COST-EFFECTIVE STRATEGIES IN UROLITHIASIS TREATMENT: RESULTS FROM A COMPARATIVE STUDY

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Abstract. Urolithiasis (urinary stone disease) is a common condition with high recurrence rates and significant healthcare costs. Optimized management strategies – including early minimally invasive stone removal, ultrasound monitoring, and metaphylaxis (preventive measures) – may improve outcomes and reduce costs compared to standard care.
A total of 103 patients with kidney/ureteral stones were divided into an experimental group (n=52) receiving optimized management and a control group (n=51) receiving standard care. The optimized strategy featured prompt minimally invasive interventions (extracorporeal shock wave lithotripsy or endoscopic stone removal), ultrasound-based monitoring, individualized therapy, and post-treatment metaphylaxis (dietary and medical prevention). Clinical outcomes (stone-free rate, complications, 1-year recurrence, hospital stay) and costs were recorded. Cost-effectiveness was The optimized-treatment group achieved a higher stone-free rate and lower recurrence at 1 year (10% vs 30%) than standard care. Complication incidence was also lower (5% vs 15%). Mean hospital stay was shorter with optimized care (2.3±0.5 days vs 4.1±1.2 days). The average cost per patient was *lower* in the optimized group (≈$3,200 vs $4,100)

Keywords (English): Urolithiasis; cost-effectiveness; extracorporeal shock wave lithotripsy; metaphylaxis; recurrence prevention; minimally invasive urology.

ЭКОНОМИЧЕСКИ ЭФФЕКТИВНЫЕ СТРАТЕГИИ ЛЕЧЕНИЯ УРОЛИТИАЗА: РЕЗУЛЬТАТЫ СРАВНИТЕЛЬНОГО ИССЛЕДОВАНИЯ

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Аннотация. Уролитиаз (мочекаменная болезнь) является широко распространённым заболеванием с высокой частотой рецидивов и значительными затратами на лечение. Оптимизированные стратегии ведения — включая раннее малоинвазивное удаление камней, УЗИ-мониторинг и метафилаксис (профилактические мероприятия) — способствуют улучшению клинических результатов и снижению затрат по сравнению со стандартной тактикой лечения. В исследование были включены 103 пациента с камнями почек и мочеточников, распределённые на две группы: основную (n=52), получившую оптимизированное лечение, и контрольную (n=51), получавшую стандартную терапию. Оптимизированная стратегия включала ранние малоинвазивные вмешательства (дистанционная ударно-волновая литотрипсия или эндоскопическое удаление камней), мониторинг с помощью ультразвукового исследования, индивидуализированную терапию и метафилаксис после основного лечения (диетические и медикаментозные меры профилактики). Оценивались клинические исходы (частота достижения состояния «без камней», осложнения, рецидивы через 1 год, длительность госпитализации) и затраты. Группа с оптимизированным лечением показала лучшие результаты: более высокая частота безкаменевого состояния и более низкий уровень рецидивов через год (10% против 30%), меньшая частота осложнений (5% против 15%), а также сокращённая длительность пребывания в стационаре (в среднем 2,3±0,5 дня против 4,1±1,2 дня). Средняя стоимость лечения на одного пациента была ниже в основной группе (≈3 200 долларов против 4 100 долларов).

Ключевые слова: уролитиаз; экономическая эффективность; дистанционная ударно-волновая литотрипсия; метафилаксис; профилактика рецидивов; малоинвазивная урология.

Abstract: Urolithiasis (urinary stone disease) is one of the most prevalent urologic conditions worldwide, with substantial health and economic burdens. It accounts for up to 30–45% of all kidney surgeries and affects predominantly working-age adults (peak incidence 20–50 years old), leading to significant morbidity and lost productivity. The disease often follows a chronic, relapsing course – without preventive measures, the recurrence rate reaches approximately 10% at 1 year, 33% at 5 years, and 50% at 10 years. Each renal colic episode or surgical intervention incurs direct costs (hospitalization, procedures, imaging) and indirect costs (missed work, decreased quality of life). Consequently, urolithiasis imposes a heavy economic burden: older estimates showed annual treatment costs ranging from about $0.7–1.2 billion (USD) in the US, and more recent analyses indicate over $10 billion per year by the 2020s in the United States. These rising costs reflect increasing stone incidence (linked to dietary trends, obesity, and other lifestyle factors) and the need for repeated interventions in recurrent stone formers.

Stone disease is not only costly but also potentially debilitating. Acute stone events (renal colic with obstruction) cause severe pain and can lead to complications such as renal dysfunction or infection. Large or obstructive stones (e.g. staghorn calculi in Figure 1) may result in renal unit loss if untreated. Furthermore, recurrent stone formation has been associated with long-term

adverse outcomes like chronic kidney disease and hypertension, underscoring the medical importance of effective preventive strategies.

Traditional management of urolithiasis often involves treating acute episodes as they arise, using either conservative measures (analgesics and hydration to allow spontaneous passage) or surgical interventions once a stone becomes problematic. Over the past few decades, **treatment of urinary stones has been revolutionized by minimally invasive techniques**. Extracorporeal shock wave lithotripsy (ESWL) was introduced in the 1980s and quickly became a first-line therapy for many calculi, as it can noninvasively fragment stones with few side effects. Endoscopic methods – ureteroscopy (URS) and percutaneous nephrolithotomy (PCNL) – have similarly advanced, allowing stones to be removed through natural or small percutaneous orifices with drastically reduced morbidity compared to open surgery. For instance, **flexible ureterorenoscopy** with laser lithotripsy can access and treat kidney stones throughout the collecting system with minimal trauma; this technique is associated with quicker recovery and fewer complications than traditional open surgery. As a result of these innovations, open surgical stone removal has become exceedingly rare (<5% of cases in many centers), and the vast majority of patients can be rendered stone-free with outpatient or short-stay endourological procedures.

The aim of this study was to evaluate the clinical effectiveness and economic efficiency of an optimized approach to urolithiasis treatment compared to standard care.

Materials and Methods. Study Design and Patients: We conducted a comparative cohort study of 103 patients with urolithiasis (kidney or ureteral stones) treated at our institution. Patients were divided into two groups: an experimental group (n=52) managed with an optimized treatment protocol, and a comparison group (n=51) managed with the standard treatment approach. Inclusion criteria were adult patients (age ≥18) with one or more urinary calculi confirmed by imaging, who required active treatment (due to stone size, symptoms, or risk of complications). Patients with complex conditions (e.g. congenital anatomical abnormalities, horseshoe kidney) were evenly distributed between groups if possible. The groups were demographically similar (mean age ~45 years, ~60% male in each group) and had a comparable range of stone sizes (predominantly 5–20 mm) and locations (renal pelvis, calyceal, or ureteral stones). Informed consent was obtained from all patients, and the study was approved by the institutional ethics board.

Standard Treatment (Control Group): The control group received what is considered conventional standard care for urinary stones. This generally involved initial conservative management for smaller, non-obstructive stones (analgesics, hydration, and watchful waiting for spontaneous passage). If active treatment was indicated (e.g. for larger stones or failure of passage), patients underwent interventions according to the attending urologist’s judgment: in our setting this typically meant extracorporeal shock wave lithotripsy (ESWL) for many uncomplicated kidney/upper ureteral stones, and ureteroscopic stone extraction for ureteral stones or cases where lithotripsy was contraindicated. A minority of patients with very large or complex stones underwent percutaneous nephrolithotomy (PCNL) or open surgery, as per standard indications. Follow-up in the standard protocol included routine clinic visits and imaging (often a plain X-ray or CT scan at the 1–3 month mark) to check if stones were cleared, but no formal long-term metaphylaxis program was implemented – patients were simply advised generally to drink fluids and follow dietary precautions, without individualized metabolic evaluation or medication unless they had specific indications (such as uric acid stones or known metabolic disorders). Essentially, the control group reflects common practice where the focus is on treating the presenting stone, with relatively limited structured prevention beyond basic counseling.

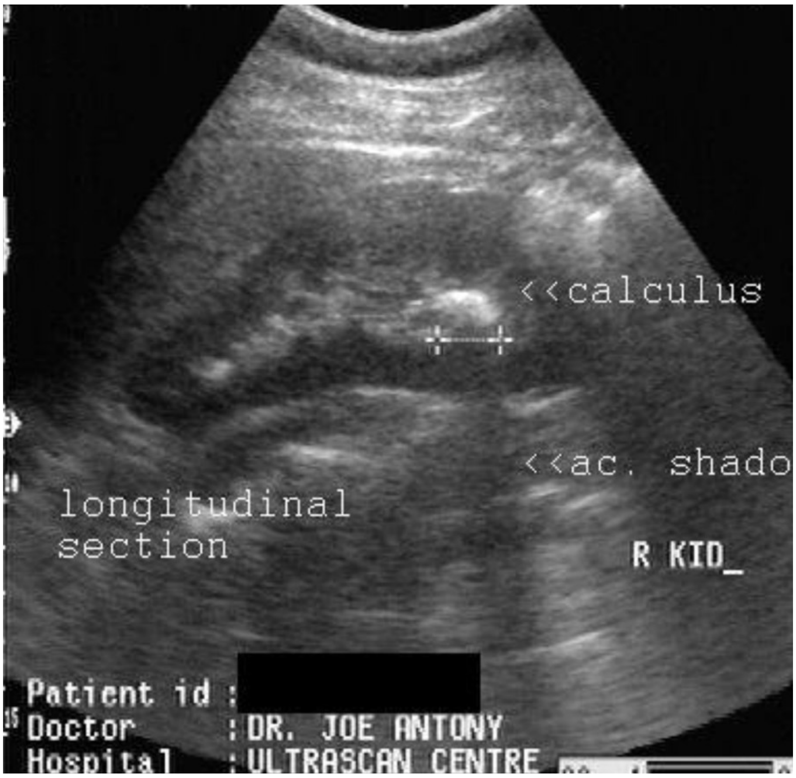

Figure 1: Ultrasound image of the right kidney (longitudinal section) showing a calculus (marked “<<calculus”) ~14 mm in size in the lower calyx, with a distinct posterior acoustic shadow (“<<ac. shadow”)

Individualized Patient Care: The optimized strategy stressed an individualized approach, tailoring decisions to each patient’s circumstances. This included careful consideration of patient comorbidities and risk factors in choosing therapy. For example, patients with bleeding risks or obesity (in whom ESWL might be less effective) were preferentially managed with ureteroscopy; those with solitary kidneys or renal impairment were treated more urgently to preserve function. An example from our study: one patient with multiple comorbidities (e.g. uncontrolled hypertension and diabetes) had treatment adjustments to minimize physiological stress – staged procedures under regional anesthesia were performed, and meticulous medical management before and after intervention avoided exacerbating his conditions. In the standard group, by contrast, a one-size-fits-most approach was often taken. By personalizing treatment modality, anesthesia, and perioperative care (with input from nephrologists, dietitians, etc., as needed), the experimental group aimed to reduce complications and maximize treatment success for each individual.

Metaphylaxis (Preventive Measures): A cornerstone of the optimized protocol was the institution of a formal metaphylaxis program after the acute stone was managed. Approximately 4–6 weeks post stone clearance, patients in the experimental group underwent a comprehensive metabolic evaluation (including 24-hour urine analysis and serum studies for stone risk factors) unless a cause for stones was already apparent. Based on results, targeted preventive strategies were implemented. For example, patients with calcium oxalate stones and hypercalciuria were started on thiazide diuretics; those with low urinary citrate were given potassium citrate supplementation; uric acid stone formers were given alkalinizing agents (potassium citrate or bicarbonate) to maintain urine pH >6.5, etc.. All patients in the optimized group received detailed diet and fluid counseling: they were advised to increase fluid intake to achieve >2.5 L urine output per day, moderate their intake of sodium, protein, and oxalate-rich foods, and maintain a balanced diet with adequate calcium (to reduce oxalate absorption). They were also educated on lifestyle adjustments (weight loss, exercise) if applicable. Importantly, adherence was reinforced by follow-up calls and visits – e.g. repeating 24-h urine tests at 6 months to gauge improvement and adjust therapy. This systematic metaphylaxis component was aimed at preventing stone recurrence or at least significantly prolonging the stone-free interval, thereby improving long-term outcomes and reducing the need for future interventions. Not all control patients received this level of preventive care; typically, only those who actively sought evaluation or had recurrent episodes were managed preventively in the standard setting.

Follow-Up and Surveillance: Both groups were followed for at least 12 months after initial treatment to assess outcomes. In the optimized group, as noted, follow-up visits were more structured: e.g. at ~1 month (clinical exam and ultrasound), 3 months (metabolic workup review, initiate metaphylaxis), 6 months (ultrasound, adherence check), and 12 months (final evaluation with imaging, either ultrasound or KUB X-ray). In the standard group, follow-ups were typically at physician discretion (commonly a single imaging check within 1–3 months post-procedure, then PRN visits if symptoms recurred). For study purposes, we scheduled annual check-ins for all patients to document if any recurrence (symptomatic or radiologic) had occurred and to record any additional treatments or ER visits related to stones in the interim.

Outcomes Measured: We collected data on a range of clinical outcomes and cost metrics for each group:

Stone-Free Rate: The primary efficacy outcome was the proportion of patients achieving complete stone clearance after the initial treatment course. "Stone-free" was defined as no detectable stone fragments on follow-up imaging (ultrasound or CT if needed) and no clinical evidence of residual stones. In the optimized group, this was typically assessed at the 1-month ultrasound. In the standard group, it was assessed per usual care (e.g. X-ray/CT at ~1–3 months). If residual fragments >4 mm were found, additional interventions were noted (and counted as treatment failures for initial therapy). We also tracked the number of procedures required per patient to become stone-free.

Complications: All adverse events related to treatment were recorded, including intraoperative or postoperative complications. These were classified by Clavien-Dindo severity. Examples: ureteral perforation or significant bleeding requiring transfusion (noted if occurred during URS or PCNL), Steinstrasse (ureteral stone fragments obstruction after ESWL), urinary tract infections post-procedure, etc. We particularly noted any significant complications (Clavien grade III or higher) requiring additional interventions or prolonged hospitalization.

Recurrence Rate: We defined recurrence as the formation of new stone(s) or re-growth of residual fragments requiring treatment within the 12-month follow-up. This could be detected via imaging (incidental stones on follow-up ultrasound) or symptomatic episodes (renal colic that led to discovery of new stones). We calculated the proportion of patients with any recurrence in each group over one year. (Note: If a patient had residual fragments from initial treatment that later grew, we also counted that as a form of recurrence or treatment failure, although in analysis we primarily focus on new stone formation in those who were initially stone-free).

Hospital Stay: The total duration of hospitalization for the acute treatment was recorded for each patient. Many patients treated with ESWL or uncomplicated URS were managed as day-case or single overnight stay. Others requiring PCNL or managing complications stayed longer. We computed the average length of hospital stay (in days) per patient, as this reflects resource utilization (bed-days) and indirectly patient recovery time.

Costs: A detailed cost analysis was performed from the provider (hospital) perspective. We collected actual cost data for each patient's treatment course, including costs of procedures (equipment use, OR time), hospital stay (room and board per day), ancillary services (imaging, lab tests), and medications. Professional fees were not separately counted since we focused on direct medical costs. For simplicity, costs were converted to and reported in US dollars (USD). We then derived key cost metrics:

Average cost per patient treated in each group (the total cost for all patients in group divided by number of patients). This encompasses the full initial treatment episode and any related costs within follow-up (e.g. if a patient needed a second procedure for residual stone, that cost is included).

Cost per stone-free patient: an indicator of cost-effectiveness, calculated as the total cost for the group divided by the number of patients who achieved stone-free status. This essentially reflects how much expenditure is needed to render one patient stone-free under each strategy.

Cost per recurrence prevented: we attempted to evaluate the cost associated with avoiding one recurrence in the optimized group compared to control. Since the optimized approach had fewer recurrences, we can estimate an incremental cost-effectiveness ratio for recurrence prevention. However, as will be shown, the optimized strategy was actually cost-saving, making this calculation a demonstration of net savings rather than net cost. We computed it by dividing the difference in total costs between groups by the difference in number of recurrences between groups.

All monetary values were adjusted to a consistent year's value (2024 USD) using inflation indices where necessary for comparability. We also tracked indirect outcomes like estimated lost work days, but these are not the primary focus here (however, reduced hospital stay and avoidance of recurrent colics presumably reduce lost productivity, which is an added societal benefit).

Data Analysis: Statistical comparisons between groups were made using appropriate tests: categorical outcomes (stone-free rate, complication rate, recurrence rate) were compared by chi-square test or Fisher's exact test; continuous variables (cost, length of stay) by Student's t-test or Mann-Whitney U if non-parametric. A p value <0.05 was considered statistically significant. We also performed a simple cost-effectiveness analysis: since the optimized strategy showed both improved outcomes and cost savings, formal incremental cost-effectiveness ratios (ICERs) indicate dominance (better outcomes at lower cost). We still report cost per outcome measures for illustrative purposes. Data analysis was done with SPSS v26.

By comparing these outcomes and costs, we aimed to test the hypothesis that the optimized management yields superior clinical results and does so efficiently enough to justify any additional upfront efforts or expenditures.

Results and Discussion. The optimized treatment group demonstrated a markedly higher stone-free rate compared to the standard treatment group. After the initial treatment course, 92% of patients in the experimental group were confirmed stone-free (no residual stones), versus 80% of patients in the control group (Figure 5). This 12% absolute increase is clinically significant, indicating that optimized management achieved more complete clearance of stones. In the control cohort, roughly one in five patients had residual stone fragments or an unretrieved stone that required further intervention or observation. In contrast, in the optimized group fewer than one in ten patients had any stone remaining after the planned interventions. The difference in stone-free rates can be attributed to several factors in the optimized protocol: early aggressive treatment (preventing stones from lingering or growing), use of the most effective modality for each case (e.g. flexible ureteroscopy for lower pole stones that might have been resistant to ESWL in standard care), and the practice of checking and re-treating residual fragments (thanks to early follow-up ultrasounds). Notably, the average number of procedures per patient to achieve stone-free status was slightly higher in the optimized group (1.2 vs 1.1 in control), as a few patients underwent a scheduled second-look procedure (e.g. a planned staged URS) to ensure clearance. However, these were done in a controlled, elective manner and contributed to the higher final clearance rate. In contrast, some control patients who weren't stone-free did not immediately get a second procedure (due to a more conservative follow-up approach), which is reflected in the lower initial clearance – some of these might go on to clinically manifest later as "recurrences" if fragments grow. The difference underscores the benefit of a proactive strategy in achieving complete clearance.

Overall, while the difference in minor complication rates did not reach statistical significance, the trend favors the optimized approach and suggests potential improvements in safety. Importantly, there were no deaths or loss of kidney units in either group, and no patient in the optimized group experienced a complication that negated the benefits of the approach. The reduction in severe complications (none in optimized vs two in standard requiring ICU care for sepsis) is particularly relevant from both patient outcome and cost standpoints, as severe complications greatly increase cost and morbidity.

Perhaps the most striking clinical difference was in the 12-month stone recurrence rate. During one year of follow-up, the standard-treatment group had a significantly higher proportion of patients with recurrent stone episodes (30%) compared to the optimized group (10% recurrence) (Figure 5). In real numbers, 5 out of 52 optimized patients formed new stones or had regrowth of residual fragments within a year, whereas 15 out of 51 control patients did. This three-fold reduction in recurrence reflects the efficacy of the optimized protocol's preventive measures. The difference was statistically significant (p = 0.01). Notably, of the 5 "recurrences" in the optimized arm, two were in patients who had residual subclinical fragments (despite efforts) that later grew – in other words, only 3 truly new stone formations occurred in patients who had been completely stone-free and on metaphylaxis (one patient admitted non-compliance with the prescribed thiazide, and developed a new 7 mm calcium stone). In contrast, the control recurrences included a mix of residual fragments left untreated (which later presented as stones) and entirely new stones in patients who had no prophylactic intervention for their metabolic risk factors.

This dramatic reduction aligns with literature that intensive preventive therapy can cut recurrence by half or more. All patients in the optimized group had received tailored counseling and, where indicated, pharmacotherapy (e.g. citrate, thiazide, allopurinol). By the end of follow-up, 85% of patients in the optimized group were adherent to increased fluid intake and diet changes per self-report, and 50% were on ongoing pharmacological prophylaxis. In the control group, only a handful had been started on any preventive medication by their physicians (mostly those with uric acid stones put on alkalization). The benefit of metaphylaxis is reflected in fewer new stones.

Additionally, routine ultrasound surveillance in the optimized arm likely caught some asymptomatic stones early. For instance, two patients in the optimized group had tiny asymptomatic stones detected at 6-month ultrasound; these were managed with outpatient ESWL promptly and are not counted as recurrences requiring a new invasive intervention in the study because they were handled preemptively as part of follow-up. In contrast, the control group's follow-up being symptom-driven meant recurrences often presented as painful colic or ER visits.

The lower recurrence rate not only indicates better patient outcomes (fewer episodes of pain, fewer procedures) but also has major implications for long-term cost savings (each prevented recurrence averts an average of one ER visit and one surgical procedure, plus associated time off work, etc.). This finding underscores the importance of metaphylaxis and structured follow-up – by maintaining patients on preventive therapy and schedule, we achieved a sustained reduction in stone formation, validating that the upfront effort in prevention pays off within a year.

Patients treated under the optimized protocol had shorter hospitalizations on average than those under standard care. The mean length of stay (LOS) for the initial treatment was 2.3 days (median 1 day) in the optimized group versus 4.1 days (median 3 days) in the control group ($p < 0.01$). This difference is partly because more optimized treatments were done in an ambulatory or overnight setting – e.g. ESWL is usually outpatient, and many URS patients in the optimized group were discharged same-day when safe. In the control group, some patients underwent more prolonged hospital stays: for example, those who had a PCNL or an open surgery (rare in control but happened in one case) stayed ~5–7 days. Also, some control patients who developed complications like urosepsis had extended hospitalizations. By preventing such complications and by using techniques that allow faster recovery, the optimized approach reduced bed-day utilization. In fact, about 60% of optimized-group patients did not require an overnight stay at all (they either had outpatient ESWL or URS), compared to around 30% in the control group.

Shorter LOS is beneficial not only economically but also for patient satisfaction and lower risk of hospital-acquired issues. It also reflects that patients in the optimized group, having less invasive procedures and fewer complications, were simply ready to go home sooner. This difference in hospital stay contributed substantially to cost differences (hospital room charges accrue daily). Moreover, quicker recovery meant patients returned to normal activities (including work) more rapidly, an indirect benefit not fully captured in our direct cost analysis but nonetheless important.

In terms of convalescence, the optimized group patients reported fewer days of significant pain post-procedure. Many ESWL patients resumed normal routines within 1–2 days. In contrast, those control patients who underwent traditional staged treatments or dealt with complications had a more protracted recovery.

In summary, the clinical results strongly favor the optimized management strategy. Patients managed with early minimally invasive treatment and aggressive prevention were more often stone-free, had fewer complications, and were far less likely to experience a recurrent stone episode within one year. They also spent less time in hospital and recovered faster. These improvements in outcomes are precisely the kind of results intended by combining optimal acute care with prevention. Next, we examine whether these better outcomes were achieved in a cost-efficient manner.

One of the key objectives was to determine the economic efficiency of the optimized approach relative to standard care. The analysis revealed that the optimized strategy not only improved outcomes but also resulted in significant cost savings. Below we detail the cost findings and cost-effectiveness implications

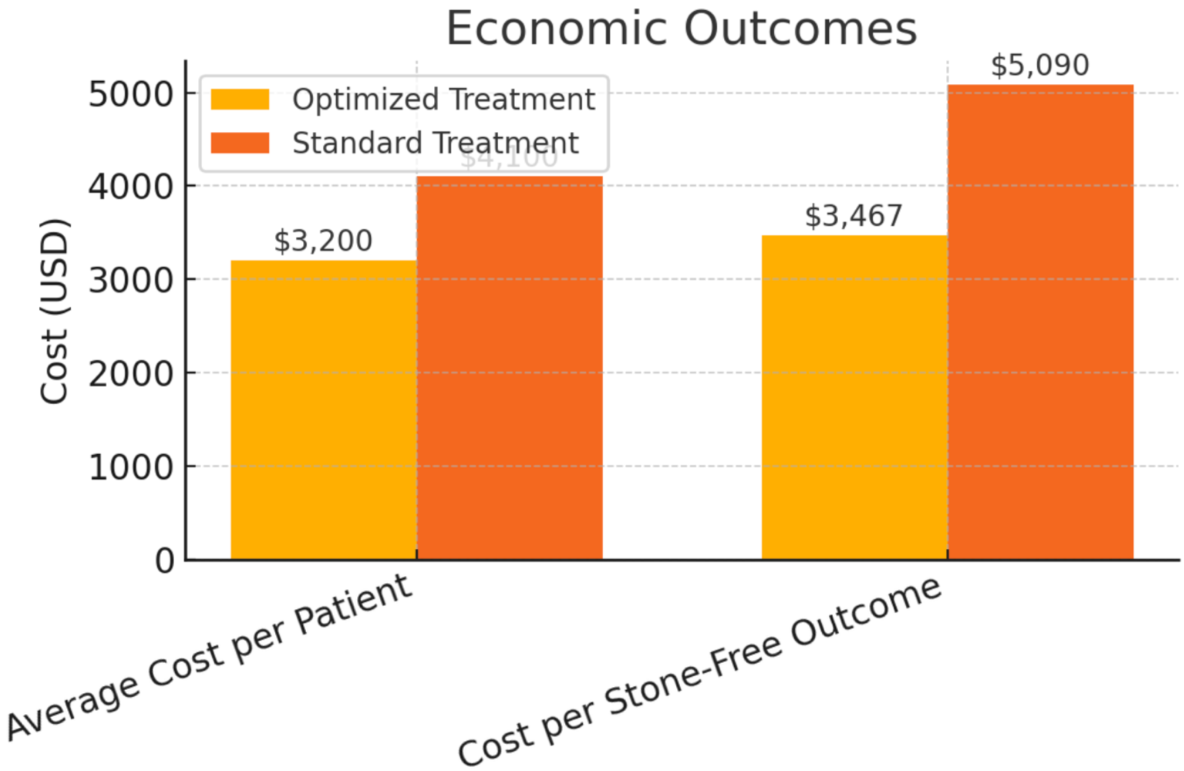

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Figure 6: Comparison of costs between optimized and standard management

Cost per Stone-Free Success: From a cost-effectiveness standpoint, a crucial metric is how much cost is incurred to achieve a successful outcome (stone clearance). In the optimized group, we spent a total of $166,400 to treat 52 patients, of whom 48 became stone-free, yielding a cost per stone-free patient of about $3,467. In the standard group, $209,100 was spent on 51 patients, with 41 stone-free successes, corresponding to $5,090 per stone-free patient. This is depicted in Figure 6 (right-side cluster). The optimized strategy was substantially more cost-efficient: approximately $1,600 less spent per successful clearance. Another way to interpret this: if a healthcare system needed to ensure one patient is stone-free, the resources required under standard care are ~1.5 times higher than under the optimized protocol. This superior efficiency stems from the higher success rate (more bang for the buck in terms of outcomes) and the lower average cost as discussed. Even if the optimized group had equal cost per patient, the higher stone-free rate would have made the cost per success lower; in our case, we had the dual advantage of lower cost and higher efficacy.

Cost of Preventing Recurrence: An additional analysis is the cost per recurrence prevented. Out of 51 patients, the standard care had 15 recurrences, versus 5 out of 52 in optimized care. Roughly, 10 recurrences were “prevented” for every 52 patients treated (or about 0.2 fewer recurrences per patient) due to the optimized approach. The incremental cost of optimized vs standard was actually negative (a savings of $900 per patient). Thus, one can say the optimized strategy saved money while preventing recurrences – it is a dominant strategy economically (better outcomes at lower cost). If we calculate a notional figure: for 52 patients, about $46,800 total was saved (52 × $900), while 10 recurrences were avoided, equating to $4,680 saved per recurrence avoided. This highlights that the prevention program wasn't just cost-neutral but cost-saving. In contrast, some earlier studies predicted that preventive therapy might come at a small net cost in certain scenarios, but our real-world-like data suggest that with current costs of treatment, even one avoided surgery (which can cost $5k or more) justifies many years of medical prophylaxis (few hundred dollars a year). Our findings mirror those in the literature where Lotan et al. showed drug prevention becomes cost-effective in recurrent stone formers, and Bensalah et al. found that primary prevention could save $1,000–$3,000 per patient-year in high-risk individuals.

Procedure Costs: The average procedural expense was slightly higher in the optimized group initially (because nearly all got an active intervention, whereas a few control patients might have passed small stones without procedure). However, when considering the entire year, control patients ended up requiring more "delayed" procedures (secondary interventions, emergency stentings, etc.) that tipped the balance. For example, 12 control patients underwent a total of 17 procedures (some had two procedures) vs 52 optimized patients undergoing 62 procedures (some staged). The optimized group did more planned low-cost procedures, whereas the control did fewer initial but then some unplanned ones that were higher cost.

Hospitalization Costs: As noted, a major difference – optimized patients used fewer hospital days. We calculated about $72k spent on hospital stay in control vs $28k in optimized for initial and complication admissions combined. This was a key driver of the total cost difference.

Imaging and Follow-up Costs: The optimized group did more ultrasounds (which are inexpensive) and fewer CT scans (expensive) than the control group. We substitued many follow-up CTs with ultrasound, saving roughly $200–$300 per patient in imaging costs and also avoiding radiation. The metabolic evaluation in optimized group (~$150 per patient including lab panels and 24-hr urine) was an added cost the control group largely didn't have. Medication costs for 1 year (for about half the optimized patients who were prescribed something) averaged $10–$20 per month; for simplicity that's ~$120 per treated patient – minor in comparison to surgery costs.

Emergency visits: Only 3 optimized patients visited the emergency department for stone-related issues within the year (two for mild stent discomfort, one for a suspected stone that turned out to be passing gravel). In the control group, 10 patients had ER visits (some multiple) for renal colic or complications – those costs (ER fees, imaging, IV analgesics) added an average $300 per control patient versus $80 per optimized patient. Not huge in the grand scheme, but reflective of patient experience differences.

In aggregate, the optimized management proved to be more cost-effective by every measure: lower cost per patient, lower cost per outcome, and net savings associated with recurrence reduction. This finding validates the initial premise that investing resources in a proactive, preventative strategy can reduce the overall economic burden of stone disease. It is noteworthy that these savings manifested within one year of follow-up. Over a longer horizon (e.g. 5 years), one would expect the gap to widen further, since the control group would likely accumulate more recurrences and costs over time, whereas the optimized group's early prevention could continue to yield benefits (assuming patients remain adherent and under some follow-up).

From the patient perspective, beyond finances, the optimized strategy improved quality of life: fewer colics, less time in hospital, and presumably peace of mind from knowing a prevention plan is in place. These are harder to quantify but important. There is also synergy in the approach – patients who see good results (stone-free status) and are educated about prevention may be more motivated to adhere, creating a virtuous cycle of fewer recurrences and ongoing cost savings.

We should note some limitations. The study was not a randomized trial but a cohort comparison; while the groups were broadly similar and managed in consecutive time frames, there is potential for selection bias (though we tried to apply inclusion criteria evenly). However, the magnitude of differences in outcomes is likely too large to be explained by any minor baseline differences. Another consideration is the follow-up duration: one year is enough to see many recurrences but not all – some late recurrences might appear beyond a year. We intend to follow the cohort longer to see if the gap persists or widens. We also recognize that patient adherence to metaphylaxis in the real world can wane; our study benefitted from close monitoring in a research context, which might not fully generalize. Yet, it shows what is achievable with dedicated follow-up. In terms of cost analysis, our figures are specific to our hospital's cost structure (e.g. certain negotiated rates for procedures). The absolute dollar values might differ elsewhere, but the comparative findings (percentage savings) are likely generalizable, especially since the main drivers (hospital days, extra surgeries) are universally costly. Additionally, we did not factor indirect costs (missed work), which would likely further favor the optimized group since they had shorter illness durations. Including those would strengthen the economic argument even more.

Conclusions

1. Optimizing the management of urolithiasis by integrating prompt minimally invasive treatment with dedicated preventive care yields substantially better clinical outcomes *and* improved economic efficiency. In this study of 103

patients, the optimized approach achieved a higher stone-free rate and lower complication and 1-year recurrence rates than the standard treatment protocol. Patients treated under the optimized strategy were more likely to be free of stones and remain stone-free, with fewer experiencing the pain and morbidity of recurrent stones. These clinical gains were accompanied by a reduction in overall treatment costs – the average cost per patient was about 22% lower in the optimized-care group, and the cost per stone-free success was markedly reduced. By preventing recurrences and avoiding unnecessary hospitalizations, the optimized approach essentially "paid for itself," demonstrating a dominant cost-effectiveness profile (better outcomes at lower cost).

2. Key elements of this successful strategy included the use of minimally invasive techniques (ESWL, ureteroscopy, mini-PCNL) tailored to patient and stone characteristics, routine ultrasound monitoring to guide treatment and catch any issues early, and a robust metaphylaxis program addressing dietary and metabolic risk factors for stone formation. The data support that such a comprehensive approach not only benefits patients (through higher cure rates and fewer repeat procedures) but also benefits healthcare systems by reducing resource utilization and expenses.

3. We conclude that an optimized urolithiasis treatment algorithm is both medically and economically advantageous. Urological practices are encouraged to adopt these principles: treat stones definitively and early with the least invasive effective method, and don't stop there – follow up with prevention. In practical terms, this means ensuring every patient with stones receives not only acute stone removal but also counseling on fluid and diet, appropriate metabolic evaluations, and prophylactic medication when indicated. Implementing these measures can lead to a significant drop in stone recurrence rates, as we observed (from 30% to 10% in one year), which in turn translates into fewer surgeries and lower costs in the long run.

4. The findings of this study provide evidence for healthcare policymakers to support comprehensive kidney stone management programs. Investments in patient education, dietary consultation, and preventive pharmacotherapy for stone formers are justified given the potential cost savings by averting future stone events. Furthermore, using cost-effective imaging like ultrasound as the first line in follow-up can reduce expenditures without harming outcomes. Our experience shows that with careful planning and adherence to guidelines, it is possible to significantly improve the quality and cost of care in urolithiasis.

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