Modified anatrophic nephrolithotomy: a useful treatment option for complete complex staghorn calculi

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Introduction: *Management of complete staghorn calculi represents a challenging problem for urologists. We describe our technique and clinical experience with modified anatrophic nephrolithotomy in patients harboring large, extensively branched staghorn calculi.*
Materials and methods: *From October 1996 to February 2005 twenty-six patients with complete staghorn calculi defined as filling the entire collecting system or at least 80% of it, were treated employing a modification of the classical anatrophic nephrolithotomy technique. The mean patient age was 46 (range 16-70) years and the mean stone size was 3150 (range 1375-4800) mm^2. Intra-operative data, complications and stone-free rates were recorded. Long-term follow-up was completed in 22 patients with a mean duration of 38 (range 12-96) months. Renal function was evaluated by ^{99m}Tc dimercapto succinic acid renal scintigraphy before and 6 months after treatment.*
Results: *The mean ischemia time was 36 (range 20-45) minutes, mean operative time was 195 (range 170-235) minutes and the mean blood loss was 475 (range 300-750) ml. Length of hospital stay averaged 8.8 days. One patient developed significant hematuria requiring renal angiography and embolization of a pseudoaneurysm. Overall, 22 patients (85%) were rendered stone-free at discharge while 23 patients (88%) were observed to be stone-free after 3 months. Long-term follow-up demonstrated recurrent stone fragments less than 4 mm in three patients. Isotope studies revealed that renal function remained unchanged in 55%, improved in 32% and became worse in the small number of remaining patients.*
Conclusions: *Modified anatrophic nephrolithotomy is a valuable treatment option for patients with complete staghorn calculi. Because of its efficacy, safety and simplicity we believe that the use of this surgical procedure is warranted in patients with a large, extensively branched, complex renal stone burden.*

Key Words: anatrophic nephrolithotomy, kidney calculi, renal calculi, staghorn calculi

Introduction

The surgical management of renal calculus disease has changed dramatically in the past two decades. Minimally invasive treatment options such as percutaneous nephrolithotomy (PNL) and extracorporeal shockwave lithotripsy (SWL) have almost eliminated the use of open surgery. In 1989, at the beginning of the technological revolution in endourology, Assimos et al[1] reported an open stone surgery rate of 4.1%. Fourteen years later Matlaga and Assimos[2] reported an even lower rate (0.7%) of open surgical procedures from the same centre. However, despite the innovations in endourology, the treatment of patients with staghorn calculi remains a challenging proposition.

Staghorn calculi are branched stones that occupy a major part of the renal collecting system. They may be broadly classified into three groups, namely 'borderline' which occupies the renal pelvis and one

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calix, 'partial' which fills the renal pelvis and branches into two calices or more and 'complete' which fills the entire collecting system or at least 80% of it.[3] Currently, most borderline and partial staghorn calculi are managed with PNL monotherapy or combination therapy utilizing PNL and SWL.[4] However, the optimal treatment of patients harboring extensively branched, complete staghorn calculi represents a complex problem. These complete staghorns are large volume calculi extending into multiple calices and often require several access tracts during PNL to achieve satisfactory stone clearance. Multiple access tracts are occasionally known to be associated with blood loss and post-operative discomfort.[5] Thus, major limitations are inherent with the PNL-based endourological techniques in patients with complete staghorn stones.

In 1968, Smith and Boyce[6] pioneered the procedure of anatrophic nephrolithotomy which remains until today the 'gold standard' open surgical technique to manage a complex renal stone burden. Herein we report our approach to complete staghorn calculi, which involves a modification of the original technique described by Smith and Boyce.[6] The purpose of this study is to document contemporary expectations regarding stone-free rates, complications and length of hospitalization after modified anatrophic nephrolithotomy from a single centre experience.

Materials and methods

Between October 1996 and February 2005, 85 patients with staghorn calculi were treated at our tertiary referral centre. Patients with borderline and partial staghorn calculi (n = 59) were managed with the combination therapy of PNL and SWL. Patients with complete staghorn stones (n = 26) were treated with modified anatrophic nephrolithotomy and formed the subject of the present study. Children, patients with chronic renal failure and those with uncontrolled coagulation disorders were excluded from the study.

Preoperative evaluation

Urine culture, serum biochemistry (creatinine, calcium, phosphorus, uric acid) and coagulation profile were performed in all cases. Radiological evaluation included renal ultrasound (USG) and excretory urography (IVU) to assess stone location, stone extension and stone surface area (determined by multiplying stone length by width on two-dimensional radiographs). Renal function was evaluated utilizing the ^{99m}Tc dimercapto succinic acid (DMSA) renal scintigraphy in all cases. All urinary tract infections were treated according to urine culture sensitivity.

Operative technique

Surgery was performed through an extra-peritoneal flank incision after excising the 11th rib. The kidney was fully mobilized and the main renal artery was selectively dissected and isolated with a non-occlusive elastic vessel loop. The proximal ureter was occluded with an elastic loop to prevent distal migration of small stone fragments. The main renal artery was occluded with a plastic bulldog clamp, a rubber dam was placed around the kidney and the kidney was immersed in iced slush for 15 minutes to allow it to cool properly to between 15 ^{o}C and 20^{o}C, Figure 1. A superficial incision was made with a scalpel through the renal capsule 1 cm to 2 cm. posterior to the convex margin of the kidney. The underlying renal parenchyma was sharply incised until the collecting system was entered through the posterior calices. The palpable stone burden often directed the exact stone location and the angle of the parenchymal incision. The caliceal infundibuli are split to relate the branched stones. The calculus was carefully mobilized from the epithelial surface to avoid fracture and extracted. All the calices were gently explored to 'feel' any residual stone fragments utilizing a combination of stone forceps and bi-manual palpation. Intra-operative radiography was routinely used to locate any remaining residual calculi. Careful hemostasis was achieved by ligating the transected vessels individually with 4-0 polyglactin sutures. The renal artery clamp was released and further bleeders were similarly controlled. A 5F double pigtail ureteral stent was routinely placed. The renal parenchyma was then carefully co-apted using interrupted 2-0 polyglactin sutures and the renal capsule was subsequently closed with running 3-0 polyglactin sutures, Figure 2.

Figure 1. Stone bearing kidney completely immersed in iced slush.

Figure 2. Running closure of the renal capsular incision.

A formal closure of the collecting system was not performed and nephrostomy tubes were not routinely placed. Emphasis was placed on adequate intra-operative hydration and brisk diuresis with timed doses of mannitol (12.5 gm intravenously 10 minutes before clamping the renal artery) and furosemide (20 mg prior to unclamping). A closed suction drain was placed in the peri-renal space. Patients were kept on bed rest for about 48 hours until the urine cleared.

Follow up evaluation

All patients had a plain film of the kidneys, ureters and bladder (KUB) on the 8th post-operative day before discharge followed by a non-contrast computerized tomography at 3 weeks to assess the stone-free status. Patients who were discharged home with residual fragments were scheduled for SWL as an outpatient. The lithotriptor had a piezoelectric generator with the facility of x-ray and ultrasound localization of stones (Piezolith 2501, Richard Wolf GmBh, Knittlingen, Germany). Urine culture, serum biochemistry and IVU were performed in all cases 3 months after the completion of treatment with subsequent urine culture, serum biochemistry, KUB and USG yearly. DMSA renal scintigraphy was performed in all patients at the 6-month follow-up visit. At each visit patients were specifically asked about the time required to return to normal activities. After surgery the stones were biochemically analyzed. The ureteral stent was removed 6 weeks after surgery under general anesthesia.

Patients with complete absence of residual stone fragments of any size on radiological imaging were considered 'stone-free'. Patients with asymptomatic, non-infected and non-obstructing fragments of less than 4 mm in diameter were considered to have 'clinically insignificant residual fragments' (CIRFs).

Results

Patient demographics

There were 17 men and 9 women between the ages of 16 and 70 (mean age 46) years, two of whom were older than 60 years. Three patients were morbidly obese, while three other patients had significant co-morbid medical diseases. Loin pain was the most common clinical presentation seen in 15 patients (58%) while 9 patients (35%) were totally asymptomatic. The remaining two patients (7%) were referred from our Accident & Emergency Department with gross hematuria. The calculi varied in size from 1375 to 4800 (mean size 3150) mm^2. Eleven patients (42%) had giant staghorns (stone size > $2500mm^2$). One patient had a solitary kidney and one patient previously underwent ipsilateral PNL.

Outcome

The mean renal ischemia time was 36 (range 20-45)

Figure 3a. Pre-operative KUB shows a giant staghorn calculus.

minutes and the mean operative time was 195 (range 170-235) minutes. The mean estimated blood loss was 475 (range 300-750) ml and post-operative bleeding requiring blood transfusion occurred in five patients (19%). The mean length of the hospital stay was 8.8 (8-11) days, reflecting the time of return of bowel function, ambulation and pain control. The mean time to return to normal activity was 33 (28-46) days.

At discharge, a total of 22 patients (85%) were rendered stone-free while four patients (15%) had residual stone fragments. Of these four patients, two were noted to have a clinically significant stone fragment (7 mm & 9 mm) in the lower calices and were subsequently treated with SWL while the other two patients each had 3 mm sized CIRFs and were managed conservatively. At the 3-month follow-up 23 patients (88%) were observed to be stone-free including one of the two patients with clinically significant residual fragments who underwent SWL.

Figure 3b. Pre-operative IVU.

Figure 3c. Post-operative KUB demonstrates complete stone-free status except for two tiny stone fragments.

The two patients who had CIRFs continued to harbor the calculi at the 3-month follow-up. The results from a 22-year-old man with a giant staghorn calculus are shown in Figures 3a-3c.

None of the patients had any major intra-operative complications related either to anesthesia, vascular control or stone retrieval. In the early years of our study, a major complication occurred in a 16-year-old boy who experienced delayed hemorrhage 5-days post-operatively. Renal arteriography revealed a false aneurysm arising from a branch of the posterior segmental artery. The aneurysm was embolized successfully, Figures 4a-4f. Minor complications occurred in three patients (12%), including pneumonia in one and superficial wound infection in two patients. Pre-operative urine cultures were positive in 20 patients: proteus mirabilis, n=13; Klebsiella pneumoniae, n=4 and Escherichia coli, n=3. Seventeen patients had sterile urine within 3 months of the operative procedure.

Figure 4a. Pre-operative KUB shows a complete staghorn calculus.

Long-term follow up

The follow-up period ranged from 12 to 96 months, with a mean of 38 months. Four patients (15%) were lost to follow-up after the 3-month visit. The rest were compliant and all data was available in 22 patients that included 15 men and 7 women. At follow-up, 19 patients remained stone-free while three patients developed stone recurrences. These stone recurrences were noted after 12, 18 and 42 months respectively; the mean size of the recurrent stone fragments were less than 4 mm. A comparison of pre- and post-operative renal function, as assessed by DMSA scans, were available in the 22 patients who were available for follow-up: renal function remained stable in 12 patients (55%), it improved in 7 (32%) and deteriorated in the remaining three patients (13%). Improvement or deterioration of renal function was defined as a change of split function greater than 10% of total value at follow-up compared to baseline. Stone analysis revealed magnesium ammonium phosphate in 18 (69%), uric acid in 2 (8%) and mixed stones in the remaining 6 (23%) patients.

Discussion

Staghorn calculi are commonly composed of mixtures of magnesium ammonium phosphate (struvite) and/or calcium carbonate apatite. They are usually associated with urinary tract infection caused by urea-splitting organisms that promote the generation of ammonia and hydroxide from urea. The resultant alkaline urinary environment, along with abundant phosphate and magnesium in urine, promote crystallization of magnesium ammonium phosphate, leading to formation of large branched stones. It is well established that struvite staghorn calculi, if left untreated, will eventually destroy the kidney and pose a significant risk to the patient's life.[7,8] Therefore, complete removal of these calculi is mandatory to

Figure 4b. Pre-operative IVU shows significant hydronephrosis.

Figure 4c. Post-operative KUB reveals complete stone-free status.

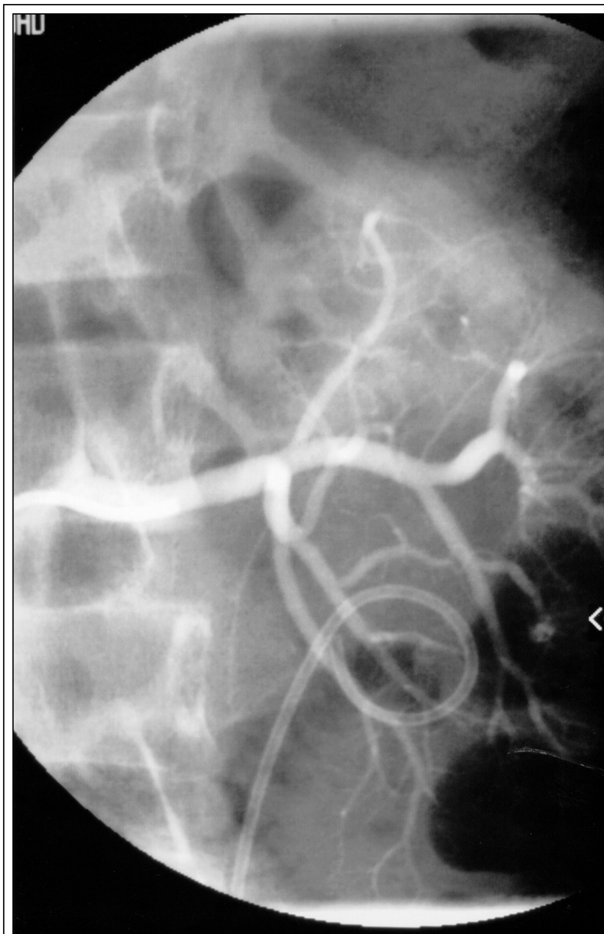

Figure 4d. Renal angiogram demonstrates a pseudoaneurysm.

preserve renal function, relieve obstruction and eradicate any causative organisms. However, while the rationale for aggressive intervention is well documented, controversy continues regarding the optimal form that intervention should take. Clearly, the treatment of large, extensively branched complete staghorn calculi is a complex problem that requires consideration of several factors including stone burden, pyelocaliceal anatomy, body habitus and co-morbid medical conditions.

In 1968 Smith and Boyce[6] used anatomic principles and reconstructive surgical techniques to synthesize the procedure of anatrophic nephrolithotomy. Our technique differs from that described by Smith and Boyce in that we incorporated several modifications with a view to reducing operating time and decrease morbidity. In their classic description Smith and Boyce[6] identified the boundary of the segmental renal blood supply by clamping the posterior arterial branch

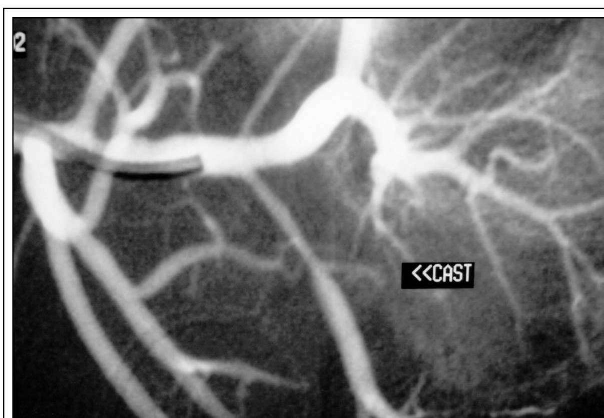

Figure 4e. The pseudoaneurysm has been embolized successfully.

Figure 4f. Follow-up IVU shows significant resolution of hydronephrosis and preservation of renal function.

followed by intravenous injection of methylene blue. In our modification, the renal capsule and the parenchyma are incised 1 cm to 2 cm posterior to the convex margin of the kidney over the palpable stone burden, without preliminary segmental vascular dissection. The incision basically lies in the avascular Brodel's 'white line' between the anterior and posterior vascular segments. Because extensive dissection of the branches of the main renal artery is avoided and the main renal vein is left untouched, the risks of arterial spasm or venous injury are minimized. Furthermore, Smith and Boyce[6] emphasized the importance of routine restoration of the entire collecting system that, theoretically, reduces the incidence of urinary extravasation and promotes healing. However, in our modification the collecting system is not formally reconstructed. Instead, we approximated the collecting system rather than closing it formally and the closure depended primarily on suturing the parenchymal surfaces together. Our opinion is that a meticulous closure of the collecting system may compromise blood supply by inadvertent ligation of the vessels around the caliceal infundibuli. Melissourgos et al[9] advocated a similar approach in which the collecting system was not formally reconstructed. It is noteworthy that these modifications resulted in shorter operative times in our study. The mean (range) operative time using our modified technique was 195 (170-235) minutes, which compared favorably with the mean (range) operative time of 526 (400-645) minutes recorded by Assimos et al[10] who employed the classic anatrophic nephrolithotomy. Finally, in classic anatrophic nephrolithotomy, the renal capsule alone is approximated with a running absorbable suture without incorporating the renal parenchyma; in our modification we approximated the superficial part of the renal parenchyma using closely applied, interrupted, absorbable sutures that provided a firm and secure renal closure. This was because, due to the co-existent chronic peri-renal inflammation, we often found the renal capsule to be scarred, flimsy, adherent to the underlying renal parenchyma and therefore unreliable to be used in a single layer closure.

Recently, the AUA nephrolithiasis guidelines panel made recommendations for the treatment of staghorn calculi based on careful analysis of an extensive body of scientific literature and meta-analysis of outcome data.[11] The panel recommended active intervention for all newly diagnosed cases of staghorn calculi. As a guideline the panel recommended percutaneous stone removal as the primary treatment modality followed by SWL and/or repeat percutaneous procedures as warranted. However, in our opinion, in the subset of patients with large, extensively branched, complete staghorn calculi, open surgery remains a viable treatment option due to several reasons. Firstly, numerous investigators have lucidly demonstrated superior stone-free rates following open surgery when compared to PNL monotherapy or the combination therapy of PNL and SWL.[10,12,13] In a study by Assimos et al[10] that compared anatrophic nephrolithotomy (10 cases), PNL monotherapy (4 cases) and combination therapy (23 cases) for large staghorn calculi, anatrophic nephrolithotomy resulted in stone-free rates of 89% to 100%, whereas PNL with or without SWL led to stone-free rates of only 12% to 25%. Esen et al[12] reported that, for patients with complete or partial staghorn calculi, open surgery resulted in a stone-free rate of 80% versus 50% for combination therapy and 25% for SWL monotherapy. Recently Al-Kohlany et al[13] compared modified anatrophic nephrolithotomy with

PNL in a randomized, prospective manner in a cohort of 79 patients with complete staghorn calculi; open surgery resulted in a stone-free rate at discharge of 67% as compared to a stone-free rate of 49% after percutaneous procedures. It is noteworthy that our group of patients undergoing modified anatrophic nephrolithotomy had an immediate stone-free rate of 85% despite 42% of the calculi being ‘giant staghorns’. PNL monotherapy or combination therapy allows patients to avoid large incisions, decreases post-operative pain, minimizes the transfusion requirements (0%-7%) and shortens the convalescence period.[13,14] But its application to complete staghorn stones often mandates multiple percutaneous tracts/ repeat nephroscopy that occasionally results in a difficult and protracted treatment course with increased morbidity and prolonged hospital stay. In the experience of Assimos et al,[10] the average hospital stay for patients with complete staghorn stones subjected to anatrophic nephrolithotomy was 12.3 days compared to 15 days for the combination group. Finally, a number of investigators have reported an economic advantage with open surgery when compared to PNL-based therapy.[10,15,16] Assimos et al[10] noted that the average cost of anatrophic nephrolithotomy ($16,731) was significantly less than that of PNL with or without SWL ($23,731). They attributed the cost differentials to the multiple procedures and longer hospitalization required to treat patients with PNL or combination therapy. Similarly, Preminger et al[15] reported that for calculi more than 2.5 cm in size, percutaneous surgery is more costly than open surgery. In a recent comparative study of 91 patients with staghorn calculi treated either with open surgery or combination of PNL and SWL, Goel et al[16] also observed that the cost of treatment in the combination group was significantly higher although the morbidity and hospital stay were similar in both groups. These reports suggest that, despite great proficiency with minimally invasive approaches, open surgery can be performed with a high rate of success, minimal morbidity and lower costs and therefore should be given consideration as a treatment option in patients with a complex renal stone burden.

TABLE 1. **Anatrophic nephrolithotomy: overview**

References	**No. patients**	**Mean operative time (mins)**	**Mean ischemia time (mins)**	**Mean hospital stay (days)**	**Stone-free at discharge (%)**	**Major complications n (%)**	**Effect on renal function (%)**
*Deger et al[26]	1	◊	45	5	100	nil	Improved from 18 to 28
Matlaga and Assimos[2]	3	◊	◊	5.3	100	nil	◊
**Al Kohlany et al[13]	5	204 ± 31	37 ± 16	10 ± 4	67	14 (31)	Improved/ remained stable in 87
***Gough and Baillie[23]	9	150	25	◊	89	nil	Deteriorated in 56
Assimos et al[10]	10	526	◊	12.3	90	1 (10)	◊
Paik et al[20]	14	216	◊	5.8	93	nil	◊
Morey et al[22]	15	222	45	4	81	nil	Deteriorated in 81
Melissourgos et al[9]	24	180	10-35	8.2	83	1 (4.1)	Improved in 63
Snyder and Smith[21]	25	266	◊	15.7	100	7 (28)	◊
Present study	26	195	36	8.8	85	1 (3.8)	Stable in 55 Improved in 32

*Describes laparoscopic technique
**Describes series that employed other techniques such as extended pyelolithotomy in addition to anatrophic nephrolithotomy
***Describes pediatric series
◊Information not specified

Morbidly obese patients and those with severe, concurrent medical conditions together comprised 23% of our series; they posed a particularly challenging problem. Several investigators from specialized units have reported excellent stone-free rates after percutaneous nephrolithotomy in morbidly obese patients,[17,18] although their body habitus precludes fluoroscopic imaging and endoscopic maneuvering required for PNL-based therapy.[19] The ideal treatment for such patients should take into consideration the desire to achieve stone-free status with a single procedure avoiding significant morbidity. Although open stone surgery in the obese can be technically difficult secondary to body habitus and limitations in surgical exposure, the benefits of achieving a stone-free state with a single procedure is considerable, particularly so when multiple, lesser invasive procedures may lead to a protracted hospital stay. In the present study all the morbidly obese and those with severe medical problems were rendered stone-free at discharge with minimal morbidity. A similar experience has been reported by Paik et al[20] who documented a 100% stone-free rate following anatrophic nephrolithotomy in morbidly obese patients harboring complex renal calculi. Therefore, anatrophic nephrolithotomy appears to be a viable treatment option in morbidly obese and medically ill patients with large staghorn calculi.

The impact of anatrophic nephrolithotomy on renal function appears to be controversial. Few reports have shown impairments while a majority have demonstrated either relative stability or improvement in renal function. Table 1[2,9,10,13,20-23,26] Morey et al[22] documented diminished renal function in 81% of their cases following modified anatrophic nephrolithotomy. Gough and Baillie[23] reported on nine children with a complex renal stone burden who underwent anatrophic nephrolithotomy; five of the nine children (56%) were noted to have deterioration of renal function. In contrast, Stubbs and associates[24] reported on 30 patients with a solitary kidney in whom anatrophic nephrolithotomy was performed with ice slush surface hypothermia; despite a mean renal artery clamp time longer than 2 hours, renal function was completely preserved in all patients. Similarly, from a series of 24 patients treated with modified anatrophic nephrolithotomy, Melissourgos et al[9] noticed an improvement in renal function in 63% of patients, while in the remaining patients there was a mild decrease in renal function from an average of 39% to 35%. More recently, Kohlany and colleagues[13] documented stable or improved split GFR in 87% of their patients treated with anatrophic nephrolithotomy. Likewise, in our experience, renal function remained stable in 55% of the patients, improved in 32% and deteriorated in the remaining 13%. These reports indicate that, although functional loss occurs after anatrophic nephrolithotomy, it is marginal and probably clinically insignificant.

The recent advent of laparoscopic stone-removing procedures has provided another minimally invasive treatment option to circumvent open surgery. Laparoscopic anatrophic nephrolithotomy was first reported by Kaouk et al[25] in a porcine model with excellent results. More recently Deger and colleagues[26] described the first successful human experience with laparoscopic anatrophic nephrolithotomy employing a four-port transperitoneal technique. As technology continues to evolve, anatrophic nephrolithotomy will possibly be performed laparoscopically in the future.

Conclusions

The optimal management strategy for patients with complete staghorn calculi is still evolving. Our results indicate that modified anatrophic nephrolithotomy is an operative procedure that can be performed effectively. Important technical caveats include adequate intravenous hydration, pharmacological renal protection with mannitol and furosemide, renal hypothermia and a minimal duration of ischemic insult. In the present era of minimally invasive surgery, performing open stone surgery should not be regarded as a sign of failure, particularly so in the select group of patients with large, extensively branched, complete staghorn calculi. ☐

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