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REVIEW

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Bladder lithiasis: from open surgery to lithotripsy

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Abstract Bladder calculi account for 5% of urinary calculi and usually occur because of bladder outlet obstruction, neurogenic voiding dysfunction, infection, or foreign bodies. Children remain at high risk for developing bladder lithiasis in endemic areas. Males with prostate disease or relevant surgery and women who undergo anti-incontinence surgery are at a higher risk for developing vesical lithiasis. Open surgery remains the main treatment of bladder calculus in children. In adults, the classical treatment for bladder calculi is endoscopic transurethral disintegration with mechanical cystolithotripsy, ultrasound, electrohydraulic lithotripsy, Swiss Lithoclast, and holmium:YAG laser. Novel modifications of these treatment modalities have been used for large calculi. Open and endoscopic surgery requires anesthesia and hospitalization. Alternatively, extracorporeal shock wave lithotripsy has been demonstrated to be simple, effective, and well tolerated in high-risk patients. Recently, simultaneous percutaeous suprapubic and transurethral cystolithotripsy has been tested as well as percutaneous cystolithotomy by using a laparoscopic entrapment sac.

Keywords Bladder · Calculus · Lithiasis · Lithotripsy · Shock wave lithotripsy

Past and present of bladder lithiasis

Among the physicians of the fifth and fourth centuries BC the symptoms of urinary lithiasis were well known [1]. Specialists for urinary lithiasis must have been in existence, as the Hippocratic Oath mentions that the treatment of calculus is to be left in their hands [1]. The oldest bladder stone so far discovered belonged to a boy in Egypt, and was dated at about 4800 BC [2]. The anatomist Scarpa, scientist Newton, philosopher Bacon, Peter the Great, Louis XIV, George IV, and Napoleon III have all been said to suffer from bladder lithiasis [1].

In Europe, during the nineteenth century, vesical lithiasis was usually diagnosed in children. Since the industrial revolution, improved nutrition and antimicrobial treatment have essentially eliminated pediatric bladder lithiasis in the Western world [3]. However, in underdeveloped countries children still suffer from endemic primary bladder calculi. Nowadays, bladder calculi represent 5% of all urinary stones in the Western world [4]. Unfortunately, few contemporary series regarding bladder calculi exist in the worldwide literature.

Etiology, pathogenesis, and presentation

Stone formation and composition

In contrast to the rapidly clearing tubules of the kidney, the bladder is a reservoir of relatively idle urine and its precipitates. Infection and bladder outlet obstruction (BOO) may cause supernaturation and heterogeneous nucleation around a nidus. In addition, aggregation results in crystal growth and stone formation.

Nutritional deficiencies in vitamin A, magnesium, phosphate, and vitamin B_6, combined with a low-protein and high-carbohydrate diet are implicated in the pathogenesis of pediatric bladder lithiasis, in Africa and Middle East [5]. Furthermore, dehydration, diarrhea, fever, and infection decrease urine production and enhance crystallization.

The composition of bladder calculus is influenced by the pH and the degree of saturation of the urine [3]. Most calculi are of mixed composition and if infection is present, struvite is the major constituent [6]. Vesical struvite calculi are highly prevalent because bladder infections are more common than renal infections. In the United States, calcium oxalate is the major constituent of calculi, while in Europe, uric acid and urate stones are most prevalent [7].

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Predisposing factors

Diet, voiding dysfunction, and uncorrected anatomic abnormalities, such as posterior urethral valves and vesicoureteral reflux, predispose children to vesical lithiasis. In adults, bladder calculi rarely occur spontaneously; there must be a predisposing factor, such as voiding dysfunction, BOO, infection, or a foreign body (sutures, catheters, self-introduced objects), to promote stone formation [3]. Hence, calculi in adults are secondary phenomena, and the primary etiology must be addressed because recurrence is likely. Any residual fragment should be considered a treatment failure since it is highly likely to result in recurrence, as spontaneous passage is unlikely, given that obstruction or incomplete emptying is usually present.

In men, factors, such as urethral stricture, benign prostatic hyperplasia (BPH), bladder diverticulum, cystocele, and neurogenic bladder, are associated with bladder calculus formation. Furthermore, surgery, such as prostatectomy and diverculectomy, can predispose to vesical lithiasis, although the use of absorbable sutures has minimized this complication [8]. In women, the majority of vesical calculi are secondary to genital prolapse, female pelvic surgery, neurogenic bladder, or foreign bodies. There are numerous reports concerning bladder migration of intrauterine devices and intravaginal accessories, including pessaries, diaphragms, and cerclages. Calculus formation around the intravesical portion of tension-free vaginal tapes after anti-incontinence operations is well documented [9].

In both genders, spinal cord injury predisposes to the development of vesical lithiasis. Indwelling Foley catheters may cause urinary tract infection, urothelial erosion, and stone formation. Similarly, encrustation is a well-known complication of indwelling ureteral double-J stents. In transplant patients, most of the bladder calculi have been associated with a foreign body or tissue ischemia. In a retrospective study among 500 consecutive renal transplant patients, 7 cases (1.4%) of bladder lithiasis were encountered. In such patients care should be taken to limit intravesical sutures and minimize the use of perivesical clips [10]. Similarly, careless surgical technique remains a significant culprit for vesical lithiasis in bladder-augmentation surgery. In such procedures the use of ileum and colon tissues may result in stone formation, because these gut segments are colonized by urease-producing organisms [3, 11].

Risk for bladder cancer

There appears to be an association between long-standing vesical lithiasis and formation of malignant bladder tumors. The calculus may cause chronic inflammation, infection, bulbous edema, pronounced congestion, and ulceration may appear. Continuous mucosal injury, disruption of the protective glycosaminoglycan layer, and subsequent inflammation secondary to vesical lithiasis substantiate the correlation between bladder carcinogenesis and vesical calculus [3].

Clinical presentation

Typical symptoms of a vesical stone are intermittent and painful voiding with terminal hematuria. Nonvoiding discomfort might be dull, or present as a sharp lower abdominal pain, which is aggravated by exercise and sudden movements. Severe pain usually occurs near the end of micturition, as the stone impacts on the bladder neck. The pain may be referred to the tip of the penis, along the course of the second and third sacral nerve, or to the scrotum. In children, the pain may be referred to the perineum through the third and fourth sacral nerves [7, 12].

Frequency of urination is usually enhanced by activity. Urgency is present in 40–50% of patients, and interruption of the stream in 30–40% of patients [7, 12]. In the presence of infection, nocturia occurs, urgency is increased, and terminal pain is pronounced. In children, priapism and noctural enuresis may occur. Lastly, more than 50% of bladder calculi are not discernible on plain X-rays [12]. The most accurate mean of diagnosis remains cystoscopy.

Treatment

Relieving BOO, eliminating infection, and performing meticulous surgery are paramount in treating bladder lithiasis. However, a recent prospective study demonstrated that bladder lithiasis is not an absolute indication for prostate surgery [13]. The size and composition of the stone, underlying co-morbidity, previous surgery, patient morphology and compliance, operative costs and available instrumentation should be considered before definite treatment. Treatment modalities for bladder lithiasis are detailed in Table 1, while an algorithm of the most frequently used modalities is presented in Fig. 1.

Conservative treatment

In children's diet, the addition of phosphorous, protein, vitamins, and magnesium can decrease significantly the incidence of vesical lithiasis in endemic areas. Furthermore, a careful metabolic assessment of young stone formers would be helpful, according to the relevant guidelines for upper tract calculi [5]. In adults, although satisfactory results for stone dissolution have been reported with the use of Suby's G or M solution, this treatment is protracted and rarely employed [7, 12]. Renacidin may be administered to dissolve struvite or phosphate calculi. It may prove beneficial in irrigating indwelling suprapubic or urethral catheters [7, 12]. Renacidin produces little bladder irritability as a 10%

Table 1 Treatment modalities for bladder lithiasis

Treatment modalities	References
Conservative treatment (e.g., renacidin, alkaline solutions)	[7, 12]
Open cystolithotomy	[14]
Mechanical cystolithotripsy	[14, 15]
Intracorporeal lithotripsy	
Ultrasound	[40]
Electrohydraulic	[10, 40]
Swiss Lithoclast	[18, 23, 40]
Neodym:YAG laser	[16]
Holmium:YAG laser	[10,18–20]
Extracorporeal shock wave lithotripsy	[26–32, 38, 39]
Percutaneous cystolithotripsy	[33–36]
Combined procedures	[34, 35]

solution. Twice or thrice daily irrigations with 0.25 or 0.5% acetic acid solution also serve as a beneficial prophylaxis against recurrent struvite calculi [7, 12]. Moreover, uric acid calculi may be dissolved by irrigation with alkaline solutions.

Open and transurethral surgery

As early as 1963, routine open cystolithotomy was challenged as the optimal treatment for vesical lithiasis [14]. As late as 1990, tactile litholopaxy was used in a series of 45 patients with a 91.1% success rate and a complication rate of 31% [15]. The classical treatment for bladder calculi is endoscopic transurethral disintegration. Vesical calculi can be treated endoscopically by mechanical cystolithotripsy, litholapaxy, ultrasound and electrohydraulic lithotripsy (EHL), Swiss Lithoclast, neodym:YAG, and holmium:YAG laser lithotripsy [7, 12, 16]. The usage of the holmium:YAG laser has revolutionized the treatment of urinary lithiasis and this might be the intracorporeal modality of choice, especially with the availability of novel fibers [17]. Several studies have addressed the advantages of holmium:YAG laser lithotripsy for treating bladder lithiasis, in comparison with other modalities [18–20].

Despite the improvement of endourologic instruments, open surgery is still the gold standard for treating pediatric vesical lithiasis. Recently, among 70 cases of pediatric vesical lithiasis, the treatment performed was open surgery in 99% [21]. In developing countries open surgery still remains the treatment of choice. For instance, a recent study among 94 patients with bladder lithiasis in Senegal reported that open procedure took place in 96% [22].

Traditionally, treatment of large (>4 cm) vesical calculi has been via open surgery. However, there are reports demonstrating that the use of the holmium:YAG laser was successful and without complications in studies upon 12 and 14 patients with mean stone diameter of 5.5 and 6 cm, respectively [19, 20]. Moreover, pneumatic lithotripsy has proven quite effective in fragmenting large, hard calculi with minimal tissue injury [7, 12]. Also, the Swiss Lithoclast has been successfully used in 17 patients with neurogenic bladder and vesical lithiasis [23].

In cases of bladder lithiasis secondary to renal transplantation, various forms of lithotripsy have been employed. Studies have demonstrated that holmium:YAG laser appeared to be both efficacious and safe [10]. In these studies, the use of EHL and litholapaxy was complicated with mucosal bleeding, which necessitated Bugbee fulguration.

The resectoscope can facilitate the removal of large stone fragments, by using a modified technique of standard cystoscopy [24]. Recently, a novel technique was introduced for transurethral cystolitholapaxy by using the Amplatz sheath in the male urethra, in cases of large bladder stones [25].

Extracorporeal shock wave therapy

Shock wave lithotripsy (SWL) for vesical lithiasis appears to be simple, well tolerated, and effective, especially in high-risk patients. Salient advantages of SWL are: avoidance of anesthesia, shortest catheterization time, and minimal hospital stay. However, SWL does not address etiology nor does it usually remove all fragments, while its efficacy is influenced by calculus size. Therefore, SWL should not be considered as a first-line treatment for the vast majority of adults with bladder lithiasis.

Several studies have demonstrated that results are similar between the different types of lithotriptors [26–31]. Kostakopoulos et al. [26] treated 36 patients with vesical lithiasis with the HM-4 Dornier lithotripter, achieving a 72% stone-free rate. The remaining patients

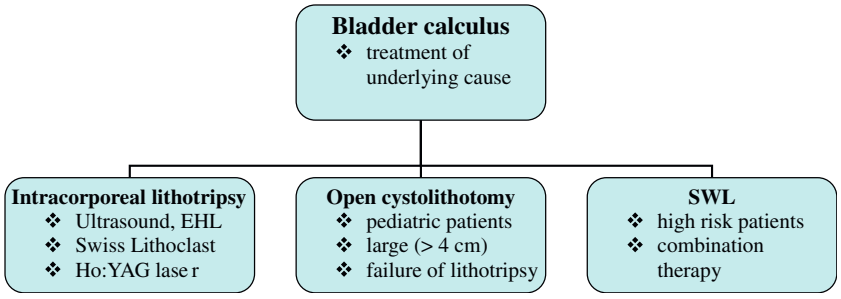

Fig. 1 Algorithm of the most frequently used treatments for bladder calculus

required cystoscopic removal of non- or poorly fragmented calculi. Husain et al. [27] performed lithotripsy with the HM-3 Dornier lithotripter in 24 patients, followed by cystolithalopaxy, and they reported a success rate of 83%. Delakas et al. [28] treated 52 patients with the MPL 9000-X Dornier lithotripter. Complete fragmentation was achieved after a single session in 88.4%, and after two sessions in 5.7%, while adjunctive cystoscopy for evacuation of stone fragments took place in 17% of patients. Garcia Cardoso et al. [29] treated 45 patients by using the Storz Modulith SL 10/SL 20. Overall stone elimination was achieved after 1–5 sessions in 99.4% and 13% of the patients required endoscopic procedures to evacuate stone fragments. Bhatia et al. [30] employed SWL with the Simens Lithostar in 18 patients with bladder lithiasis. Complete fragmentation was achieved in 77.7% after a single session, and after two sessions in 22.2%. Lastly, Kojima et al. [31] applied SWL for the elimination of bladder lithiasis in 17 patients and the overall success rate was 76.4%. However, concern has risen after Salama et al. [32] applied SWL in 18 rabbits with bladder lithiasis. Examination of the dissected animals revealed dose-independent bleeding in the testicles and prostates. More studies are needed to show the long-term sequel of these changes on the male genital system.

Percutaneous procedures

Novel percutaneous methods for stone extraction have been developed. The attempt to provide minimally invasive techniques, and spare the urethra and bladder neck is appealing. However, not enough relevant experience has been accumulated.

Recently, Salah et al. [33] performed percutaneous cystolithotomy in 155 children with endemic bladder lithiasis and concluded that this procedure is safe and effective. Sofer et al. [34] presented a combined technique of percutaeous suprapubic and transurethral cystolithotripsy in 12 consecutive patients with bladder calculus >40 mm in diameter. In particular, a percutaneous 30F access was obtained under cystoscopic control. Fragmentation and stone removal were performed simultaneously by using a Swiss Lithoclast, holmium laser, and/or ultrasound lithotripter, through both percutaneous and transurethral routes. The median operation time was 56 min, morbidity was minimal, and the median hospitalization time was 2.7 days. The simultaneous use of two modalities for stone fragmentation represents a safe, effective, and minimally invasive way for treating large bladder calculi. In the same study, 50% of the patients underwent transurethral resection of the prostate (TURP), which did not prolong hospitalization. Similarly, Ather et al. [35] demonstrated that morbidity did not increase when cystolitholapaxy was combined with TURP.

Percutaneous cystolithotomy with the use of a laparoscopic entrapment sac has been shown to be a safe, useful, and minimal invasive modification of contemporary percutaneous techniques. Miller et al. [36] successfully performed this procedure in four patients with augmented bladders, on an outpatient basis. Under endoscopic guidance, a 10 mm laparoscopic trocar was placed percutaneously into the bladder through the previous suprapubic tube site.

Comparative treatment studies

Comparative studies concerning the treatment of vesical lithiasis are scanty. Mahran et al. [37] compared open cystolithotomy in 25 children, with endourologic treatment (transurethral or suprapubic) in 27 children. In the latter group, 15% of the patients developed early and late complications.

Bhatia et al. [38] treated 128 patients with open cystolithotomy (5 patients), manual lithalopaxy (80 patients), or SWL (43 patients). Open surgery resulted in 100% stone removal at one setting, but required the longest hospital stay (5.2 days). Manual lithalopaxy had the biggest complication rate (25%), including bladder perforation, intraoperative bleeding, and urethral stricture, while it resulted in a mean hospital stay of 2.4 days. SWL had the shortest hospitalization time (20 h), but in four patients additional SWL was required for complete fragmentation, and in two cases urethral fragment impaction was recorded. The same investigators treated 144 bladder calculus with either mechanical cystolithotripsy (86 patients) or ESWL (58 patients), under spinal anesthesia and intravenous sedation, respectively [39]. The early complication rate was 19.7 and 6.8%, respectively, while the corresponding mean hospital stay was 60 and 18 h.

Razvi et al. [40] compared the efficacy of manual lithotripsy, ultrasonic lithotripsy, EHL, and Swiss Lithoclast devises in 53, 17, 16, and 20 patients, respectively. The success rates were, respectively, 90 and 10%, 88 and 2.5%, while the complication rates were 63 and 8%, 85 and 10%. Lastly, in a comparative study between the holmium:YAG laser (23 patients) and the Swiss Lithoclast (10 patients), the authors concluded that the holmium:YAG laser is preferable for larger bladder calculi [18].

Epilogue

Bladder lithiasis remains a clinical problem in both developing and developed countries. The best treatment for pediatric vesical lithiasis is prevention by improving the standard of living. Relieving BOO, eliminating infection, and removing foreign bodies are paramount in treating bladder lithiasis. Stone characteristics, physical status, operative costs, and available instrumentation should be considered before definite treatment.

Open surgery is the treatment of choice for bladder lithiasis in children. In adults, the classical treatment for

vesical lithiasis is endoscopic transurethral disintegration with several modalities. Recently, the usage of the holmium:YAG laser has shown very promising results. However, open and endoscopic surgery requires anesthesia and hospitalization. Alternatively, SWL has been demonstrated to be simple, effective, and well tolerated in high-risk patients. Novel treatment modalities, such as SWL and percutaneous techniques, are subject to further evaluation through comparative randomized clinical trials.

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