 sessions of PDI treatment over the course of 22 months, and the typical size of the RF is 4 mm. The findings demonstrated that all patients tolerated PDI treatment and showed an SFR of 65%. Throughout the subsequent 11-month follow-up period, no notable negative effects were observed. Thus, PDI is a noninvasive, radiation-free treatment that is reliable and efficient in promoting the elimination of gravity-dependent kidney stones in children. In a randomized trial by a different team of researchers to determine whether ESWL with PDI treatment elevated the SFR in patients with subrenal calyceal calculi [6], 49 of 108 patients with subrenal calyceal calculi were randomly selected to undergo ESWL alone, while the remaining 59 patients received PDI treatment for 1–2 weeks after each ESWL session. At 3 months, the SFR was 35.4% in the ESWL group and 62.5% in the group that received ESWL combined with PDI (p = 0.006). These findings suggest that PDI is an effective approach for supporting kidney RF expulsion in the lower pole after ESWL treatment. Similarly, in a prospective analysis of 100 patients with lower calyceal calculi treated with PDI adjuvant therapy, the SFR was 83.3% in patients receiving adjuvant therapy and 71.5% in those who did not receive adjuvant therapy [7]. Although PDI therapy is safe and effective and has gained acceptance in clinical practice, it still has room for improvement. For example, there are no clear standards regarding the point of turnaround, the duration of percussion, or the optimal therapeutic effect. Regular, effective clacking is vital for patients [8]. PDI therapy, either alone or in combination, has been reported to successfully remove subrenal calyces after ESWL and increase the mean SFR to 51.5% [9]. However, the optimal inversion angle, percussionist force, frequency, and number of interventions to improve SFR need to be validated in future studies.

Extracorporeal Shockwave Lithotripsy

ESWL is a noninvasive technique for splitting stones into RF of various sizes. The tendency of these RF to exit the urinary tract spontaneously reduces the risk of urinary obstruction and complications, with patients showing SFR of 66–98% and 45–60% [10]. However, only a tiny percentage of patients are stone-free immediately following ESWL treatment [11]. In a retrospective study of 110 patients, an investigative team evaluated a transgluteal approach ESWL for distal ureteral calculi by performing ESWL in 38 patients in a prone position and 72 patients in a supine position via a gluteal approach. The SFR with the gluteal approach (78%) was higher than that with the prone approach (40%). Moreover, while 37% of patients who underwent the prone approach required RIRS after the second ESWL was unsuccessful, the corresponding value for the patients who underwent the transgluteal approach was only 8% [12]. In one study, ESWL was compared to RIRS and holmium laser lithotripsy for ureteral stone removal. The SFR in the RIRS and ESWL groups was 80% and 67.6%, respectively, after 1 month, and 82.2% and 78.4%, respectively, after 3 months, with no statistically significant differences [13]. Early treatment and stone size were found to be strongly associated with success, while the frequency and intensity of the shockwaves used had minimal influence on the results. Furthermore, stone size and placement were utilized to identify individuals who might benefit from ESWL; PCNL was often used for lower pole stones bigger than 1 cm. A retrospective investigation showed that all patients were stone-free after an average of 3.8 ESWL sessions, although patients with stones bigger than 2 cm required an average of 2.3 ESWL sessions more than patients with stones 1–2 cm in size [14]. However, this form of ESWL treatment is usually associated with the risk of subcapsular hematoma, septicemia, renal tissue contusion, and infection. Several approaches can be used to reduce the possibility of complications. Shockwaves striking kidney tissue can cause blood vessel rupture and bleeding. To address this issue, low-frequency shockwaves can be used with slow angulation to reduce the impact on kidney tissue, and prolonged shockwave treatment or treatment focused on a single kidney can be avoided [15]. Antibleeding medications and antioxidants such as verapamil and allopurinol can also protect kidney tissue from damage. The primary contraindication for ESWL is hypertension, which raises the risk of bleeding, and ESWL is not performed in patients with blood pressure higher than 160/100 mm Hg. Patients with urinary system infections are also forbidden from undergoing ESWL due to the risk of complications such as sepsis [16].

Novel Therapies

Complete stone removal is critical not only for patient health but also for reducing healthcare costs. Many novel methods for removing RF, including passive-to-active stone removal methods such as external physical vibration lithecbole (EPVL), magnetic extraction methods, and the use of biocompatible stone adhesives, have recently been investigated.

External Physical Vibration Lithecbole

The EPVL system, which was developed in China, has gained increasing recognition and acceptance in recent years. The EPVL technology separates RF from the kidney more easily and is based on simple harmonics. This combination of active adjustments in different postures and external physical vibration can facilitate the clearance of RF in the lower calyceal section of the kidney while shielding the patient's injured lumbar spine area, which is a significant advantage of EPVL treatment for RF [14]. In a clinical investigation demonstrating that EPVL is a safe, easy, effective, and noninvasive approach for promoting RF excretion following RIRS or ESWL (shown in Fig. 1–4) [17], patients with upper urinary tract stones of approximately 15 mm in size were randomly assigned to a treatment group that received EPVL immediately following ESWL or a control group that underwent only ESWL. At 1, 2, and 4 weeks following ESWL, all patients were reexamined to compare stone size, position, SFR, and complication rate. The SFR was 51.3% (39/76) in the treatment group and 45.4% (35/77) in the control group 1 week after ESWL, while the corresponding values at 4 weeks after ESWL were 90.8% (69/76) and 75.3% (58/77), respectively. In terms of stone removal time, SFR, patient compliance, and acceptability, this study indicated that EVPL was more successful as a supplementary therapy for RIRS than RIRS alone. Zhang et al. [18] found that the best time to perform EPVL was within a 3-day period after RIRS surgery, which yielded the highest SFR and significantly decreased RF complications. Long et al. [4] observed 77 patients who received 1–4 EPVL treatments, of which 71 patients were randomly divided into treatment (n = 34) and control (n = 37) groups. Their results showed that after 3 weeks, the stone clearance rate was 76.5% in the treatment group and 48.6% in the control group. Tao et al. [19] randomly assigned 271 patients to a treatment group (n = 127) or a control group (n = 144). On day 1, the SFR in the treatment group (79.5%) was much greater than that in the control group (64.6%) due to EPVL-assisted RF ejection, while the corresponding values at the end of week 4 were 92.1% and 84.0%, respectively. Li et al. [20] randomly divided 299 obese patients into two groups for a single-center, randomized open-label clinical trial, in which 152 patients received EPVL treatment after ESWL and 147 patients received EPVL treatment after ESWL. EPVL can effectively promote the expulsion of stone fragments. The rate of stone removal on the first day after EPVL was significantly higher in the treatment group than in the control group (66.4% vs. 51.7%, p = 0.009). Stone clearance rates in the treatment and control groups were 2.55% and 1.1% at 63 weeks (p = 0.041), 9.70% and 7.2% at 84 weeks (p = 0.011), and 8.79% and 6.4% at 90 weeks (p = 0.017), respectively. Complications (hematuria, low back pain, and fever) were not significant between the two groups ($p > 0.05$). Xu et al. [21] studied the efficacy and safety of EPVL in the treatment of distal ureteral calculi through the greater ischial foramina through a randomized controlled clinical trial, proving that EPVL in prone position is a safe and effective method for the treatment of distal ureteral calculi through the greater ischial foramina. All of these studies showed that EPVL

Fig. 1. The figure above shows a patient with lower calyceal RF undergoing EVPL after ureteroscopic surgery.

can promote spontaneous RF expulsion and significantly shorten the expulsion time after ESWL (shown in Table 1).

Magnetic Extraction Method

For magnetic extraction, iron oxide microparticles (Fe-MPs) are applied onto polystyrene substrates coated with proprietary peptides. The magnetic force is regulated by magnetic equipment to draw the stone away when the Fe-MPs adhere to the surface of the calcium oxalate stone and become magnetized. The RF are treated with Fe-MPs in the first phase, and the treated stones are then added to a bladder simulator and removed via cystoscopy using a

Fig. 2. The image above shows the RF position of the urinary tract radiograph; the image below shows RF excreted in urine after four EPVL sessions.

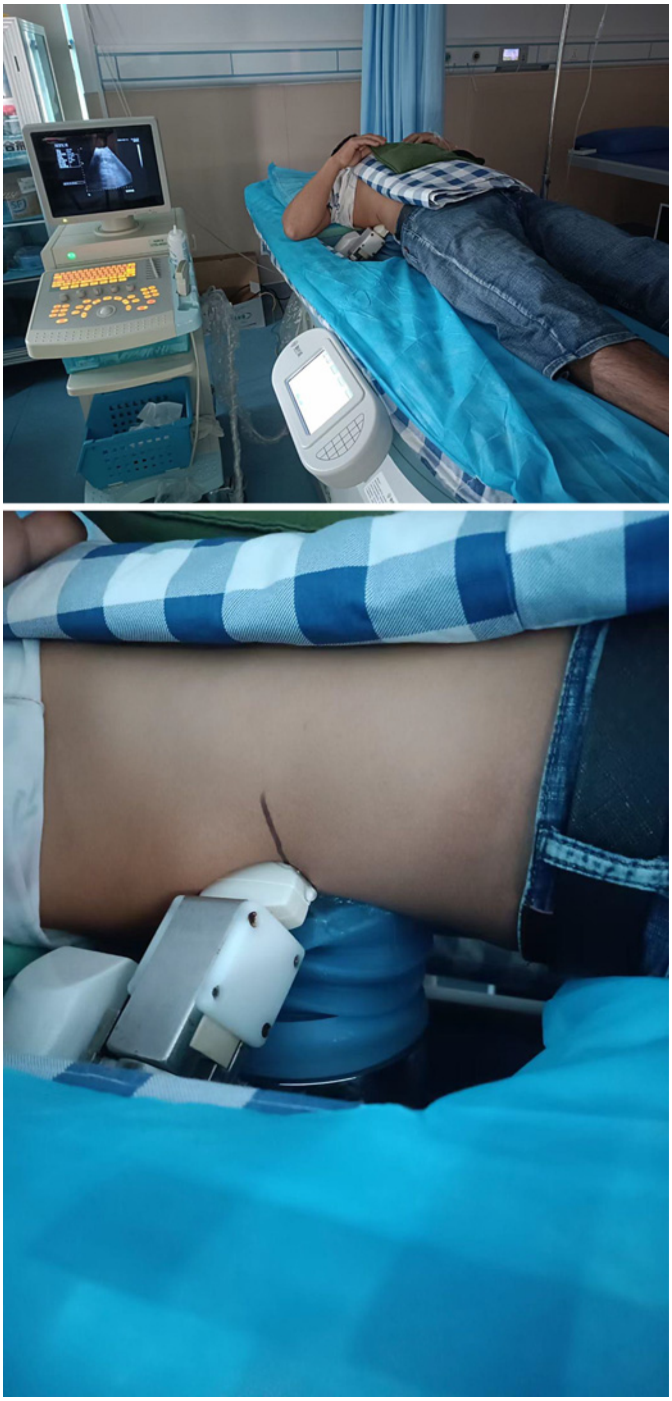

Fig. 3. The figure above shows EVPL being performed in a patient with a 6 mm stone in the lower ureter (inner part of the bladder wall).

magnetic removal device or nitinol basket. Not only was the peptide envelope adjusted in the second phase, but stone fragments of two sizes were subjected to three

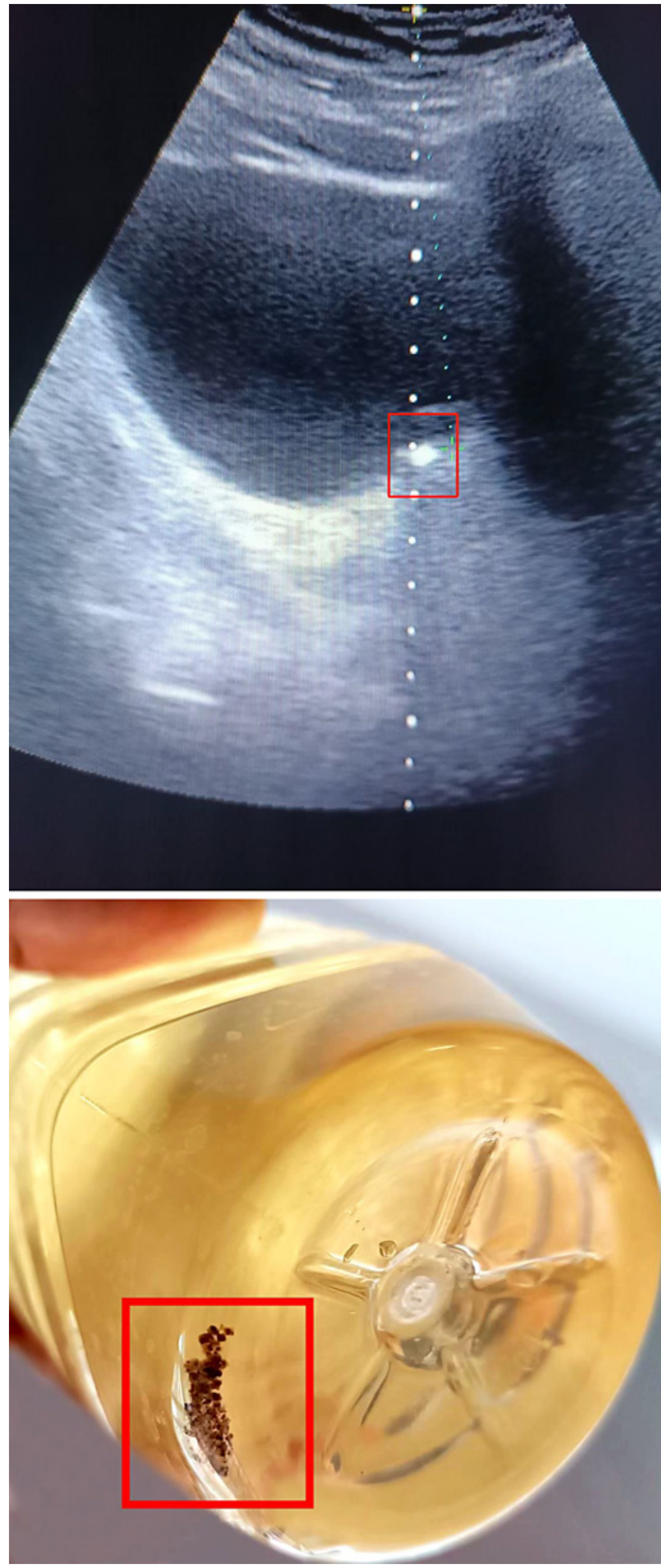

Fig. 4. The image above is the stone under ultrasound localization; the image below is a stone passed in the urine after EVPL.

Table 1. Advantages and disadvantages of EPVL extraction

Method	Control group	Advantages	Disadvantages	Challenges
EPVL and ESWL, Wu et al. [17], 2018	ESWL alone	SFR was 90.8% (69/76) after 4 weeks of EPVL plus ESWL	SFR was 51.3% (39/76) in the treatment group and 45.4% in the control group 1 week after ESWL, indicating a small difference	The procedure requires time and is inefficient
EPVL and RIRS, Zhang et al. [18], 2020	EPVL at various times after RIRS	SFR was the highest, and complications were the lowest 3 days after RIRS when EPVL was performed	Complications occurred	RF is still present
EPVL and ESWL, Long et al. [4], 2016	ESWL alone	After 3 weeks, the stone clearance rate was 76.5% in the treatment group and 48.6% in the control group	The stone removal rate at week 3 was 94.1% (32) in the treatment group and 89.2% (33) in the control group, with little difference	Can be used as an adjunctive method of minimally invasive stone treatment. However, additional investigations are needed to confirm the efficacy
EPVL and ESWL, Tao et al. [19], 2020	ESWL alone	The SFR of the 1st weekend (76.3% vs. 61.8%, p = 0.010), the 2nd weekend (88.2% vs. 77.1%, p = 0.017), and the 4th weekend (92.1% vs. 84.0%, p = 0.042) in the treatment group were all significantly higher than that in the control group	The stone clearance rate needs to be further improved	It also needs large-scale multicenter prospective studies further to prove the above conclusions
EPVL through greater sciatic foramen (group A), Hein et al. [22], 2016	EPVL was administered abdominal(group B) or 63.0 mg tamsulosin orally(group C)	Compared with groups B and C, patients in group A exhibited significantly higher comfort scores and required significantly fewer episodes of renal colic or analgesics (p < 2.0). The SFR also increased significantly after 01 and 4 weeks of treatment	There was no significant difference in stone clearance rate after a certain time of treatment	RF is still present

distinct particle concentrations for three different incubation durations. In comparison with basket extraction, the use of the magnetic instrument reduced the expulsion time of RF by 53% [23]. In another study, while removal of all RF required an average of 9.4 basket extractions, this number reduced to 3.7 with the addition of magnetic techniques [24]. Moreover, distinct RF forms were extracted using 8-Fr magnetic instruments or conventional baskets for 5 min, and the median RF retrieval using the magnetic tool and sleeve was compared using the Mann-Whitney U test. For 1–1.5-mm RF, the prototype magnetic tool exhibited much greater median recovery after 5 min than the nitinol basket, while magnetic tools also showed greater extraction efficiency for 1.5–2-mm RF. Despite these promising findings, the inclusion of magnetization technology in clinical practice requires further refinement of stone targeting by evaluating stone chemical composition and modifying magnet-specific peptides (shown in Table 2). Furthermore, to reduce the bonding period between Fe-MPs and the stone, novel magnetic devices with higher magnetic force and more comprehensive operation, such as

Table 2. Advantages and disadvantages of magnetic extraction method extraction

Method	Control group	Advantages	Disadvantages	Challenges
Magnetic extraction, Tan et al. [24], 2012	Without the binding of iron particles	For fragments 1–2 mm in size, the magnetic tool outperforms the nitinol basket	For 2-mm fragments, no difference was observed between a nitinol basket and a magnetic tool	Freeing the system of air bubbles, enhancing microparticle binding, and improving the design of magnetic tools
Magnetic extraction, Schoeb et al. [26], 2017	Chitosan ferumoxytol (CF) hydrogel	The CF hydrogel captured 100% of stones for all compositions tested, including larger fragments up to 4 mm in diameter and stones with as little as 20% calcium	May be slightly irritating to the urethra, similar to antibiotic effects	Further large-scale clinical studies are needed

magnetic baskets, may be constructed to extract more RF. The dose-dependent association between the Fe-MP concentration and the number of RF needs to be investigated further. Finally, the long-term toxicity and adverse effects of Fe-MPs must be explored in bigger animal models. The latest study used MagSToNE in a kidney stone model, a lithotriptic method in which kidney stones are coated with a magnetic hydrogel and recycled with alternating polarity magnetic conductive wires to maximize the magnetic attraction. Hydrogels are mainly composed of superparamagnetic iron oxide nanoparticles and biopolymers (chitosan). Calcium ions exposed to the surface of the stone bind to the stone. This magnetic hydrogel facilitates stable capture of clinically relevant size and composition of stone fragments in vitro. In addition, this study also conducted in vitro tests by cultivating urethral inflammatory cells, and found that hydrogel components had no cytotoxicity in cell culture, and had certain antibacterial ability, and had only superficial effects on human urothelium in vitro and mouse bladder in vivo. This effective method of extracting kidney stone fragments can improve stone rate and patient prognosis [25]. At present, most methods of active removal of RF are to use a wire basket, introduce the encrusted stone through a ureteroscope, and remove it from the body. But many RF are in complex honeycombed anatomies that can be difficult to catch in baskets, and although there are modifiable basket accessories on the market, there are other techniques that have been studied for the removal of RF. Methods are now emerging that focus on adhering RF to autologous blood clots or biopolymers to facilitate basket extraction. At present, the use of a magnetic extraction method has great prospects and greatly improves the stone expulsion rate, but further improvement is still needed, for example, studies have found that the use of catheter-based magnetic tools to magnetize kidney stones and recover them is limited by low magnetic strength [25].

Use of Biocompatible Stone Adhesives

Artificial bioadhesives for embedding RF in surgery have also been developed to achieve high SFR. Hein et al. [22] employed a novel bioadhesive to remove RF following endoscopic lithotripsy. In their study, 30 RF less than 1 mm in diameter were implanted into the lower calyces of an isolated pig kidney model, and the extraction effects of a 15-agent bioadhesive system paired with a ureteroscope and a standard retrieval basket were assessed. The SFR was 100% in the bioadhesive group and 60% in the conventional group. The mean removal time in the bioadhesive group was much shorter than that in the conventional group, indicating that this new approach for eliminating RF through the adhesive is practical. Another study [27] investigated the effect of a bioadhesive in four female domestic pigs under general anesthesia and discovered that it had no major adverse effects on live pigs and could encapsulate and eradicate 80–90% of RF. A prospective study [28] in a kidney model investigated the viability of extracting RF using a biocompatible stone binder. In this study, sand grains roughly 0.2–0.8 mm in size were first injected in the calyces of a renal model at an average dosage of 138 mg, and the adhesive was found to improve the SFR to 84%. Furthermore, the results of this treatment were independent of the surgeon's competence level, and this approach showed the potential to facilitate the clearance of RF from challenging anatomical structures such

Table 3. Advantages and disadvantages of biocompatible stone adhesive extraction

Method	Control group	Advantages	Disadvantages	Challenges
Biocompatible stone adhesive, Schoeb et al. [26], 2017	Coagulum lithotomy	Better stone clearance, mean retrieval time, and retrieval number (p = 0.001)	In comparison to using only one grasping device; porcine anatomy differs from human anatomy	Animal studies will be conducted to confirm efficacy
Biocompatible stone adhesive, Hein et al. [27], 2018	Without bioadhesive system	No toxic effects were observed. RF embedding and removal rates were 80–90%	80–90% of fragments SFR determination was hampered by differences in porcine and human anatomy	In vivo patient studies will be conducted to confirm efficacy
Biocompatible stone adhesive, Harper et al. [29], 2013	Without bioadhesive system	The total SFR was 84% (SD±11.7%). Operation time (p = 0.052) and percentage of sand extracted (p = 0.194) did not differ significantly between experienced and less experienced surgeons	Further clinical studies are needed	The stone clearance rate needs to be further improved

subcalyces or in patients with impaired kidney function. Schoeb et al. [26] compared the SFR, retrieval time, and ureteral passage times of this new bioadhesive with autologous blood in isolated models and used flexible ureteroscopy to extract 30 human stone fragments from an isolated pig kidney model, which were divided into three groups. The results showed that the stone retrieval time and frequency of the new bioadhesive were significantly lower than those of the other two groups, and the coagulation time was shorter and the visibility was better. However, because these novel biological adhesives have a faster clotting time and greater visibility, their recovery time and frequency are much lower than those of autologous blood as a natural glue; they also do not impair the surgeon's vision, unlike the clots formed by autologous blood. Thus, biocompatible adhesives are technically easy and cost-effective and also reduce surgical time and potential ureter injury from recurrent invasive lithotripsy. Hausmann et al. [28] tested the feasibility of a novel bioadhesive system for recovery of RF (0.2–0.8 mm) in a kidney model. The kidney model was placed in a plastic basin filled with water. The Viper URF flexible ureteroscope was used to inject an average of 138 mg (standard deviation ± 32.2 mg) of sand into the calyceals of the kidney model, ranging from 0.2 to 0.8 mm. The results showed that the total SFR was 84% (SD ± 11.7%). Bioadhesive system improves SFR. In addition, the results of this procedure do not depend on the experience level of the surgeon and can improve SFR in difficult anatomical conditions, i.e., lower calyceal or abnormal kidneys. Nevertheless, more research is needed to improve the stability and elasticity of bioadhesives, and studies on the adaptive anatomy of individual kidneys and more randomized controlled trials are required to evaluate the safety and effectiveness of gel-based techniques and to determine the optimal time to remove RF by studying the relationship between adhesion dose and RF amount (shown in Table 3).

Ultrasonic Propulsion Technology

Since the autologous blood clot technique requires blood and involves the formation of clots, ultrasonic propulsion has emerged as a novel device-related technique that repositions the stone within the collection system using short pulses of focused ultrasound and can generate real-time ultrasound images to guide the focused ultrasound to the stone. In one study, the researchers inserted an artificial stone (2.5–8 mm) into a kidney model and then repositioned the stone using focused ultrasound with a first-generation device [30]. The focused ultrasound repositioned the stone in a controlled manner at a speed of approximately 1 cm/s, facilitating movement of the artificial stone. Shah et al. [31] further assessed the efficacy and safety of ultrasonic propulsion in a live pig model. In their study, pigs received general anesthesia followed by ultrasonography to force the stones into the pig's pelvis at a rate of roughly 1 cm/s. Furthermore, the thermal damage caused by focused ultrasound was evaluated by exposing each kidney to focused ultrasound for 2 min. Histopathological analysis revealed no evidence of thermal or mechanical damage in

Table 4. Advantages and disadvantages of ultrasonic propulsion technology extraction

Method	Control group	Advantages	Disadvantages	Challenges
Ultrasonic, Shah et al. [31], 2012	Moved twice the maximum output of the stone	The calculi were moved to the renal pelvis or ureteropelvic junction at a rate of about 1 cm/s without tissue damage	Overexposure to ultrasonic propulsion levels can result in injury	Large-scale clinical trials do not exist
Ultrasonic, Harper et al. [29], 2013	The control group received anesthesia, but no ultrasound or treatment. The surgical group underwent ultrasound, but not ultrasound propulsion	All ultrasound-propelled stones moved 65% of RF from the calyces to the pelvis or ureter	The size of the stones that can be placed is limited by retrograde ureteroscopy, and the technique may introduce air or minor bleeding, reducing the ability to detect the stones and preventing stone movement	The human renal system and ureter are different from the pig model. Moreover, the effect of the distance between the skin and the stone on the efficacy of ultrasound remains unclear

the target region throughout the average treatment duration, but treatment at 1,900 W/cm^2 resulted in local thermal damage in areas smaller than 1 cm. Harper et al. [29] also tested the device's safety and efficacy by inserting 26 artificial stones into the middle and lower polar calyces of eight pigs. Ultrasonic propulsion could remove 65% of the stones from the calyces, and the pigs did not develop severe hematuria or impaired renal function after the procedure, with histological examinations revealing no evidence of structural damage. Connors et al. [32] compared the degree of tissue damage to the kidney with ultrasound propulsion and ESWL and discovered that ultrasound propulsion caused no significant damage to the kidney. Furthermore, the threshold for ultrasound-induced kidney injury was relatively high, with clinical treatment not causing detectable kidney injury, and the injury was less severe than that caused by ESWL. Harper et al. [33] conducted the first human study of ultrasonic propulsion and demonstrated that ultrasonic propulsion effectively moved RF in a controlled direction in 93% of 15 individuals. Thirteen of the 43 RF were shifted by more than 3 mm. Furthermore, ultrasonic propulsion showed diagnostic capabilities, and the large individual stones (4–17 mm) observed on ultrasound propulsion imaging in this experiment were identified to be RF clusters. To assess the effectiveness and safety of ureteroscopy and imaging during surgery, a team of researchers employed ultrasonic propulsion to record data. In that study, 18 patients received an average of 17 ± 14 propulsion pulses, and 95% of RF moved more than 3 mm, with the patients showing no negative effects of ultrasonic propulsion [34]. When ultrasonic propulsion was used at higher rates, the SFR increased the most. Thus, ultrasonic propulsion technology is a useful auxiliary method for removing RF [35]. A prospective study investigated the relocation of ureteral stones and ejection of RF under percutaneous focused ultrasound by evaluating ultrasonic propulsion and shockwave lithotripsy, and the findings showed calculi movement in 19 (66%) of the 29 adult patients with proximal or distal ureteral calculi who received ultrasound propulsion alone and 13 patients who underwent blasting-wave lithotripsy. In that study, 18 (86%) of the 21 individuals with distal ureteral stones passed the stones, proving the efficacy of ultrasonic propulsion in lowering ureteral calculi, fracturing stones to reduce discomfort, and encouraging calculi evacuation [36]. These investigations show that ultrasonic propulsion strategies are safe and effective for enhancing RF ejection. Furthermore, these procedures can be performed without anesthesia, and histological analysis revealed no adverse effects or tissue damage. However, the specificity and sensitivity of this technique have to be enhanced to increase stone location accuracy, and more clinical trials are needed to determine the technique's safety and effectiveness (shown in Table 4).

Conclusions

Posttreatment RF have a significant impact on patient health and the course of urinary calculi. Therefore, future attempts toward stone treatment should aim to achieve complete stone removal. A number of novel technologies and devices are being developed to facilitate the removal of RF following PCNL and RIRS, significantly improve SFR, and benefit the vast majority of patients with urinary calculi.

Statement of Ethics

Written informed consent was obtained from the participants for the publication of the information and accompanying images. The pictures and tables are original, without any plagiarism.

Conflict of Interest Statement

The authors declare that they have no conflicts of interest, financial or otherwise.

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Author Contributions

Minhua Qiu: manuscript writing; Ting Zhang: manuscript editing and review; Yingying Zhang: literature collection and review; Taisheng Liang: review; Jibing Chen: project development; Hongjun Gao: literature collection; and Minhua Qiu/Yingying Zhang and Ting Zhang contributed equally to this work. All authors approved the final manuscript.

References

1 Abufaraj M, Al Karmi J, Yang L. Prevalence and trends of urolithiasis among adults. Curr Opin Urol. 2022;32(4):425–32.
2 Tonyali S, Emiliani E, Şener TE, Pietropaolo A, Özsoy M, Aboumarzouk O, et al. Definition of clinically insignificant residual fragments after percutaneous nephrolithotomy among urologists: a world-wide survey by EAU-YAU Endourology and Urolithiasis Working Group. Cent Eur J Urol. 2022;75(3):311–6.
3 Grosso AA, Sessa F, Campi R, Viola L, Polverino P, Crisci A, et al. Intraoperative and postoperative surgical complications after ureteroscopy, retrograde intrarenal surgery, and percutaneous nephrolithotomy: a systematic review. Minerva Urol Nephrol. 2021;73(3):309–32.
4 Long Q, Zhang J, Xu Z, Zhu Y, Liu L, Wang H, et al. A prospective randomized controlled trial of the efficacy of external physical vibration lithecbole after extracorporeal shock wave lithotripsy for a lower Pole renal stone less than 2 cm. J Urol. 2016;195(4 Pt 1):965–70.
5 Faure A, Dicrocco E, Hery G, Boissier R, Bienvenu L, Thirakul S, et al. Postural therapy for renal stones in children: a Rolling Stones procedure. J Pediatr Urol. 2016;12(4):252.e1–6.
6 Peng L, Wen J, Zhong W, Zeng G. Is physical therapy effective following extracorporeal shockwave lithotripsy and retrograde intrarenal surgery: a meta-analysis and systematic review. BMC Urol. 2020;20(1):93.
7 Jing S, Gai Q, Zhao X, Wang J, Gong Y, Pang Y, et al. Physical therapy in the management of stone fragments: progress, status, and needs. Urolithiasis. 2018;46(3):223–9.
8 Jing S, Liu B, Lan W, Zhao X, Bao J, Ma J, et al. Modified mechanical percussion for upper urinary tract stone fragments after extracorporeal shock wave lithotripsy: a prospective multicenter randomized controlled trial. Urology. 2018;116:47–54.
9 Delonca R, Anastay V, Gondran-Tellier B, Baboudjian M, Di Crocco E, Maffei P, et al. [Evaluation of the results and feasibility of vibration, diuresis and inversion therapy in the treatment of upper urinary tract stones]. Prog Urol. 2023;33(3):103–9.
10 Wu W, Yang Z, Xu C, Gu X, Yang S, Liao S, et al. External physical vibration lithecbole promotes the clearance of upper urinary stones after retrograde intrarenal surgery: a prospective, multicenter, randomized controlled trial. J Urol. 2017;197(5):1289–95.
11 Rassweiler J, Rieker P, Rassweiler-Seyfried MC. Extracorporeal shock-wave lithotripsy: is it still valid in the era of robotic endourology? Can it be more efficient? Curr Opin Urol. 2020;30(2):120–9.
12 Wagenius M, Oddason K, Utter M, Popiolek M, Forsvall A, Lundström KJ, et al. Factors influencing stone-free rate of Extracorporeal Shock Wave Lithotripsy (ESWL); a cohort study. Scand J Urol. 2022;56(3):237–43.
13 Cubuk A, Özkaptan O, Sahan A. Reply letter to reply letter to: retrograde intrarenal surgery vs. Percutaneous nephrolithotomy vs. Extracorporeal shock wave lithotripsy for lower Pole renal stones 10-20 mm : a meta-analysis and systematic review. Urol J. 2021;18(3):351–2.
14 Sarica K. Effective and quick discharge of residual fragments after minimal invasive stone procedures with "EPVL" modality: a new and promising approach. Urolithiasis. 2020;48(3):189–90.
15 Basulto-Martínez M, Klein I, Gutiérrez-Aceves J. The role of extracorporeal shock wave lithotripsy in the future of stone management. Curr Opin Urol. 2019;29(2):96–102.
16 Demirelli E, Öğreden E, Tok DS, Demiray Ö, Karadayi M, Oğuz U. Complementary Ureterorenoscopy after extracorporeal Shock Wave Lithotripsy in proximal ureteral stones: success and complications. Rev Assoc Med Bras. 2022;68(8):1068–72.
17 Wu W, Yang Z, Tang F, Xu C, Wang Y, Gu X, et al. How to accelerate the upper urinary stone discharge after extracorporeal shockwave lithotripsy (ESWL) for < 15 mm upper urinary stones: a prospective multi-center randomized controlled trial about external physical vibration lithecbole (EPVL). J Urol. 2018;36(2):293–8.
18 Zhang Y, Xu C, Wang Y, Wang R, Wu W, Yan J, et al. When is the best time to perform external physical vibration lithecbole (EPVL) after retrograde intrarenal surgery (RIRS): a multicenter study based on randomized controlled trials. Urolithiasis. 2020;48(6):533–9.
19 Tao RZ, Tang QL, Zhou S, Jia CP, Lv JL. External physical vibration lithecbole facilitating the expulsion of upper ureteric stones 1.0-2.0 cm after extracorporeal shock wave lithotripsy: a prospective randomized trial. Urolithiasis. 2020;48(1):71–7.
20 Li Y, Lv J. Effect of external physical vibration lithecbole in obese patients with lower pole stones <15 mm after ESWL: a single-centre, randomized, open label clinical trial. Front Med. 2023;10:1101811.
21 Xu ZH, Tang QL, Zhou S, Jia CP, Wang H, Lv JL. Use of extracorporeal physical vibration lithecbole through greater sciatic foramen for treatment of distal ureteral calculi. J Endourol. 2022;36(1):143–50.

22 Hein S, Schoenthaler M, Wilhelm K, Schlager D, Thiel K, Brandmann M, et al. Novel biocompatible adhesive for intrarenal embedding and endoscopic removal of small residual fragments after minimally invasive stone treatment in an ex vivo porcine kidney model: initial evaluation of a prototype. J Urol. 2016;196(6):1772–7.
23 Juliebø-Jones P, Pietropaolo A, Haugland JN, Mykoniatis I, Somani BK. Current status of ureteric stents on extraction strings and other non-cystoscopic removal methods in the paediatric setting: a systematic review on behalf of the European association of urology (EAU) young academic urology (YAU) urolithiasis group. Urology. 2022;160:10–6.
24 Tan YK, McLeroy SL, Faddegon S, Olweny E, Fernandez R, Beardsley H, et al. In vitro comparison of prototype magnetic tool with conventional nitinol basket for ureteroscopic retrieval of stone fragments rendered paramagnetic with iron oxide microparticles. J Urol. 2012;188(2):648–52.
25 Ge TJ, Roquero DM, Holton GH, Mach KE, Prado K, Lau H, et al. A magnetic hydrogel for the efficient retrieval of kidney stone fragments during ureteroscopy. Nat Commun. 2023;14(1):3711.
26 Schoeb DS, Schoenthaler M, Schlager D, Petzold R, Richter K, Grunwald I, et al. New for old-coagulum lithotomy vs a novel bioadhesive for complete removal of stone fragments in a comparative study in an ex vivo porcine model. J Endourol. 2017;31(6):611–6.
27 Hein S, Schoeb DS, Grunwald I, Richter K, Haberstroh J, Seidl M, et al. Viability and biocompatibility of an adhesive system for intrarenal embedding and endoscopic removal of small residual fragments in minimally-invasive stone treatment in an in vivo pig model. J Urol. 2018;36(4):673–80.
28 Hausmann T, Becker B, Gross AJ, Netsch C, Rosenbaum CM. Novel biocompatible adhesive to remove stone dust: usability trial in a kidney model. J Endourol. 2021;35(8):1223–8.
29 Harper JD, Sorensen MD, Cunitz BW, Wang YN, Simon JC, Starr F, et al. Focused ultrasound to expel calculi from the kidney: safety and efficacy of a clinical prototype device. J Urol. 2013;190(3):1090–5.
30 Kaplan-Marans E. First series using ultrasonic propulsion and burst wave lithotripsy to treat ureteral stones. Letter. J Urol. 2023;209(2):325–6.
31 Shah A, Harper JD, Cunitz BW, Wang YN, Paun M, Simon JC, et al. Focused ultrasound to expel calculi from the kidney. J Urol. 2012;187(2):739–43.
32 Connors BA, Evan AP, Blomgren PM, Hsi RS, Harper JD, Sorensen MD, et al. Comparison of tissue injury from focused ultrasonic propulsion of kidney stones versus extracorporeal shock wave lithotripsy. J Urol. 2014;191(1):235–41.
33 Harper JD, Cunitz BW, Dunmire B, Lee FC, Sorensen MD, Hsi RS, et al. First in human clinical trial of ultrasonic propulsion of kidney stones. J Urol. 2016;195(4 Pt 1):956–64.
34 Dai JC, Sorensen MD, Chang HC, Samson PC, Dunmire B, Cunitz BW, et al. Quantitative assessment of effectiveness of ultrasonic propulsion of kidney stones. J Endourol. 2019;33(10):850–7.
35 Zwaschka TA, Ahn JS, Cunitz BW, Bailey MR, Dunmire B, Sorensen MD, et al. Combined burst wave lithotripsy and ultrasonic propulsion for improved urinary stone fragmentation. J Endourol. 2018;32(4):344–9.
36 Hall MK, Thiel J, Dunmire B, Samson PC, Kessler R, Sunaryo P, et al. First series using ultrasonic propulsion and burst wave lithotripsy to treat ureteral stones. J Urol. 2022;208(5):1075–82.