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Review

Metabolic evaluation and medical management of staghorn calculi

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Abstract Staghorn renal calculi are large renal calculi that occupy nearly the entirety of the renal collecting system. They may be composed of metabolic or infection stone types. They are often associated with specific metabolic defects. Infection stones are associated with urease-producing bacterial urinary tract infections. The ideal treatment for staghorn calculi is maximal surgical removal. However, some patients are either unwilling or unable to proceed with that modality of treatment, and therefore other management must be used. One such technique is the metabolic evaluation with directed medical management. Based on contemporary evidence that the majority of staghorn stones are metabolic in etiology, and furthermore that even infection stones are usually associated with metabolic abnormalities, metabolic evaluation with directed medical management is recommended for all staghorn stone formers. The scientific basis of this recommendation is reviewed in the present work.

1. Introduction

Staghorn renal calculi are large intrarenal stones which fill most or all of the potential space within the renal collecting system including the renal pelvis, major calyces, and minor calyces. The term "staghorn" is attributable to the multiple branches and pointed nature of such stones—an appearance which is said to resemble the antlers of a male stag moose (Fig. 1). Staghorn calculi may be referred to as "partial" if they only fill some of the calyces within the collecting system, or "complete" if they fill all of the space within the collecting system. To date, there is no universally accepted objective classification system for the description or categorization of staghorn calculi aside from the aforementioned partial versus complete designation.

Staghorn calculi may be of metabolic or infectious origin, and whenever possible it is beneficial to obtain stone analysis data in order to determine this information for

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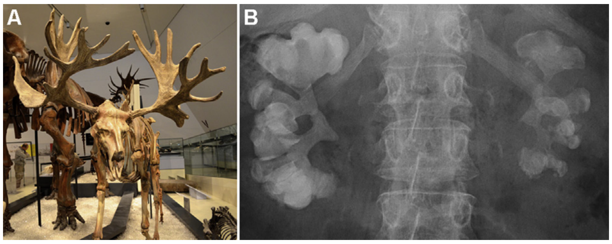

Figure 1 Staghorn. (A) Skeleton of a stag moose, cervalces scotti, housed at the Royal Ontario Museum; (B) Plain abdominal X-ray depicting bilateral staghorn calculi.

guiding treatment and patient counseling. Patient history may also be revealing in this regard; for instance, patients with infection staghorn calculi often report a history of recurrent urinary tract infections with or without fever. The term "infection stone" is used to describe stones comprised of magnesium ammonium phosphate (struvite) with or without admixed calcium carbonate apatite (carbonate apatite) [1]. Infection stones are strongly associated with urinary tract infections caused by urease-producing bacteria [2,3]. The presence of any component of calcium oxalate, uric acid, or cystine is indicative of an underlying metabolic abnormality, and these stones are commonly referred to as "metabolic" stones.

In most cases, the cornerstone of management for staghorn calculi is maximal surgical removal. The advent of newer, smaller, and better surgical instrumentation and techniques over the past 30 years has revolutionized the modern urologist's ability to surgically removal large stones through a minimally invasive approach. However, it is a fact that there are patients with staghorn calculi who are either cannot safely undergo surgery or alternatively who refuse surgical management altogether. In order to be able to treat these complex cases optimally, we must address two major gaps in clinical knowledge. The first question is whether it is safe or efficacious to treat staghorn calculi medically rather than pursuing aggressive surgical removal. The second issue which deserves attention—and which is in many ways related to the first—is to better define the role of the metabolic evaluation in patients with staghorn calculi, particularly in those for whom surgical stone removal is not possible.

2. Evolving perspectives on staghorn calculi

2.1. Composition

In the past, it was believed that most staghorn calculi were composed of struvite or calcium carbonate apatite due to the general association of these stones with recurrent urinary tract infections and the known association of urease-producing uropathogenic bacteria with struvite formation [1,4,5]. In some cases, this dogma influenced decisions to forego metabolic evaluation in staghorn formers with infection type stones and instead only address the infectious risk factors in longitudinal follow-up. However, more contemporary studies have shown that, contrary to long-standing belief, metabolic stone types are now more common than infection stone types (Table 1).

Viprakasit and colleagues [6] reported on their series of 48 patients with staghorn calculi who underwent percutaneous nephrolithotomy (PNL) between 2005 and 2010. Of the 52 staghorn stones that were treated, 29 (56%) were metabolic stones compared to 23 (44%) infection stones. Predominant stone compositions within the metabolic group were calcium phosphate (CaP) 55%, uric acid (UA) 21%, calcium oxalate (CaOx) 14%, and cystine 10%. Thirteen of the 29 (48%) patients with metabolic stones completed 24-h urine testing, and all of them were noted to have metabolic abnormalities. In a separate series with strikingly similar findings, Haden and colleagues [7] reported on the results of 72 patients who underwent PNL for staghorn calculi between 2010 and 2015. Forty-four (61%) had metabolic stones, and 28 (39%) had infection stones. The compositions of the stones within the metabolic group were CaP 52%, UA 18%, CaOx 18%, and cystine 12%.

The reasons behind this apparent shift toward a predominance of metabolic stone types in modern staghorn series are not immediately clear. It has been postulated that increases in obesity rates in the United States over the past few decades could be contributing to the trend [6] since obesity and the metabolic syndrome are known to be risk factors for stone formation [8], although this does not account for the fact that the trend is being observed internationally as well [9,10]. Further complicating matters is the issue of the heterogeneity of technical stone analysis and the incumbent standard error that exists for that process. The technique for performing stone analysis can involve a variety of different imaging and chemical-based technologies which have been refined over the past several decades. Even with the use of modern techniques at high-volume reference laboratories, however, reproducibility between assays can be suboptimal [11]. This concern for variance is compounded upon consideration of the span of time over which many of the cited large series were published. Moreover, as noted in the Krambeck study [11], even the nomenclature used for specific mineralogic stone components is not standardized between different labs and therefore may be reported inconsistently between series. These limitations notwithstanding, the best available evidence that exists tells us that the majority of modern staghorn calculi are of metabolic subtypes, and this fact has important implications when considering the feasibility of metabolic evaluation and medical management of these patients.

2.2. Association with metabolic defects

For many years, the prevailing dogma was that all staghorn calculi should undergo a metabolic evaluation [12]. The reasoning behind this practice was the thought that there was likely a metabolic nidus which initiated microscopic lithogenesis, which then served as a scaffold upon which urease-producing bacteria could grow and create the alkaline, ammonia-rich milieu that is known to promote the growth of struvite infection stones. This practice went mostly unquestioned until the 1990s.

In 1995, Lingeman et al. [13] published their seminal work examining the results of metabolic evaluation following removal of infection calculi. In their series of 21 patients, stone analysis revealed that 14 patients had pure

Table 1 Prior publications of staghorn calculus case series in which stone type is identified.

Year	Authors	Patients, *n*	Renal units, *n*	Infection stones, *n* (%)	Proportion of infection stones by gender	Metabolic stones, *n* (%)	Proportion of metabolic stones by gender	Total No. of patients with metabolic abnormality	Metabolic stone compositions, as reported
1980	Resnick and Boyce [19]	44	88	26 (59%)	Male: 23%; Female: 77%	18 (41%)	Male: 55%; Female: 45%	Male: 88%; female 63%	CaP: 17%; CaOx: 17%; Mixed CaP/CaOx: 50%; Cystine: 17%
1982	Vargas et al. [27]	95	105	77 (98%)	Not given	1 (2%)	Not given	18/105 (17%)	Cystine: 100%
1986	Wall et al. [20]	33	33	21 (64%)	Not given	10 (30%)	Not given	26/33 (79%)	Mixed CaP/CaOx: 100%
1995	Teichman et al. [21]	177	112	40 (36%)	Not given	68 (61%)	Not given	46/112 (41%)[a]	Calcium: 38%; Mixed: 53%; UA: 6%; Cystine: 3%
2004	Akagashi et al. [10]	82	85	26 (32%)	Male: 35%; Female: 65%	55 (67%)	Male: 62%; Female: 38%	14/37 (38%)[b]	CaP: 12%; CaOx: 14%; Mixed CaP/CaOx: 22%; UA: 17%; Cystine: 2.5%
2011	Viprakasit et al. [6]	48	52	23 (44%)	Male: 17%; Female: 73%	29 (56%)	Male: 55%; Female: 45%	13/48 (27%)[c]	CaP: 55%; CaOx: 14%; UA: 14%; Cystine: 10%
2013	Shafi et al. [9]	45	45	4	Male: 50%; Female: 50%	39	Not given	Not given	CaOx: 47%; UA: 18%; Mixed CaP/CaOx: 16%; Cystine: 4.4%
2017	Haden et al. [7]	72	75	28 (39%)	Male: 43%; Female: 57%	44 (61%)	Male: 48%; Female: 52%	Not given	CaP: 52%; CaOx: 18%; UA: 18%; Cystine: 12%

CaOx, calcium oxalate; CaP, calcium phosphate; UA, uric acid.
[a]Only 112 patients had sufficient data for analysis.
[b]Only 37 patients completed 24-h urine testing, and 14 were noted to have hypercalciuria.
[c]Only 13 patients, all with metabolic stone types, underwent metabolic testing, and all had multiple abnormalities.

struvite/carbonate apatite infection stones while the remaining seven had mixed stones containing struvite/carbonate apatite plus calcium oxalate. On subsequent metabolic evaluation, they found abnormalities in 2/14 (14%) of pure infection stone formers and in 7/7 (100%) of mixed infection stone formers. These proportional differences were significant, allowing the authors to conclude that metabolic evaluations were unlikely to be revealing in patients with pure infection stones. To date, major American and European guidelines do not mention the performance of metabolic evaluation following surgical removal of infection calculi [14—17].

More recent data, however, have called this practice into question and suggest that the majority of patients with staghorn calculi—regardless of stone type—are likely to have an underlying metabolic defect and therefore would benefit from a metabolic evaluation. Iqbal and colleagues [18] examined their cohort of 75 patients treated with PNL for infection stones and observed that metabolic abnormalities were found in 4/7 (57%) of pure struvite stone formers and in 26/32 (81%) of mixed struvite stone formers ($p=0.32$). The overall prevalence of metabolic abnormalities in staghorn calculus formers has been demonstrated to be similarly elevated in several other large reported series, ranging from 27% to 79% in populations with infection stone prevalence of between 32% and 64% (Table 1) [6,10,19—22]. While these pooled study data do not compare directly to the Lingeman and Iqbal populations of pure versus mixed infection stone formers, the results suggest that a substantial proportion of all-comer staghorn stone formers do harbor metabolic abnormalities regardless of their specific stone composition. However, because of non-uniform reporting methods across series, rates of individual metabolic abnormalities in specific groups of stone formers cannot reliably be compared between series. In general, the most common defects (>40% prevalence within several of the cited series) are hypercalciuria, hypocitraturia, and hypernatriuria.

2.3. The primacy of surgical management

Until the middle of the 20th century, the prevailing management strategy for staghorn calculi was observation without intervention. In 1949, Priestly and Dunn [23] examined this practice and reported a dismal 41% survival rate at 15 years in patients with non-operative unilateral staghorn calculi, compared to 76%—81% 15-year survival in patients who underwent stone removal surgery. From this data, the authors concluded that surgical treatment of staghorn calculi was superior to non-operative management.

Subsequently from the 1970s through the 1990s, several additional series examining operative versus non-operative management of staghorn calculi were published which continued to demonstrate the superiority of surgical management with complete stone removal over observation in decreasing risk of recurrent urinary tract infection and pyelonephritis, sepsis, progressive renal failure, sepsis, and death [21,24—28]. It is on the basis of these studies that the 2005 American Urological Association (AUA) Guideline on Management of Staghorn Calculi codified surgical treatment as the standard of care for patients newly diagnosed with staghorn calculi [1]. This clinical principle that staghorn stones should be removed if attendant comorbidities do not preclude treatment was reiterated in the 2016 Surgical Management of Stones Guideline from the AUA [29].

A notable limitation of these studies and others like them is their non-randomized and heterogeneous nature which precludes meaningful direct comparisons between groups. Additionally, the potential for reasonable pooling of data between studies for meta-analysis is restricted since the body of literature was produced over a span of 6 decades during which significant advances were made in surgical therapy for stones, antibiotic therapy, and medical therapy for common medical comorbidities. On this basis alone, one may justifiably question whether observation of staghorn calculi in a modern cohort—with improved medications and diagnostic and therapeutic modalities for managing previously unimagined degrees of comorbidity—would manifest to be the harbinger of mortality as has been described in decades past.

3. Medical management of staghorn calculi

3.1. Primum non nocere: The necessity of medical management

Despite an abundance of clear evidence supporting maximal surgical stone removal as the standard of care for staghorn calculi, a significant number of patients with staghorn calculi are either too comorbid to undergo maximal stone removal or refuse surgery altogether [30,31]. Across the globe, patients are living longer and developing increasingly complex disease processes [32]. This consolidation of advanced medical conditions in patients, particularly elderly patients, contributes to frailty. Contemporary population-level studies are increasingly finding significant association between patient frailty and postoperative complications and mortality [33,34]. When evaluating and managing these frail and comorbid patients, the recommendation of maximal surgical stone removal may not be appropriate if there is a reasonable chance that the surgery would pose a greater risk to the patient than non-surgical management.

Conversely, offering an observation-only strategy—as was done in the past prior to the middle of the 20th century—is similarly non-ideal since reasonable management strategies may exist which could help minimize these patients' stone-related suffering. Therefore, if it is established that surgical stone removal is unreasonable on the basis of nonmaleficence, and likewise that non-interventional observation is unacceptable on the basis of suboptimal beneficence, then it is imperative that urologists must be able to offer a middle ground option for the optimal management of staghorn calculi in this special, non-operative population. This conservative medical management option should, to the greatest extent possible, minimize stone-related suffering as well as risk of stone progression.

3.2. The feasibility of medical management

Having established the existence of a need for medical management strategies in a subset of staghorn calculi patients, we now address our originally identified question of whether such a technique is safe or efficacious.

3.2.1. Safety

In 2016, Deutsch and Subramonian [31] from the UK published their prospective series of 22 patients with staghorn calculi who were treated conservatively with observation and monitoring of symptoms, urine cultures, and renal function. The reason for observation was patient comorbidity in 13 (59%) and patient choice in nine (36%). Primary outcome measures were UTI incidence, changes in renal function, and mortality rates. Mean follow-up time was 8.1 years. During the follow-up period, the authors reported recurrent UTI rate of 50%, stone-related hospital admission in 27%, and progressive decline in renal function in 14% with new dialysis-dependence in 9%. Patients with bilateral staghorns were significantly more likely to experience stone-related morbidity or mortality than patients with a unilateral staghorn. Two patients (9%) died from stone-specific causes—both of whom had complete bilateral staghorns—and six additional patients died from other causes for an overall mortality of 36%. The authors concluded that these results compared very favorably to the historical data from Singh et al. [24] who wrote the seminal paper advocating for aggressive surgical management of staghorn calculi in 1973. They reported on a series of 54 patients with staghorn calculi over a 17-year period, 20 of whom underwent immediate primary nephrectomy and 34 of whom were managed expectantly. Among the 34 expectantly managed patients, 16 eventually required nephrectomy. Three (19%) nephrectomy patients died from related causes, whereas 13/18 (72%) patients who remained on expectant management died from related causes. The mortality rate for the 20 patients who did undergo primary nephrectomy was 4/20 (20%) over the same period. The most common cause of death in both sets of patients is reported to have been renal failure.

More recently, there was a retrospective series of 29 staghorn calculi patients who were treated conservatively with observation and monitoring of imaging studies and renal function [30]. The reason for observation was patient comorbidity in 14 (48%), patient choice in 12 (41%), and aberrant anatomy in three (10%). Mean follow-up time was 2 years. No patients were managed on daily antibiotic prophylaxis. Fifty five percent of patients underwent 24-h urine studies. All patients were offered recommendations for general dietary management of their stones as well as directed medical therapy based on their metabolic evaluation when available. During the follow-up period, the authors noted decline of renal function in 34%, although no patients progressed to dialysis-dependence. Only one (3.4%) stone-related admission for pyelonephritis was noted during the period. There were two total deaths (6.9%) in the cohort, one for unrelated cardiac reasons and one secondary to urosepsis. The authors concluded that the outcomes in this select group of conservatively managed patients were reasonable and called for future prospective studies to better validate the safety of this technique.

Taken together, the results of these two studies would suggest that a conservative approach to the management of staghorn calculi in the modern era may not be as detrimental as it was shown to be in the past. It is plausible that advances in antibiotic therapy and in the treatments for complex comorbid medical conditions could have contributed to the overall improved survival compared to historical groups. It is interesting that of the three total stone-related deaths in the aforementioned recent studies, all three patients had complete bilateral staghorns. Notably, these studies are limited by their relatively brief mean follow-up intervals of 8.1 and 2.0 years, which may be too short to truly capture the impact on outcomes like progression to renal failure, dialysis, or death.

3.2.2. Efficacy

There have been no randomized controlled trials directly comparing the outcomes of surgical versus medical therapy for staghorn calculi. However, there are several studies of adjuvant medical therapy following surgical management which tangentially address the issue and which may form a helpful basis for extrapolation.

In 1994, Cicerello and colleagues [35] published their study addressing the fate of post-shockwave lithotripsy (SWL) stone fragments and the possibility of improving outcomes through pharmacologic intervention. They analyzed the records of 70 total SWL patients with two to five residual sub-5 mm stone fragments on plain abdominal X-ray approximately 2-months following lithotripsy. As determined by analysis of passed stone fragments, 40 patients had CaOx stones and no history of UTI, and 30 patients had struvite stones and a history of UTI. These two groups were then randomly subdivided into two study arms: Treatment and control. The treatment arm of both groups received oral citrate therapy, and the control group received only dietary counseling. Additionally, all patients in both arms of the infection stone group received a 10-day course of oral antibiotics once monthly. At 12 months of follow-up, 75% of patients in the citrate-treated CaOx group had no residual stone fragments, compared to only 32% in the controls. Compared to 40% of patients treated with antibiotics alone, 86% of the infection stone patients treated with citrate plus antibiotics were stone free. The authors hypothesized that the success of the combination treatment in the infection stone group may have been due to a combination of eliminating bacterial urease and ammonia production via antibiosis as well as reduction of renal ammoniagenesis due to the citrate [36].

A subsequent study by Fine and colleagues [37] examined the impact of post-SWL medical management on stone formation rate in 80 patients with and without residual fragments. Stone formation rate was defined to represent both the formation of new stones as well as the growth of existing ones, as assessed on serial abdominal radiography. The authors observed that post-SWL specific medical therapy resulted in reduction in stone formation rates of 91% and 81% in stone-free and residual fragment groups, respectively. Patients who elected to pursue dietary measures alone, conversely, experienced reduction in stone free rates of only 35% and 17% in stone-free and residual fragment groups, respectively. The authors concluded from these results that while the presence of residual fragments post-SWL can attenuate the response to medical management, metabolic evaluation and specific medical therapy can inhibit stone growth and new stone formation regardless of residual fragment status.

Similar results demonstrating the efficacy of specific medical therapy in a post-PNL population regardless of stone-free status were reported by Kang et al. [38]. They reviewed 70 patients who underwent both PNL and postoperative comprehensive metabolic evaluation. The patients were divided into subgroups based on their stone-free status as well as whether or not they elected to pursue specific medical therapy. During the 3-year mean follow-up period, patients who received specific medical therapy after surgery demonstrated a stone formation rate which was 98% lower than that of patients who did not pursue medical therapy, regardless of stone-free status (0.02 stones per patient per year versus 1.0, respectively). Moreover, 71.4% of untreated patients showed an increase in stone burden during the evaluation period, versus only 18.4% of patients on medical therapy.

Data presented by Iqbal and colleagues [18] are informing as to the question of whether or not metabolic evaluation and medical management are effective in pure struvite stone formers following PNL. Within their cohort of pure struvite stone formers, they reported decreased rates of stone growth (20% versus 42%) and stone events (20% versus 25%) in patients who underwent postoperative metabolic evaluation and selective medical management ($n=5$) compared to those who did not ($n=12$). Similar proportions of patients in each group were maintained on acetohydroxamic acid (AHA) and antibiotic prophylaxis. Although the differences in their stone outcomes did not reach statistical significance, likely due to the small numbers of patients in each group, the results are nonetheless intriguing and provide hope that perhaps medical treatments could be effective in patients with pure struvite stones.

3.3. Summary and recommendations for the metabolic evaluation and medical management of staghorn calculi

3.3.1. Question one: Can staghorn calculi be medically managed?

There are several established facts which support the reasonability of medical management for staghorn calculi as an acceptable treatment option in well-selected, non-surgical staghorn calculi patients. First, the best available evidence indicates that stone formation rate can be significantly decreased through the use of comprehensive metabolic evaluation and selective medical therapy. While the evidence supporting this approach is the strongest for patients with metabolic or even mixed metabolic-infection stone types, the Iqbal findings clearly demonstrate that a substantial proportion of pure struvite stone formers harbor underlying metabolic defects as well which could identified on metabolic evaluation and targeted with selective medical therapy. Additionally, in contrast to past observational series, the morbidity and mortality of conservative management for staghorn calculi in the two recently published modern cohorts does not seem to be as exaggerated as it was in prior decades. The reasons for this discrepancy are not immediately clear, however medical advances in management for these patients' comorbid conditions likely play a key role.

3.3.2. Question two: Should metabolic evaluation be performed in patients with staghorn calculi?

It has been established that the majority of staghorn calculi are of metabolic stone types. Among infection stones, which constitute 35%–45% of stones in contemporary series, mixed metabolic-infection stones are found most commonly, and a minority are pure struvite. Mixed metabolic-infection stones are classically associated with metabolic abnormalities. While there is some controversy regarding the incidence of metabolic defects in pure struvite stone formers, contemporary studies show that the prevalence of such defects in these patients exceeds 50% [39]. Correspondingly, a significant portion of staghorn stones—regardless of metabolic versus infection stone type—are associated with specific metabolic abnormalities. Therefore, it is reasonable for all patients with staghorn stones to undergo metabolic evaluation.

3.3.3. Recommendations

All patients with staghorn calculi should undergo comprehensive metabolic evaluation as most will harbor identifiable, and potentially treatable, metabolic defects. This evaluation should include, at a minimum, 24-h urine testing on a random diet, serum chemistries including calcium levels, comprehensive urinalysis and culture, and stone analysis when available. Any identified metabolic abnormality should be identified and treated with directed medical therapy. After initiating medical therapy, a repeat 24-h urine collection within 3–4 months is helpful to assess for adequacy of therapy. All patients should additionally be thoroughly counseled regarding conservative dietary measures of elevated fluid intake, low sodium/low animal protein diet.

The goal of the evaluation and medical therapy in the staghorn calculus patient who is not a surgical candidate should be not only to minimize stone progression, but also to minimize the patient's exposure to risk from their inoperable stone. Comprehensive metabolic evaluation with directed medical therapy should be initiated, as described above. For patients with a history of recurrent UTIs or in whom infection stone might otherwise be suspected, urinalysis and culture should be performed as part of routine follow-up, and culture-directed antibiotic therapy should be administered as necessary. There is minimal evidence to support or refute the utility of continuous antibiotic prophylaxis over an aggressive culture-and-treat strategy, so the clinician's best judgement should be used. Comorbidities such as hypertension and diabetes mellitus should be tightly controlled to reduce the likelihood of renal functional and infectious complications. Because of the possibility of progression to end-stage renal disease, if there is any indication of chronic renal failure then nephrology referral is warranted. Surveillance imaging may be helpful to assess for stone activity or evidence of progressive renal obstruction. If there is radiographic evidence of upper tract obstruction, then decompression with either indwelling ureteral stent or percutaneous nephrostomy tube may be indicated. Because the treatment of these non-operative patients by definition precludes the availability of stone analysis data, the role of AHA and/or urinary acidification in these patients is unclear. These agents are classically reserved for patients with proven struvite calculi as a result of a urease-producing bacterial urinary tract infection. Some patients may possess enough risk factors for struvite stone, including recurrent urinary tract infection with urease-producing bacteria, to warrant empiric trial of these modalities in an attempt to "break the cycle" and take control of the disease process as best as possible. However, caution must be taken as AHA has a profound side effect profile which merits very close monitoring while taking the medication. Furthermore, patients who are prescribed AHA for this reason should be counseled regarding this type of off-label use of the medication. Based on their high risk for developing problems related to their stones, it is recommended to follow these patients very closely at first to screen for any problematic sequelae. Once stability is established, it may be reasonable to stretch out scheduled follow-up intervals to every 6 or 12 months.

For staghorn calculus patients who are able to undergo maximal surgical removal, postoperative metabolic evaluation with directed therapy should similarly be pursued. For patients with infection stone types, urinalysis and urine culture should be performed routinely with prescription of culture-directed antibiotic therapy for findings of infection. Again, consideration may be given to continuous antibiotic prophylaxis at the clinician's discretion if an aggressive culture-and-treat strategy fails. If the predominant culture isolates are urease-producing species, then careful consideration should be given to initiation of AHA therapy. As staghorn calculus patients are considered to be high risk stone formers, periodic surveillance imaging is mandatory to assess for new stone activity. The AUA Guidelines on the Medical Management of Kidney stones recommend a 1-year imaging interval for stable patient, which may be tailored based on stone activity [17]. Prior to reaching this point of stability, however, it may be wise to perform surveillance imaging every 3–6 months so that recurrence may be detected and treated as expeditiously as possible.

4. Conclusion

Ideally, the majority of patients with staghorn stones will undergo maximal surgical stone removal followed by comprehensive metabolic evaluation and directed medical therapy. However, the unfortunate reality is that increasing numbers of patients around the world are too medically ill to undergo surgery for staghorn calculi removal, and therefore it is incumbent upon urologists to be able to offer these patients non-surgical management options. Presented herein is an evidence-based set of recommendations for the metabolic evaluation and medical management of these non-operative staghorn calculi patients. With thoughtful evaluation and fastidious management of identified metabolic derangements, there is hope for these patients that they may be granted relief from their stone-related suffering.

Author contributions

Study concept and design: Russell S. Terry, Glenn M. Preminger.
Data acquisition: Russell S. Terry, Glenn M. Preminger.
Data analysis: Russell S. Terry, Glenn M. Preminger.
Drafting of manuscript: Russell S. Terry.
Critical revision of the manuscript: Russell S. Terry, Glenn M. Preminger.

Conflicts of interest

The authors declare no conflict of interest.

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