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REVIEW

Laparoscopic urinary stone surgery: an updated evidence-based review

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Abstract The treatment of urinary lithiasis has been revolutionized during the last three decades. Minimally invasive therapies in the form of endoscopic surgery in companion with the advent of shock wave lithotripsy have diminished the role of open stone surgery. Laparoscopy, another minimally invasive treatment, is continuously gaining place in the treatment of urinary stones, mainly replacing open surgery. We have tried to identify the level of the evidence and grade of recommendation, according to the evidence-based medicine criteria, in studies supporting the laparoscopic approach to stone extraction. The highest level of evidence (IIa) was found for laparoscopic ureterolithotomy. It is technically feasible with the advantage of being minimally invasive and having lower postoperative morbidity compared to open ureterolithotomy. It is mostly recommended (grade B) for large impacted stones or when endoscopic ureterolithotripsy or shock wave stone disintegration have failed. Laparoscopic pyelolithotomy is feasible but rarely indicated in the present era (III/B). Laparoscopic nephrolithotomy may be indicated to remove a stone from an anterior diverticulum or when PNL or flexible ureteroscopy have failed (III/B).

Keywords Evidence-based medicine · Laparoscopy · Urinary stones

Introduction

The management of calculus disease has changed with the advent of extracorporeal shock wave lithotripsy (SWL), percutaneous nephrolithotomy (PNL), and rigid or flexible ureteroscopy (URS) [1, 2]. However, despite the technical development and the expanding indications, the new technologies have not been able to completely replace open surgery [3]. There are still some situations where open surgery could be the "most suitable option" for treating calculus disease [4]. These are the cases that could be considered for potential management with laparoscopic surgery, which can actually replicate the steps of open surgery [5, 6].

Wickham et al. [7] were the first to describe an attempted removal of ureteral calculus using the laparoscope in the retroperitoneum. Since then, several studies have been reported on laparoscopic management of calculus disease including ureterolithotomy [6, 8–12], pyelolithotomy [13–17], anatrophic nephrolithotomy [18], nephrectomy, and nephroureterectomy [15, 19]. Various indications for laparoscopic surgery for calculus disease are summarized in Table 1. However, these indications have not been clearly defined and may vary from center to center depending on the available expertise (Evidence level IV/C). There are few comparative studies between laparoscopic and open stone surgery [8, 20] and laparoscopic and percutaneous surgery [17] (Evidence level IIa/B).

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Table 1 Indications for laparoscopic stone surgery

Organ	Procedure	Indication
Kidney	Pyelolithotomy	Failure of endourologic management
		Complex renal anatomy
		Concomitant repair of PUJ obstruction
	Nephrolithotomy	Failure of endourologic management
		Complex calculi
		Concomitant repair of caliceal diverticula
	Polar nephrectomy	Non-functioning kidney portion
		Duplex system with non-functioning moiety
	Simple nephrectomy-nephroureterectomy	Non-functioning kidney
Ureter	Ureterolithotomy	Failure of endourologic management
		Lager or impacted stone
		Stone in megaureter
Bladder	Stone retrieval	Stone retrieval and diverticulectomy

Our objective was to identify the level of the evidence published in literature supporting the laparoscopic approach to stone extraction.

Materials and methods

Searching for human Randomized Controlled Trials/Clinical trials/Review articles/Meta-analysis/Practiced Guidelines and Editorials, the Medline, MeSH, EMBASE, and Cochrane databases were searched for the level of the medical evidence to indications, contraindications, and technical considerations on laparoscopic stone surgery. We did not review the simple or partial nephrectomy issues for treating stone disease as this should be reviewed under a chapter considering the evidence for simple nephrectomies.

Results: comments

Laparoscopic pyelolithotomy

Gaur and colleagues introduced the retroperitoneoscopic pyelolithotomy in five patients in 1994 and recommended the procedure for stones not amenable to SWL or PNL or when both the facilities were unavailable [13] (Evidence level IV/C). Review of the literature by Hoening et al. [14] revealed 11 pyelolithotomies with a conversion rate of 27% and an operative time of 2–5 h [14]. This article confirmed the feasibility of laparoscopic pyelolithotomy (Evidence level III/B).

Since then many authors have reported their experience with laparoscopic pyelolithotomy [2, 15, 16, 21–36]. Indications for the laparoscopic approach included the following: study of the feasibility of the procedure [15, 30–34], preceded failed endourologic approach [23, 24, 29–31], treatment of complex staghorn calculi [25, 30], stone-removal from an anomalous or ectopic kidney [15, 20, 26, 27, 35], assistance of getting access during PNL [22, 23, 26, 27, 35], concomitant correction of a pelvi-ureteric junction obstruction [2, 16, 30, 32], and finally, absence of endourologic facilities in developing countries [13, 21].

The results of these studies indicated that the laparoscopic pyelolithotomy, performed either transperitoneally [2, 16, 22, 23, 27, 30, 32–36] or retroperitoneally [15, 21, 24–26, 30, 31], is a feasible as well as an effective and a safe procedure for selected cases. Depending on indication, overall success rates and stone-free rates ranged from 71 [15] to 100% [30]. Open conversion rates ranged from 0 [30] to 27% [15]. Mean operative time, hospital stay, and complication rate were all within acceptable rates. However, all these studies were either case reports or retrospective studies enrolling a small number of patients and presented no comparison with other treatment modalities (Evidence level III/B).

Goel et al. [17] retrospectively compared retroperitoneoscopic pyelolithotomy ($n = 16$) to PNL ($n = 12$) in the management of a solitary renal pelvic calculus more than 3 cm in size (Evidence level III/B). The two groups were similar regarding patient age and sex. Mean stone sizes were 3.6 versus 4.2 cm, respectively. There were two conversions in the laparoscopic group for stone migration into the calyx and dense perirenal adhesions, making dissection difficult. Mean operating time was 142 versus 72 min for PNL ($p < 0.0001$). Blood loss was similar: 173 versus 141 cc. Mean hospital stay was 3.8 versus 3 days, although the duration of convalescence was somewhat shorter in the PNL group. Laparoscopic pyelolithotomy was associated with longer operating time, longer recuperation, was more invasive, less cosmetic, and required more skill as compared with percutaneous nephrolithotomy. Advanced endourologic facilities, such as laparoscopic ultrasound, were required for removal of calyceal stones in the event of migration or for localization of stone. The authors concluded that PNL is the best treatment modality for renal stones and laparoscopy should be offered to those who need adjunctive procedures such as pyeloplasty or puncture under vision during PNL (Evidence level III/B).

Maria et al. [37] retrospectively compared laparoscopic transperitoneal pyelolithotomy with PNL for the treatment of pelvic stones >20 mm in diameter. There was no difference between the two groups regarding the characteristics of patients and stones. Operative time was significantly longer in the laparoscopic group (129 vs. 75 min; $p = 0.001$) and conversion was required in two patients (12%). Postoperative complication rates (12 vs. 18%), hospital stay (6.5 vs. 5.6 days; $p = 0.17$), and stone-free rates (88 vs. 82%) were comparable. The authors concluded that specific indications of each technique must be determined although PNL remains the gold standard for most large pelvic stones (Evidence level III/B).

In a comparative study [38], 15 patients undergoing laparoscopic pyeloplasty with concomitant pyelolithotomy were matched with 15 control patients undergoing laparoscopic pyeloplasty without concomitant calculus disease (Evidence level IIa/B). Overall stone-free rate after laparoscopic pyelolithotomy was 80%. The mean operative time was 174 versus 170 min for the control group ($p = 0.81$). Laparoscopic graspers alone were used in 73.3% patients, flexible nephroscopy in 13.3% patients, and laparoscopic irrigation in 13.3% for renal stone removal. The authors concluded that laparoscopic pyelolithotomy, primarily using laparoscopic graspers, is an efficient procedure with associated high stone-free rates without significant increase in operative time or morbidity. However, patients must be counseled about the possibilities of ancillary procedures to achieve complete stone clearance. In a recent study [39] among 20 patients undergoing transperitoneal laparoscopic dismembered pyeloplasty and concomitant pyelolithotomy complete stone clearance was possible in 75% (Evidence level III/B). Three patients underwent subsequent SWL and 2 required PNL, while all patients were rendered stone-free at 6 months' follow-up.

Laparoscopic nephrolithotomy

Current relative indications for laparoscopic nephrolithotomy include the ablation of diverticular mucosa for symptomatic caliceal diverticula with stones and the removal of staghorn calculi via an anatrophic nephrolithotomy performed laparoscopically.

Several authors have explored the role of laparoscopy for caliceal diverticula containing calculi, and 19 cases have been published in literature. Of these, six were performed by transperitoneal [40–43] approach and 13 by retroperitoneal approach [44–47]. Indications for the laparoscopic approach included a stone located in anterior diverticula, with or without a thin overlying renal parenchyma, need for ablation of the diverticula, and previously failed endourologic procedures such as PNL or flexible ureteroscopy. All stones were located in the upper pole, with one exception [42]. Stone localization was achieved by palpation and visual contact, especially when the overlying renal cortex was either bulging or depressed because of scarring, and by retrograde injection of indigo carmine, fluoroscopy or ultrasonography. Stones and diverticula were successfully treated without open conversion in all cases. The diverticula were generally managed by fulguration [30], although in some cases the cavity was closed with perirenal fat [45], gelatine resorcinol formaldehyde glue [46], or suture closure of the diverticular neck [44]. Operative times ranged from 60 to 200 min [30]. These studies indicate that laparoscopic diverticulectomy and stone removal is an efficient and a safe alternative or adjunct to endourologic procedures (Evidence level III/B).

Relative contraindications to the laparoscopic approach include failed PNL with perirenal adhesions overlying the site of surgical interest and a thick rim of renal parenchyma obscuring the diverticula and make the localization of its cavity and the stone difficult [30]. These cases could be challenging and impose an indication for a limited anatrophic nephrolithotomy [44] (Evidence level III/B). The latter was shown to be feasible in an animal model [18]. Although three cases of successful clinical laparoscopic anatrophic nephrolithotomy have been published [44, 48], more studies on its feasibility, safety and success rate should be performed. Recently, Simforoosh et al. [49] performed laparoscopic transperitoneal anatrophic nephrolithotomy in five cases with large staghorn renal stones unsuitable for PNL (Evidence level III/B). The renal artery was clamped using a bulldog clamp; the stone was removed through a nephrotomy incision on the Brodel line, which was closed using 3/0 polyglactin continuous sutures, and sutures were buttressed by hemostatic clips. The mean (range) stone size was 53 (45–65) mm, and the warm ischemia and operative duration were 32 (29–35) and 170 (120–225) min, respectively. Intraoperative ultrasonography was used to evaluate residual stones All of the procedures were uneventful and there was no blood transfusion or urine leakage. Only an 8-mm and a 6-mm residual stone remained. All of the procedures were uneventful and there was no urine leakage after surgery. Eventually, only an 8-mm and a 6-mm residual stone remained and were treated with SWL.

Recently, Micali et al. [50] reported for the first time five cases of symptomatic multiple peripelvic cysts and concomitant kidney stones treated by a laparoscopic approach (Evidence level III/B). The mean cyst size was 45 mm, the mean stone size was 25 mm, and the mean operative time was 173 min. There were neither intraoperative complications nor conversions to open surgery. Computed tomography after 6 months showed clearance of all cysts and stones without sign of recurrence. Although the procedure is technically challenging, it is safe and effective, and it avoids a staged treatment.

Laparoscopic ureterolithotomy

Since Wickham et al. [7] presented the first laparoscopic ureterolithotomy, its popularity has been increasing in developing countries that do not have easy access to endourologic facilities and SWL [13, 51–53]. However, the vast experience and excellent results with the new endourologic technology in developed countries has led to a rarity of reports of large series of laparoscopic ureterolithotomy patients [2, 8, 10–12, 20, 21, 25, 31, 32, 51, 53–64] until recently [65–74].

The vast majority of the studies published today are exposing the surgeons' initial experience, while in a minority a review of the literature has also been performed (Evidence level III/B). Laparoscopic ureterolithotomy was performed via the transperitoneal [10–12, 20, 22, 25, 51–56, 60, 64] or the retroperitoneal approach [6, 8, 11, 13, 21, 25, 32, 52, 53, 56, 58–63] (Table 1). Indications for the laparoscopic approach included large impacted ureteral stones, failure of SWL or endourologic approach, need for a concomitant laparoscopic operation for separate indication, and lack of the appropriate technological facilities (i.e. flexible ureteroscope, laser). The stone-free rate in most series approached 100% with a low conversion rate. Reasons for conversion included stone migration into the kidney, inability to locate the stones through extensive peri-ureteral fibrosis, loss of pneumoretroperitoneoum secondary to peritoneal tear, and injuries of adjacent organs. The most common early postoperative complication was ureteral leak. This was common in those patients in which the ureterotomy was not closed or a ureteral stent was not placed. The most serious late complication was ureteral stricture formation which occurred at an incidence of up to 20% [10, 53, 57]. These were probably developed secondary to periureteritis, urinary leak, use of diathermy to incise the ureter, and stone impaction (Table 2).

All these studies confirmed the feasibility of the laparoscopic ureterolithotomy as an alternative to open ureterolithotomy and the safety profile of the procedure. However, these studies were retrospective in nature and did not compare laparoscopic ureterolithotomy with either other endourologic techniques or to open ureterolithotomy (Evidence level III/B).

In a review of the literature Rofeim et al. [57] compared the results of SWL, ureteroscopy, and laparoscopic ureterolithotomy for the treatment of ureteral calculi (Evidence level III/B). Ureteroscopy with the use of a lithotripter and a basket provided a success rate of almost 100%. Laparoscopic ureterolithotomy was indicated for large impacted, upper ureteral stones when endourologic therapy failed (Evidence level III/B). The learning curve for laparoscopic upper ureterolithotomy is short as demonstrated in a study by Fan et al. [65] (Evidence level III/B). In this study, the authors compared the first 20 cases with the following 20 cases. Operative time and complications were measured as a basis for the assessment of the learning curve. In the first 20 cases, the complication rate was 15%, including two patients whose procedure was converted to open surgery because of intraoperative bleeding, and one patient who experienced urine leakage because of a displaced double-J stent. In the following 20 cases, no postoperative complications occurred, while the mean operative time was significantly shorter compared with the earlier operations (65 vs. 120 min).

Skrepetis et al. [20] retrospectively compared laparoscopic transperitoneal ureterolithotomy in 18 patients with open ureterolithotomy in another 18 patients. Patients who underwent laparoscopy experienced a longer operative time (130 vs. 85 min for open surgery) but lower analgesia requirements (1 vs. 4 days) and shorter hospital stay (3 vs. 8 days; Evidence level III/B).

In a prospective non-randomized study, Goel et al. [8] compared laparoscopic retroperitoneal ureterolithotomy in 55 patients to open ureterolithotomy in 26 patients (Evidence level IIa/B). The two groups had similar distributions for age, sex, stone size, and stone location. The laparoscopic approach proved to be superior in terms of lower analgesia requirements (41.1 vs. 96.6 mg of pethidine), shorter hospital stay (3.3 vs. 4.8 days), and shorter convalescence (1.8 vs. 3.1 weeks), whereas there were no significant differences in terms of mean operative time (108.8 vs. 98.8 min) or mean blood loss (58.5 vs. 50.5 ml) between the two groups.

The largest series of laparoscopic ureterolithotomy was upon 123 patients and reported a stone-free rate of 96.7% [66]. The calculi were between 1 and 5.6 cm and located in the upper, middle, and lower ureter in 73.2, 16.3, and 10.5% of the patients, respectively. Intraperitoneal approach was used in 84.6% and extraperitoneal in 15.4%. The mean operative time was 143.2 ± 60.5 min and minor complications occurred in 11.4%. Conversion to open surgery was required in 1 patient due to migration of the calculus, while intra-abdominal hematoma led to re-operation in one patient. Operative time was significantly different between extraperitoneal and intraperitoneal approaches (171.3 ± 91.3 min and 137.3 ± 52.2 min,

Table 2 Descriptive statistics and functional results of laparoscopic ureterolithotomy

Reference	Number of procedures	TP/RP†	Mean stone size (mm)	Stone location L/M/U‡*	Mean operative time (minutes)	Mean hospital stay (range) (days)	Leakage	Stricture (%)	Conversion*	Success rate (%)	Suture of incision*	Stent insertion*
2	6	TP	14.7	L4/M1/U1	245	3 (1–6)	Yes	No	Yes (1)	83	Yes	Yes
8	55	RP	21	M15/U40	108.8	3.3 (2–14)	Yes	2/38 (5%)	Yes	82	Yes	Yes (35)
10	14	TP	27.2	U	105	5.6	Yes	–	No	100	Yes (5)	Yes (9)
11	9	TP8/RP1	13.2	M3/U6	158	5.2 (2–13)	Yes	No	No	100	Yes	Yes
12	21	TP	–	U	90	–	–	No	No	90	Yes	Yes
20	18	TP	–	M8/U10	130	3.2(2–5)	Yes	No	No	100	Yes (18)	Yes (5)
21	24	RP	–	–	61	3.6	–	2 (15%)	No	100	–	–
25	101	TP1/ RP100	16	L15/M11/U75	79	3.5	Yes	–	8	92	Yes (45)	Yes (27)
31	20	RP	21	M/U	140	3 (1–10)	–	No	Yes (1)	94	Yes	Yes (17)
48	1	TP	17	M	–	–	No	No	No	100	Yes	Yes
52	10	TP	9.3	U	181	–	Yes	1 (20%)	No	100	Yes (6)	–
53	5	RP	19	U	125	–	–	–	No	100	Yes	–
54	2	TP	10	M1/U1	–	–	No	No	No	100	No	Yes
55	1	RP	–	–	–	–	–	–	–	–	–	–
56	24	TP21/RP3	11.5	L3/M2/U19	RP140/TP107	3.8 (2–10)	No	3 (4%)	No	95	Yes (23)	Yes (17)
58	6	RP	25.7	U	160	–	Yes	No	Yes (1)	83	Yes (2)	Yes (2)
60	75	TP6/RP69	25	M/U 69/L6	45	3 (2–5)	–	No	Yes (1)	98.7	–	–
61	2	RP	24	M	–	–	–	–	No	100	Yes	Yes
62	12	RP	18.1	U	109	4.6 (2–7)	Yes	No	Yes (6)	50	–	–
63	30	RP	19.03	U	121	–	Yes	No	–	97	Yes	No
54	27	TP	19	L2/M16/U9	145	4.1 (2–21)	Yes	–	No	100	Yes	Yes (17)
65	40	RP	22.5	U	93	7(± 3.1)	No	No	Yes (2)	100	Yes	Yes
67	74	TP 8/RP66	18	L2/M18/U54	58.7	6.4	Yes (1)	1 (13.5)	Yes (4)	94.6	Yes	Yes
69	35	TP18/ RP17	TP23/RP20	–	TP75/RP102	TP4(2–7) RP5 (2–6)	Yes (1)	No	TP1/RP0	100	Yes	Yes
74	20	RP	13.7	M2/U18	38.2	3(2–5)	No	No	No\	100	Yes (64)	Yes

† TP/RP, transperitoneal/retroperitoneal

‡ L/M/U, lower/middle/upper ureter

* In parentheses the actual numbers are given

respectively; $p = 0.02$). In contrast to this study, El-Moula et al. [67] preferred the retroperitoneal approach in 66 out of 74 patients that underwent laparoscopic ureterolithotomy. Interestingly, the ureter was stented and not sutured in 86.5% of the cases. Open conversion was carried out in 5.4% of the patients. The mean operative time was 58.7 min, and the mean blood loss was 90.6 ml. Prolonged urinary leakage occurred in one patient and another patient developed ureteral stricture. The safety and efficiency of retroperitoneal laparoscopic ureterolithotomy was also demonstrated in another study [68] upon 50 patients with large (>1.5 cm) lumbar ureteric stones. The mean operating time was 97 min and the surgical conversion rate was 8%. The considerable percentage of 20% developed urinary fistula requiring secondary drainage by double J stent. In a prospective study [69] comparing trasperitoneal and retroperitoneal approach during the learning curve (Evidence level IIa/B) significant differences were demonstrated in favor of the transperitoneal procedure in terms of time for access operating field, time for suturing the ureter, and total operative time. The authors concluded that urologists in training should perform laparoscopic ureterolithotomy using a transperitoneal route [69].

In a retrospective comparative study [70] among 71 patients with large (>1.5 cm) midureteric stones, there was no statistical difference in terms of stone clearance rate (79.2% for ureteroscopic pneumatic lithotripsy vs 100% for laparoscopic ureterolithotomy). However, hospital stay and morbidity was significantly greater in the laparoscopic group. Therefore, URS still remains the treatment of choice for the treatment of large midureteric calculi considering the low morbidity and acceptable stone-free rate of the procedure (Evidence level III/B).

Novel retroperitoneal single-port laparoscopic urologic surgery, particularly in patients requiring free-hand suturing, is technically feasible. Recently, Ryu et al. [71] used the Alexis wound retractor with flexible laparoscopic instrumentation and performed successfully two cases of laparoscopic ureterolithotomy (Evidence level IV/C).

Combined laparoscopic and endourological procedures

Laparoscopic and endourological techniques can be successfully combined in a one-procedure solution that deals with complex stone disease and repairs underlying urinary anomalies [75]. Recently, Nadu et al. [76] treated 13 patients with renal stones and concomitant urinary anomalies (ureteropelvic junction obstruction, horseshoe kidney, ectopic pelvic kidney, fussed-crossed ectopic kidney, double collecting system) with laparoscopic stone surgery combined with ancillary endourological assistance as needed (Evidence level III/B). Treatment included laparoscopic pyeloplasty, pyelolithotomy, and nephrolithotomy combined with flexible nephroscopy. Intraoperative complications were lost stones in the abdomen diagnosed in two patients during the follow up. Stone free status was 77 and 100% after one ancillary treatment in the remaining patients. One patient had a postoperative urinary leak, which was managed conservatively.

Moreover, laparoscopic assisted PNL has been reported in two studies [77, 78] among four patients with stones (2.5–4 cm) ectopic pelvic kidney (Evidence level III/B). The mean operative time was 110–150 min and complete stone clearance was achieved in all cases.

Take-home messages (Table 3)

Laparoscopy gives the benefits of a mini-invasive treatment with reduced blood loss, pain, hospital stay, and recovery. SWL and endourologic approaches are highly successive and constitute the treatment of choice for urinary calculi. Laparoscopic pyelolithotomy is feasible but rarely indicated in the present era. Laparoscopic nephrolithotomy may be indicated to remove a stone from an anterior diverticulum or when PNL or flexible ureteroscopy have failed. Open ureterolithotomy is being less frequently practiced nowadays. Laparoscopic ureterolithotomy is technically feasible (retroperitoneal or transperitoneal approach depending on relevant experience) with the advantage of being minimally invasive and having lower

Table 3 Recommendations on laparoscopic stone extraction

Recommendation	Level of evidence
Laparoscopic pyelolithotomy is feasible but rarely indicated in the present era	III/B
Laparoscopic nephrolithotomy may be indicated to remove a stone from an anterior diverticulum or when PNL or flexible ureteroscopy have failed	III/B
Laparoscopic ureterolithotomy is technically feasible with the advantage of being minimally invasive and having lower postoperative morbidity compared to open ureterolithotomy	IIa/B
Laparoscopic ureterolithotomy should be recommended when endourological procedures have failed or when large impacted stones of the upper ureter are confronted	III/B

postoperative morbidity compared with open ureterolithotomy. It should be recommended when SWL and/or endourologic procedures have failed or when large impacted stones of the upper ureter are confronted.

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