

Perspective Article

Endourological Ureteral Strictures After Urolithiasis Treatment: A Narrative Review of Incidence, Pathophysiology, Risk Factors, Prevention, Surveillance, and Management

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ABSTRACT

Background: Ureteral stricture is an uncommon but disproportionately morbid late complication of endourological stone surgery, presenting weeks to years after an ostensibly successful procedure and capable of producing silent, progressive renal damage if surveillance is inadequate.

Objective: To synthesize contemporary evidence on the incidence, pathophysiology, risk factors, prevention, surveillance, and management of ureteral strictures after ureteroscopy (URS), retrograde intrarenal surgery (RIRS), percutaneous nephrolithotomy (PCNL), and shock-wave lithotripsy (SWL), focusing on impacted ureteral stones and ureteral access sheath (UAS)-related injury as two consistently implicated and potentially modifiable contributors.

Evidence Acquisition: This narrative review was informed by a structured literature search of PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Library, supplemented by reference-list screening and forward citation tracking. The core search window was January 2015 through December 2025, with earlier landmark studies retained when foundational and targeted citation updating performed during manuscript revision. Because the work is a narrative review rather than a systematic review, no de novo meta-analysis or formal study-level risk-of-bias scoring was undertaken. Database-specific search strategies are provided in Supplementary Appendix S1.

Evidence Synthesis: Pooled stricture rates are 1.9% after URS (4.9% with impacted stones), 2.1% after PCNL, and 1.3% after SWL; UAS-related injury requiring prolonged stenting occurs in 1.8% of RIRS cases in the largest registry, while any-grade endoscopic UAS wall injury reaches 46.5%. Ureteral perforation at the site of an impacted stone is the most consistently reported risk factor. Pathophysiologically, macrophage- and fibroblast-derived TGF- β 1 contributes to a myofibroblast-collagen cascade triggered by ischemia, chronic obstruction, and infection. Prevention evidence supports pre-stenting in selected difficult ureters, sheath-size matching, controlled laser energy, and drainage of a substantially traumatized ureter. Postoperative surveillance remains unstandardized. Endoscopic management can achieve high early technical success, but durability decreases over time in anatomically complex strictures, whereas reconstructive surgery offers more durable treatment at the cost of greater invasiveness.

Conclusions: Post-endourological ureteral stricture is uncommon but clinically important. The highest-risk setting is an impacted or proximal stone complicated by perforation or high-grade ureteral injury. Prevention, documentation of intraoperative injury, selective early imaging in high-risk patients, and anatomy-based treatment selection are the most practical strategies supported by the current evidence.

Keywords: Ureteral Stricture; Urolithiasis; Ureteroscopy; Retrograde Intrarenal Surgery; Percutaneous Nephrolithotomy; Ureteral Access Sheath; Impacted Ureteral Stone; Endourology

Introduction

Urolithiasis remains one of the most common urological conditions worldwide, and its global burden has continued to rise over the past three decades. Using Global Burden of Disease (GBD) modelling, the number of incident urolithiasis cases increased from roughly 77.8 million in 1990 to 115.6 million by 2019, even as the age-standardised incidence rate (ASIR) itself declined in most regions over the same period, reflecting population growth and demographic shift rather than a true rise in per-capita risk (2). The most recent GBD 2021 analysis places the annual number of new urolithiasis cases above 100 million globally, with a persistently higher burden among men, and confirms that age-standardised rates have continued to fall even as absolute case counts climb (1). Regional trend analyses show this pattern is far from uniform: incidence has risen markedly in some areas — the Caribbean and parts of Central Asia showing the steepest increases — while falling in Eastern and Central Europe and Southeast Asia, a divergence that underscores how diet, climate, metabolic disease prevalence, and access to imaging all shape local epidemiology (3).

This rising absolute disease burden has been accompanied by a parallel transformation in how urinary stones are treated. Open surgery for stone disease has been almost entirely replaced by minimally invasive endourological techniques — ureteroscopy (URS), retrograde intrarenal surgery (RIRS), percutaneous nephrolithotomy (PCNL), and shock-wave lithotripsy (SWL) — a shift that systematic reviews of worldwide treatment patterns have documented consistently across health systems over the last two decades (4,5). Advances in laser lithotripsy, smaller-caliber digital flexible ureteroscopes, and the routine use of ureteral access sheaths (UAS) have all expanded the indications for endoscopic stone removal, with both European and American guidelines now favoring URS/RIRS as first-line therapy for an increasing range of stone sizes and locations (6,7).

This growth in endourological volume has brought renewed attention to a complication that, while individually uncommon, carries disproportionate long-term morbidity: the post-procedural ureteral stricture. A ureteral stricture is a fibrotic, obstructive narrowing of the ureteral lumen that can develop weeks to years after instrumentation, and — unlike most other endourological complications — it tends to present late, after the patient and surgeon alike consider the index procedure successfully concluded (10). Symptomatic strictures can produce silent or symptomatic hydronephrosis, recurrent infection, flank pain, and, if undetected, progressive and sometimes irreversible

loss of ipsilateral renal function (17,23). Because routine long-term radiological follow-up after endourological stone surgery is inconsistent in clinical practice — a controversy with a documented history spanning more than two decades, discussed in full in Section 10 — the true incidence of stricture formation is almost certainly underestimated in many published series (41,65,66).

A detailed review of contemporary evidence is timely for several converging reasons. First, reported stricture rates vary enormously across the literature — from under 0.5% to over 24% — depending on the modality used, the definition of stricture applied, the completeness of follow-up imaging, and whether the underlying stone was impacted (8,9). Second, the pathophysiological cascade linking ureteral mucosal injury to fibrotic stricture formation — ischemia, chronic inflammation, myofibroblast activation, and pathological extracellular matrix remodeling — has been characterized mainly through small mechanistic or histopathological studies rather than large prospective cohorts, leaving important gaps in understanding of why some injured ureters heal normally while others progress to fixed stenosis. Third, the introduction of UAS as a near-routine adjunct to RIRS has generated its own dedicated body of literature on instrumentation-related injury, with the Traxer endoscopic grading system now providing a common language for severity but with continuing controversy over whether UAS use itself independently raises stricture risk once stone- and patient-related confounders are accounted for (26,27). Fourth, the absence of a standardized postoperative surveillance algorithm means that the diagnosis of stricture is frequently delayed, undermining attempts at early, minimally invasive management before reconstructive surgery becomes the only remaining option.

This narrative review, informed by a structured literature search, aims to synthesize contemporary and foundational evidence on the incidence, pathophysiology, risk factors, prevention, surveillance, and management of ureteral strictures following endourological treatment of urolithiasis, with particular attention to impacted ureteral stones and ureteral access sheath-related injury as two of the most consistently implicated — and most modifiable — contributors to this complication, and to translate this evidence into a practical clinical decision framework spanning risk stratification, prevention, diagnosis, and management.

Methods

Review design and reporting approach

This article was designed as a narrative review informed by a structured and reproducible literature search. The objective was to identify, critically appraise, and clinically synthesize evidence on incidence, pathophysiology, risk factors, prevention, surveillance, and management rather than to perform an exhaustive systematic review or de novo meta-analysis. Accordingly, formal PRISMA flow reporting and study-level risk-of-bias scoring were not used as components of the evidence synthesis.

Information sources

The literature search framework covered PubMed/MEDLINE, Scopus, Web of Science, Embase, and the Cochrane Library. Reference lists of relevant systematic reviews and meta-analyses were examined for additional primary studies, and forward citation tracking was used for key landmark reports.

Search period and update

The core search window was January 2015 to December 2025. Earlier studies were retained when they were the original or still-primary source for a foundational concept, such as impacted-stone stricture formation, UAS injury grading, postoperative surveillance, or historical endoscopic management outcomes. Targeted citation updating was performed during manuscript revision to capture highly relevant later publications.

Search concepts and reproducibility

Searches combined three concept blocks: (1) ureteral stricture/stenosis/obstruction; (2) endourological stone procedures including URS, RIRS, PCNL, SWL, UAS, and related endourology terms; and (3) urolithiasis/ureteral stone/impacted stone/nephrolithiasis. Controlled vocabulary was combined with free-text terms where supported by the database. Database-specific search strategies are provided in Supplementary Appendix S1.

Table 1. Structured literature search framework

Component	Details
Databases	PubMed/MEDLINE, Scopus, Web of Science, Embase, Cochrane Library
Search period	January 2015 – December 2025 (landmark pre-2015 studies by hand-search)
Block 1 (condition)	“ureteral stricture” OR “ureteral stenosis” OR “ureteric stricture” OR “ureteral obstruction”
Block 2 (intervention)	“ureteroscopy” OR “retrograde intrarenal surgery” OR “percutaneous nephrolithotomy” OR “shock wave lithotripsy” OR “ureteral access sheath” OR “endourology”
Block 3 (disease)	“urolithiasis” OR “ureteral calculus” OR “ureteral stone” OR “impacted stone” OR “nephrolithiasis”
Boolean logic	Blocks 1 AND 2 AND 3
Selection focus	Adults ≥18 years; URS/RIRS/PCNL/SWL; ureteral stricture/stenosis or relevant ureteral injury as an outcome; systematic reviews, meta-analyses, cohort/registry studies, randomized/comparative studies, and translational work; English language
Evidence appraisal in this revision	Narrative evidence weighting by study design, sample size, directness, consistency, and follow-up quality. No numerical NOS/AMSTAR-2 scores are claimed because a prespecified study-level appraisal dataset was not available for this revision.

Source selection and data capture

Sources were selected for direct relevance to post-endourological ureteral stricture incidence, mechanisms, risk factors, prevention, surveillance, or treatment. Priority was given to systematic reviews/meta-analyses, prospective cohorts, multicenter registries, comparative studies, randomized trials, and mechanistic studies directly

linked to ureteral injury or fibrosis. For each source used in the synthesis, the review considered study design, sample size, population, outcome definition, follow-up duration and modality, reported effect estimates, and applicability to the clinical question.

Critical appraisal and evidence weighting

Because this is a narrative review and a prespecified study-level NOS/AMSTAR-2 assessment

was not completed, no numerical quality scores are presented. Instead, the synthesis explicitly distinguishes pooled evidence and prospective/multicenter data from small retrospective cohorts, historical series, and mechanistic work. Greater interpretive weight is given to larger, directly applicable, internally consistent studies with adequate follow-up, while recommendations based mainly on retrospective or heterogeneous data are labeled as low-certainty or pragmatic evidence syntheses.

Epidemiology of Post-Endourological Ureteral Strictures

Reported incidence figures vary substantially by modality, by whether the cohort was enriched for impacted or proximal stones, by the duration and method of postoperative surveillance, and by publication era — laser technology, UAS design, and operative volume have all changed materially over the study period. The most informative recent estimate is a

Evidence synthesis
No de novo meta-analysis was performed. Quantitative pooled estimates are cited from published meta-analyses. The narrative synthesis is organized thematically as incidence, pathophysiology, risk factors, impacted stones, UAS-related injury, biomarkers, prevention, surveillance, management, and future directions, with conflicting evidence and residual uncertainty described explicitly.

2024 systematic review and meta-analysis pooling 43 studies, which reported a pooled ureteral stricture rate of 1.9% after URS (rising to 2.7% when restricted to studies from the most recent five years, and to 4.9% specifically among impacted stones), 2.1% after PCNL, and 1.3% after SWL (8). Full incidence data by modality are summarized in Table 2.

Table 2. Incidence of ureteral stricture according to treatment modality

Modality	Stricture rate	Source population	Reference
URS — unselected cohorts	1.9% (pooled)	43 studies, meta-analysis	Moretto 2024 (8)
URS — last 5 years (subgroup)	2.7% (pooled)	Subgroup of above	Moretto 2024 (8)
URS — impacted stones (pooled)	4.9% (pooled); up to 24% in individual series	43 studies / individual cohorts	Moretto 2024 (8); Roberts 1998 (11)
URS — impacted, perforated subgroup	80% (vs 5.6% if non-perforated)	Retrospective, 81 patients	Bayar 2016 (15)
RIRS — any-grade UAS wall injury	46.5%	Prospective, 359 patients	Traxer & Thomas 2013 (26)
RIRS — high-grade UAS wall injury	13.3%	Prospective, 359 patients	Traxer & Thomas 2013 (26)
RIRS — UAS injury requiring stenting	1.8%	FLEXOR registry, 6,669 patients, 21 centers	Giulioni 2024 (34); Gauhar 2023 (35)
PCNL — ureteral stricture	2.1% (pooled)	43 studies, meta-analysis	Moretto 2024 (8)
SWL — ureteral stricture	1.3% (pooled)	43 studies, meta-analysis	Moretto 2024 (8)

Figures are heterogeneous across studies owing to differing stricture definitions, follow-up duration/modality, and case-mix (impacted vs. non-impacted stones). Pooled URS/PCNL/SWL figures derive from a single 2024 meta-analysis (ref. 8); individual-study figures are presented for context and are not pooled with the meta-analytic estimates.

After ureteroscopy (URS)

Historical series first drew attention to ureteroscopy-associated stricture as a distinct, delayed complication: an early predictive-factors analysis identified ureteral perforation and prolonged operative

time as key drivers (10), and a dedicated cohort study of impacted-calculus removal — encompassing endoscopic, laparoscopic, and open approaches — reported stricture rates as high as 24% when ureteral perforation occurred at the site of stone impaction (11), a figure that still anchors much of the subsequent literature on impacted stones. In contemporary digital-ureteroscopy cohorts, reported URS-specific stricture rates are considerably lower in unselected populations: a multi-institutional outcomes study characterized the morbidity of strictures once they occur (17), while a large single-center retrospective series of post-URS

stricture management reported a rate in the range of roughly 2% in an unselected cohort (23). A 2021 single-institution series similarly catalogued ureteral strictures following ureteroscopic stone treatment and reinforced that proximal, impacted, and

perforated cases carry disproportionately higher risk than uncomplicated distal-stone URS (12). A systematic literature review focused specifically on impacted ureteral stones identified five eligible comparative studies and found per-study stricture rates ranging from 2.2% to 14.2%, with ureteral perforation and/or mucosal injury as the most consistently identified predictor across all included series (9).

A randomized comparative trial directly relevant to contemporary laser selection adds an important — and somewhat counterintuitive — data point: among 478 patients randomized to holmium:YAG versus thulium-fiber laser lithotripsy, the thulium-fiber arm had a significantly higher stricture rate (4.62% vs 1.67%, $p < 0.001$), despite thulium-fiber laser having been promoted on theoretical thermal-safety grounds (58). The accompanying editorial commentary noted that incomplete reporting of total laser power and frequency in both arms limits causal interpretation, and called for further randomized data before drawing firm energy-setting recommendations (59) — a point taken up further in Section 9 below.

After retrograde intrarenal surgery (RIRS)

RIRS-specific stricture data are inseparable from the literature on ureteral access sheath (UAS) injury, since the UAS is used in the large majority of contemporary flexible ureteroscopy. In the original prospective description of endoscopic UAS-injury grading, 46.5% of 359 patients undergoing RIRS with UAS had some grade of visible ureteral wall injury, and 13.3% had a high-grade injury extending into the muscularis or serosa (26). In the Global Multicentre Flexible Ureteroscopy Outcomes Registry (FLEXOR), comprising 6,669 RIRS procedures across 21 centers in 15 countries, ureteric injury due to the access sheath requiring prolonged stenting occurred in 1.8% of patients, and was significantly associated with multiple stones, lower-pole location, and longer lasing and total operative time (34,35). Patients who developed UAS-related injury in the FLEXOR cohort were not distinguishable by age, sex, or baseline stone size, suggesting that intraoperative factors (operative

duration, stone multiplicity) outweigh static patient characteristics in driving acute injury risk, though the registry's short-term follow-up window could not capture later stricture development (34). Mechanistically, this risk has been linked to UAS outer diameter exceeding the native ureteral caliber by 4–8 French and to excessive insertion force during deployment (29,30), and at least one dedicated study has directly examined the relationship between UAS size and postoperative stricture occurrence (29). A broader systematic review of UAS use concluded that, while acute mucosal injury is common, the additional long-term stricture risk attributable to the sheath itself — independent of stone and patient factors — remains incompletely resolved (27).

After percutaneous nephrolithotomy (PCNL)

Compared with the URS/RIRS literature, dedicated cohort data isolating ureteral (as opposed to infundibular or pelvicalyceal) stricture after PCNL are sparser, since percutaneous access bypasses much of the ureter. The pooled estimate from the 2024 meta-analysis places the PCNL-associated ureteral stricture rate at 2.1% (8), broadly comparable to contemporary URS rates, though the mechanism is presumed to differ — related more to antegrade ureteral instrumentation, nephrostomy tract drainage dynamics, and incidental ureteral manipulation during stone clearance than to UAS-type mucosal trauma. Infectious complications, which are independently more frequent after PCNL than after URS/RIRS, may compound this risk through the inflammation–fibrosis pathway described in Section 4 (39). Dedicated cohort data isolating PCNL-specific ureteral (rather than infundibular) stricture remain the thinnest part of this literature and represent a priority area for future primary research.

After shock-wave lithotripsy (SWL)

SWL is associated with the lowest pooled ureteral stricture rate among the four modalities, at 1.3% (8), consistent with its non-instrumented, extracorporeal mechanism of stone fragmentation. Where strictures do occur after SWL, they are generally attributed to passage of fragmented debris (steinstrasse) through an already narrowed or anatomically vulnerable ureteral segment rather than to direct procedural trauma. As with PCNL, SWL-specific mechanistic and cohort data are comparatively underdeveloped relative to the URS/RIRS literature.

Pathophysiology

The mechanistic cascade linking ureteral injury to fibrotic stricture is best understood as a wound-healing process that fails to terminate. Direct evidence from a swine model of iatrogenic ureteral injury

showed that wound-healing macrophages infiltrating the injury site are an important paracrine source of TGF- β 1, and that this macrophage-derived TGF- β 1 — together with TGF- β 1 secreted by fibroblasts

themselves — drives fibroblast proliferation, α -smooth muscle actin expression, and collagen deposition at the site of injury; in vitro, pirfenidone (an antifibrotic agent that modulates TGF- β 1 activity) limited both macrophage TGF- β 1 secretion and fibroblast scar-forming activity, identifying a candidate pharmacological target for prevention strategies discussed further in Section 13 (40). This macrophage–fibroblast–TGF- β 1 axis is consistent with the broader pattern described across the urinary tract, where progressive luminal narrowing is histologically characterized by epithelial denudation, chronic inflammatory infiltrate, smooth-muscle disruption, and replacement of normal ureteral wall architecture with disorganized collagen-rich scar tissue (25).

Three clinical circumstances recur throughout the literature as the proximate triggers of this cascade. First, ischemia: full-thickness or near-full-thickness ureteral wall injury — whether from perforation, thermal energy, or sustained mechanical compression by an oversized instrument — compromises the submucosal microvasculature, and the resulting local hypoxia is a recognized driver of fibroblast activation

and impaired re-epithelialization. Second, chronic mechanical obstruction by an impacted stone: prolonged endoluminal pressure from a calculus that has remained lodged against the urothelium for an extended period produces localized inflammation, urothelial hypertrophy, and interstitial fibrosis even before any instrument is introduced, which is why impacted stones carry a substantially elevated baseline stricture risk independent of the technique subsequently used to remove them (9). Third, infection and recurrent urothelial injury: in vitro work using ureteral specimens colonized by *Escherichia coli* demonstrated upregulation of epithelial pro-apoptotic gene expression, providing a plausible mechanistic link between chronic or recurrent urinary tract infection and the heightened vulnerability of already-traumatized urothelium to progress toward fibrotic narrowing rather than normal healing (38); this observation is echoed clinically in the FLEXOR registry, where patients who went on to develop UAS-related ureteric injury had a significantly higher rate of preoperative antibiotic treatment for positive urine cultures than those who did not (34).

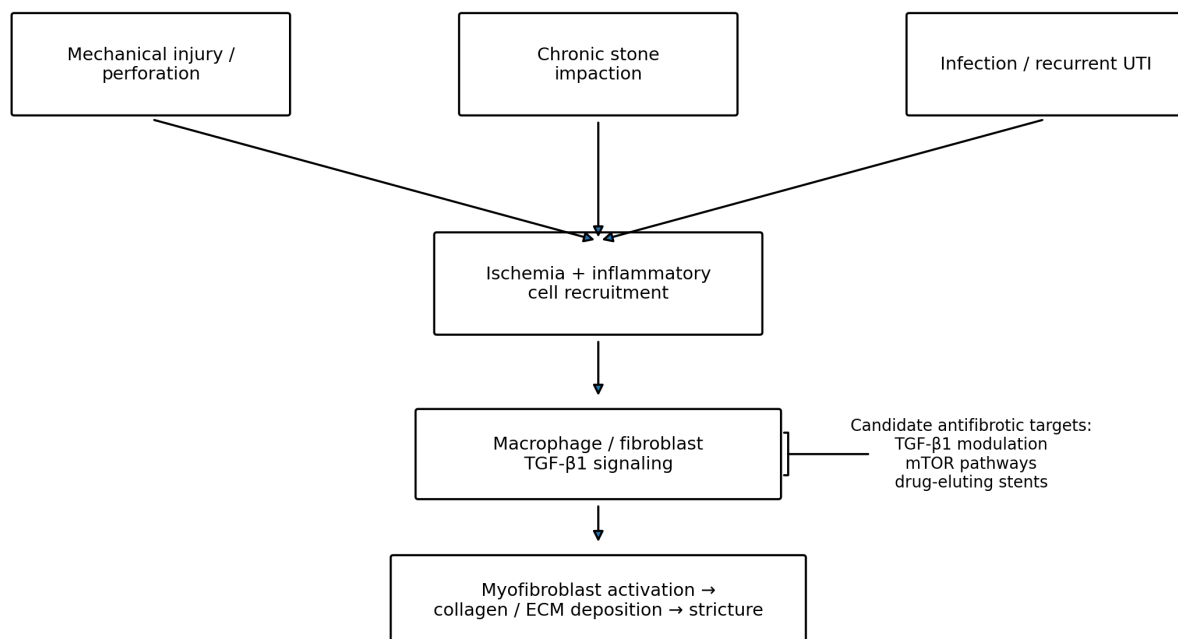


Figure 1. Mechanistic pathways linking ureteral injury to fibrosis and stricture formation.

Risk Factors

A purely list-based enumeration of risk factors understates how unevenly developed this evidence base is: procedural and stone-related factors are supported by large, internally consistent datasets, whereas patient-level factors remain strikingly understudied for this specific outcome.

Patient-related factors

Direct, ureteral-stricture-specific evidence on classical patient factors (age, sex, body mass index, diabetes, chronic kidney disease, recurrent urinary tract infection, smoking, prior interventions) remains thin compared with the procedural literature, and this is

itself a notable evidence gap rather than a reassuring null finding. Across the comparative series reviewed here, age and sex have not emerged as consistent independent predictors: the FLEXOR registry found no significant difference in median age or sex distribution between patients who did versus did not develop UAS-related ureteric injury (34), and a dedicated biomarker study similarly found no significant difference in mean age between patients with and without post-URS stricture (43). What does recur as significant is a history of recurrent or active urinary tract infection: FLEXOR patients with ureteric injury had significantly higher rates of preoperative antibiotic treatment for positive urine cultures (34), and the mechanistic data linking *E. coli* colonization to pro-apoptotic urothelial gene expression provides biological plausibility for infection as a patient-level vulnerability factor (38). BMI, diabetes, chronic kidney disease, and smoking specifically as independent ureteral-stricture risk factors have not been adequately isolated in the dedicated literature identified to date — a genuine gap rather than evidence of no effect, and one that future prospective registries (Section 13) are well positioned to address. A history of prior intervention or repeat instrumentation is the one patient-history variable with reasonably consistent support: cumulative instrumentation was a significant univariate factor for stricture in at least one comparative biomarker cohort (43), consistent with the general principle that repeated injury compounds fibrotic risk.

Stone-related factors

Stone characteristics are among the most consistently reproduced risk factors in this literature. Impaction is the single most influential stone-related variable: the pooled stricture rate after URS rises from 1.9% in unselected cohorts to 4.9% when restricted to impacted stones (8), and individual series report stricture rates as high as 14.2–24% in impacted-stone cohorts depending on perforation status and follow-up duration (9,11). Stone multiplicity and lower-pole location were independently associated with UAS-related ureteric injury in the FLEXOR registry (multiple stones 58.8% vs 41.5%, $p < 0.001$; lower pole 63.5% vs 44.1%, $p < 0.001$) (34). Proximal ureteral location of an impacted stone carries disproportionate risk: in one impacted-stone series, the stricture rate in the proximal ureter was 44% versus 8.3% (mid) and 4.7% (distal) (14). Stone size/burden correlates with operative complexity and downstream complication risk more broadly across the FLEXOR cohort, where larger stones were associated with higher hematuria and sepsis rates (34), and degree of hydronephrosis and duration of obstruction were both identified as predictors of stricture in a large ureteroscopic cohort (13). Critically,

these stone-related factors do not act in isolation — impaction, proximal location, and prolonged obstruction frequently co-occur in the same patient, and the literature has not yet adequately disentangled their independent versus synergistic contributions, a gap that adequately powered multivariable cohorts could address.

Procedure-related factors

Ureteral perforation and mucosal injury are the most robustly and repeatedly identified procedural risk factors across this literature: perforation raised the stricture rate roughly 14-fold in one impacted-stone series (5.6% without perforation vs 80% with perforation) (15), and a systematic review of impacted-stone studies concluded that perforation and/or mucosal damage were the most consistent predictors across all included series (9). Ureteral access sheath use and sizing form a dedicated sub-literature discussed in full in Section 7; in brief, larger UAS outer diameter relative to native ureteral caliber and excessive insertion force both raise acute injury risk (29,30). Operative and lasing time were significantly longer in FLEXOR patients who developed ureteric injury (total operative time 65 vs 54 minutes, $p < 0.001$; lasing time 27 vs 22 minutes, $p = 0.020$) (34), a pattern mirrored in a separate Clavien/Satava-graded RIRS cohort (37). Laser energy settings are now directly implicated by randomized data: the higher stricture rate observed with thulium-fiber relative to holmium:YAG laser in a 478-patient randomized trial (4.62% vs 1.67%, $p < 0.001$) occurred despite comparable starting energy settings, and editorial commentary has specifically criticized the lack of reported maximal power and frequency as a barrier to translating this finding into a concrete dosing recommendation (58,59) — in vitro thermal-injury data support the principle that higher power settings, regardless of laser type, increase ureteral wall thermal damage even as they shorten operative time (60). Residual stone fragments and embedded fragments within the ureteral wall during lithotripsy were independently associated with stricture formation in a large retrospective cohort (13). Irrigation pressure as an independently quantified procedural variable (as opposed to UAS use as its surrogate, discussed in Section 7) remains comparatively under-studied as a direct predictor in the stricture-specific literature, despite its established mechanistic role in intrarenal pressure dynamics.

Postoperative factors

Sepsis is both a serious early complication and a marker of a more inflamed, injury-prone ureter: a dedicated systematic review found sepsis incidence after RIRS ranging from roughly 0.1% to 4.3%, with stone size repeatedly identified as the strongest

associated factor (36), and the FLEXOR registry recorded ICU-level sepsis in 1.3% of 6,669 RIRS cases, again linked to larger stone diameter (34). Stent dwell time and the presence or absence of a draining stent after ureteral instrumentation has direct mechanistic relevance: in a historical but still-cited series, ureteric stricture developed in 8 of 11 patients left with a free-draining nephrostomy and an unstented, traumatized ureter, versus none of 7 patients who instead received a double-J stent or had the nephrostomy closed — leading the authors to conclude that a traumatized ureter must not be left dry and unstented (22). Repeat or multiple prior interventions were a significant univariate factor for ureteral stricture in at least one comparative biomarker cohort (43), consistent with the

general principle that cumulative instrumentation compounds injury risk.

Critical synthesis: taken together, the risk-factor literature points to a coherent mechanistic narrative — impaction and perforation create the initial injury, UAS-related mechanical trauma and excessive laser energy compound it, and an unstented or infected postoperative ureter prevents normal resolution — but it remains overwhelmingly retrospective and procedure-specific, with few studies adjusting simultaneously for the full panel of stone, procedural, and postoperative variables in a single multivariable model. Table 3 summarizes the quantitative effect estimates underlying this section.

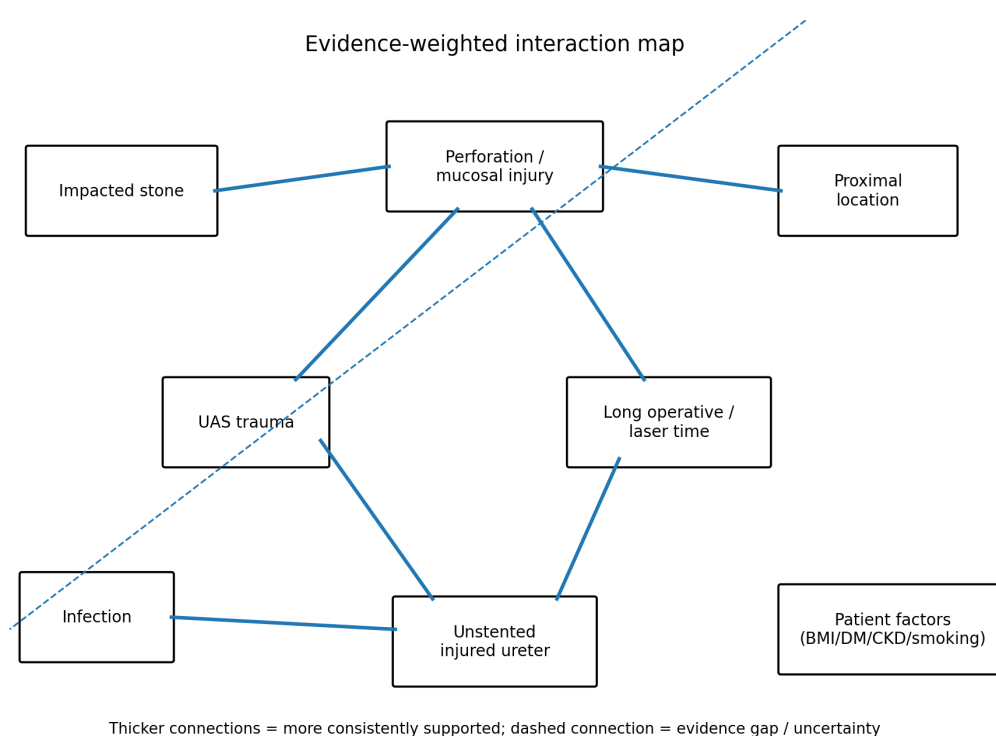


Figure 2. Evidence-weighted interaction network for major post-endourological stricture risk factors.

Table 3. Risk factors and reported OR/HR/comparative values

Risk factor	Reported association	Study / design	Reference
Ureteral perforation (impacted stone)	Stricture rate 80% (perforated) vs 5.6% (non-perforated)	Retrospective, 81 pts	Bayar 2016 (15)
Stone impaction (vs. non-impacted)	Pooled stricture rate 4.9% vs 1.9% overall	Meta-analysis, 43 studies	Moretto 2024 (8)
Proximal vs mid/distal location (impacted)	Stricture 44% (proximal) vs 8.3% (mid) vs 4.7% (distal)	Retrospective, 42 pts	Brito 2006 (14)
Multiple stones (RIRS/UAS injury)	58.8% vs 41.5% (injury vs no-injury), $p < 0.001$	FLEXOR registry, 6,669 pts	Giulioni 2024 (34)

Risk factor	Reported association	Study / design	Reference
Lower-pole stone location (UAS injury)	63.5% vs 44.1%, $p < 0.001$	FLEXOR registry, 6,669 pts	Giulioni 2024 (34)
Total operative time (UAS injury)	65 vs 54 min, $p < 0.001$	FLEXOR registry, 6,669 pts	Giulioni 2024 (34)
Lasing time (UAS injury)	27 vs 22 min, $p = 0.020$	FLEXOR registry, 6,669 pts	Giulioni 2024 (34)
Non-prestented ureter (UAS injury)	~7-fold higher injury risk vs prestented	Prospective, 359 pts	Traxer & Thomas 2013 (26)
Unstented traumatized ureter + nephrostomy drainage	8/11 developed stricture vs 0/7 if stented/closed	Retrospective, 18 pts	O'Sullivan 1994 (22)
Balloon circumference (per-mm increase)	OR 1.221 (95% CI 1.002–1.491), $p = 0.05$	Retrospective, 97 pts	Wang 2023 (50)
Multiple/multi-segmental stricture (balloon dilation failure)	OR 0.143 (95% CI 0.023–0.895), $p = 0.038$	Retrospective, 97 pts	Wang 2023 (50)
Elevated NLR (spontaneous stone passage)	OR 0.46 (95% CI 0.33–0.64) for successful passage	Meta-analysis, 10 studies, 4,859 pts	Chen & Cao 2026 (42)
Elevated NLR (ureteric sepsis risk)	OR 2.50 (95% CI 1.31–4.76)	Meta-analysis, 10 studies, 4,859 pts	Chen & Cao 2026 (42)
NLR / PLR (ureteral stricture specifically)	Not statistically significant ($p = 0.139$ / $p = 0.076$)	Observational, 130 pts	Ordulu 2024 (43)

CI = confidence interval; NLR = neutrophil-to-lymphocyte ratio; OR = odds ratio; PLR = platelet-to-lymphocyte ratio; pts = patients. Values are reproduced as reported in each source and are not pooled into a single combined effect estimate.

Impacted Ureteral Stones

Impacted ureteral stones merit dedicated treatment as a standalone section because they alter both the baseline pathophysiology and the achievable surgical outcome before any instrument is introduced. While there is no single universally accepted definition, the literature converges on three operational criteria: (i) inability to pass a guidewire beyond the stone on first attempt, (ii) stone-associated hydronephrosis (mild to severe), and (iii) radiological evidence that the stone has remained lodged in the same ureteral location for an extended period (commonly ≥ 2 months) (9). Histologically, prolonged impaction is associated with localized inflammation, urothelial hypertrophy, and interstitial fibrosis, attributed both to ischemia from sustained endoluminal pressure and to an immunological reaction to the calculus itself (9).

A systematic literature review identifying five eligible comparative studies on impacted-stone stricture formation reported stricture rates ranging from 2.2% (Al-Nabulsi, 297 patients) to 14.2% (Brito, 42 patients), with the common thread across all five being that ureteral perforation and/or mucosal damage was the dominant predictor of subsequent stricture

(9,13,14,15,16). In the largest of these cohorts, the stricture rate was 3.3% overall, but hydronephrosis grade, residual fragments, nephrostomy/stent placement, and intraoperative mucosal injury were all significant univariate predictors (13). In a separate, heterogeneous cohort that included multiple surgical approaches (retrograde and antegrade ureteroscopy, laparoscopic and open ureterolithotomy), the historical landmark study by Roberts et al. reported a 24% stricture rate when perforation occurred specifically at the site of stone impaction, establishing perforation-at-the-impaction-site — rather than perforation elsewhere in the ureter — as the most dangerous configuration (11).

Comparative data also inform technique selection for impacted stones. Laser lithotripsy and pneumatic (ballistic) lithotripsy appear to carry different stricture profiles: in one comparative cohort, the stricture rate was significantly higher with laser than with pneumatic lithotripsy (4.9% vs 1%, $p = 0.02$), a difference attributed to the differing tissue-injury mechanisms — photothermal effect for laser versus a “jack-hammer” mechanical effect for pneumatic

devices — though overall complication rates (perforation, bleeding) were comparable between the two modalities (9,24). Where retrograde access to an impacted stone is difficult, comparative series of antegrade ureteroscopy, retroperitoneal laparoscopic ureterolithotomy (RPLU), and open ureterolithotomy with concurrent resection of the pathological ureteral segment have shown variable but generally favorable stricture profiles relative to retrograde URS, albeit at the cost of greater invasiveness (18,19,20,21). One direct comparison found RPLU and ureteroscopic holmium-laser lithotripsy (URSL) had similar stricture rates (2% vs 2.5%, $p = 1.000$) but significantly higher immediate and first-month stone-free rates with RPLU (100% vs 78.6% and 100% vs 82.4%, both $p < 0.001$) (19), while another found a significantly higher rate of strictures requiring surgical intervention after URSL than after RPLU (2.9% vs 0%, $p = 0.046$) in stones larger than 12 mm (20).

Critical appraisal: the impacted-stone literature is internally consistent on its central message —

perforation at the impaction site is the dominant driver of stricture — but almost entirely retrospective, drawn from heterogeneous single-center cohorts with inconsistent stricture definitions and follow-up duration, and the laser-versus-pneumatic and retrograde-versus-antegrade comparisons rest on a small number of comparative (not randomized) studies. The clinical implication is nonetheless reasonably clear: for an impacted stone where perforation risk appears elevated (severe hydronephrosis, very proximal location, prior failed attempt), a lower-perforation-risk strategy — whether that means pneumatic rather than laser energy, a planned antegrade or laparoscopic approach, or simply a lower threshold for abandoning the attempt and pre-stenting for a delayed second-stage procedure — is better supported by the evidence than persisting with an aggressive single-session retrograde approach. Full study-level data are presented in Table 4.

Table 4. Studies evaluating impacted ureteral stones

Study (year)	N patients	Stricture rate	Key predictor	Reference
Roberts et al. (1998)	Multiple modalities	24% (perforation at impaction site)	Perforation at stone impaction site — highest-risk configuration	(11)
Tonyali et al. (2023) — pooled review	5 studies	2.2–14.2% (per-study range)	Ureteral perforation and/or mucosal damage across all included series	(9)
Al-Nabulsi et al. (2021)	297	2.2%	Hydronephrosis grade, residual fragments, mucosal injury	(13)
Brito et al. (2006)	42	14.2%	Proximal location (44%), mucosal damage	(14)
Bayar et al. (2016)	81	80% (perforated) vs 5.6%	Perforation — ~14-fold increase in stricture rate	(15)
Hu et al. (2017) — RPLU vs URSL	Comparative cohort	2% (RPLU) vs 2.5% (URSL), $p = 1.000$	Comparable stricture rates; RPLU superior stone-free rates	(19)
Shao et al. (2015) — stones >12 mm	Comparative cohort	0% (RPLU) vs 2.9% (URSL), $p = 0.046$	Higher stricture rate with URSL for large impacted stones	(20)
Degirmenci et al. (2014)	Comparative cohort	4.9% (laser) vs 1% (pneumatic), $p = 0.02$	Photothermal injury (laser) vs mechanical injury (pneumatic)	(24)

RPLU = retroperitoneal laparoscopic ureterolithotomy; URSL = ureteroscopic holmium-laser lithotripsy.

Ureteral Access Sheath

The ureteral access sheath occupies a central place in this literature because it is both an enabling technology for modern RIRS and a documented, graded source of iatrogenic ureteral injury. The reference classification system remains the one originally described by Traxer and Thomas, who prospectively assessed 359 consecutive RIRS patients using digital flexible ureteroscopic inspection of the ureter on UAS withdrawal: 46.5% of patients had some grade of visible wall injury, and 13.3% had a high-grade injury extending into the muscularis or serosa; notably, the risk of injury was roughly sevenfold higher in non-prestented than in prestented patients (26).

Mechanism and sizing. UAS outer diameter typically exceeds native adult ureteral caliber by 4 to 8 French, and this mismatch — combined with the force required for deployment — is the proposed mechanical basis for acute mucosal injury (30). A porcine-model force-sensor study demonstrated that higher UAS deployment force is associated with greater injury risk, supporting careful, low-force insertion technique (30). A dedicated clinical study examining UAS size directly in relation to postoperative stricture found a measurable relationship between sheath caliber and stricture occurrence, reinforcing sizing as a modifiable intraoperative choice rather than a fixed procedural constant (29). A prospective study analyzing high-grade UAS injuries specifically in relation to subsequent stricture formation, although limited in size, lends further support to the principle that injury grade at the time of surgery — not merely UAS use per se — is the variable that should drive postoperative surveillance intensity (32).

Intrarenal pressure effects. Functionally, the UAS also serves a pressure-protective role: in vitro intrarenal pressure modelling using an anatomic kidney model showed that, without a UAS, intrarenal pressure during forced irrigation could exceed 165 cmH₂O, whereas UAS use consistently kept pressure below 40 cmH₂O across a range of irrigation settings (33) — meaning the sheath simultaneously reduces one injury mechanism (pressure-related mucosal/pyelovenous injury and the associated risk of pyelovenous backflow and sepsis) while introducing another (direct mechanical trauma on insertion and withdrawal). This dual, opposing-risk profile is the central reason the field has not converged on a simple “use UAS” or “avoid UAS” recommendation, and instead increasingly frames the decision around individualized sizing and technique.

Clinical injury rates. In the Global FLEXOR registry of 6,669 RIRS procedures, UAS-related ureteric injury requiring prolonged stenting occurred in 1.8% of

patients and was significantly associated with multiple stones, lower-pole stone location, longer lasing time, and longer total operative time — but not with UAS size, scope type, laser type, or anesthesia modality in that particular dataset (34,35). Other single- and multi-center series report a wide range of UAS-related injury rates (roughly 16–46%, depending on whether all Traxer grades or only high grades are counted, and on whether prestenting was used), reflecting heterogeneity in injury definition and follow-up duration across the field (26,28). A systematic review of UAS use overall concluded that, while acute mucosal injury during UAS insertion/withdrawal is common and readily visualized endoscopically, the magnitude of additional long-term stricture risk attributable to the sheath itself — once stone- and patient-level confounders are accounted for — remains incompletely resolved, and this is reflected in ongoing controversy over routine UAS use versus selective use in higher-risk anatomy (27). A related cohort specifically examining the association between UAS use and abnormal postoperative upper-tract imaging adds further weight to the position that UAS use is an independent contributor to detectable upper-tract changes, even if the long-term stricture implications of those changes are not yet fully characterized (31).

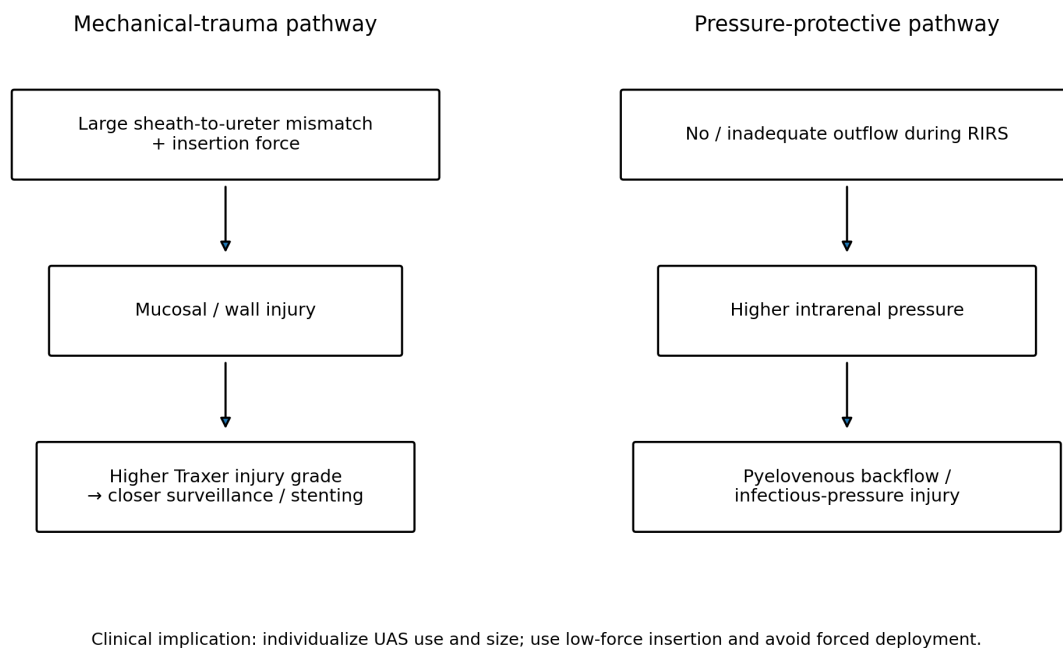


Figure 3. Dual mechanical-trauma and pressure-protective pathways associated with ureteral access sheath use.

Prestenting as a modifier. Across multiple datasets, pre-stenting prior to UAS insertion is associated with lower injury risk, consistent with the mechanical principle that a previously stented ureter has undergone gradual, lower-force dilation rather than acute forced dilation at the time of the index procedure (26). This

observation, together with data on the natural incidence of the technically “difficult ureter” that prestenting is meant to pre-empt (48,49), directly motivates the prevention strategies discussed in Section 9.

Table 5 summarizes the key UAS-focused studies discussed above in tabular form.

Table 5. Studies evaluating ureteral access sheath (UAS)-related injuries

Study (year)	Design / N	UAS size	Key injury finding	Reference
Traxer & Thomas (2013)	Prospective, 359 pts, 2 centers	Not size-stratified	46.5% any-grade injury; 13.3% high-grade; 7× higher risk if not prestented	(26)
Giulioni et al. — FLEXOR (2024)	Registry, 6,669 pts, 21 centers	Per-center protocol	1.8% injury requiring stenting; assoc. with multiple stones, lower-pole location, longer op./lasing time	(34)
Aykanat et al. (2022)	Comparative, single-center	Size-stratified comparison	UAS size associated with perioperative parameters and postoperative stricture occurrence	(29)
Kaler et al. (2019) — porcine model	Experimental, force-sensor	Standard UAS, force-calibrated	Higher deployment force independently associated with greater ureteral injury	(30)
Patel et al. (2021) — in vitro model	Bench model, IRP measurement	With vs without UAS	Without UAS: IRP >165 cmH ₂ O; with UAS: IRP <40 cmH ₂ O across all irrigation pressures tested	(33)
Cooper et al. (2020)	Retrospective, upper-tract imaging cohort	Standard UAS	UAS use independently associated with abnormal postoperative upper-tract imaging findings	(31)

Study (year)	Design / N	UAS size	Key injury finding	Reference
De Coninck et al. (2018) — systematic review	Systematic review, all reported sizes	All reported sizes	Acute mucosal injury common; independent long-term stricture risk attributable to UAS not fully resolved after confounder adjustment	(27)

IRP = intrarenal pressure.

Biomarkers and Prediction Models

The inflammatory-marker literature in this space is more developed for spontaneous stone passage and post-stone-surgery sepsis than for ureteral stricture specifically, and the limited stricture-specific evidence to date has been largely negative. A dedicated prospective biomarker study comparing 130 patients with versus without ureteral stricture after prior endoscopic upper-tract surgery found that, although both the neutrophil-to-lymphocyte ratio (NLR) and platelet-to-lymphocyte ratio (PLR) were numerically higher in the stricture group (NLR 2.62 vs 2.29; PLR 136.6 vs 118.7), neither difference reached statistical significance ($p = 0.139$ and $p = 0.076$, respectively), leading the authors to conclude that NLR and PLR are not currently useful for predicting ureteral stricture risk in this specific setting (43).

This contrasts with a considerably more robust evidence base for NLR in adjacent clinical questions within stone disease: a 2026 systematic review and meta-analysis of 10 cohort studies (4,859 patients) found that elevated NLR was significantly associated with lower spontaneous stone passage rates (OR 0.46, 95% CI 0.33–0.64) and significantly higher risk of ureteric sepsis (OR 2.50, 95% CI 1.31–4.76) (42), and NLR has been

separately validated as a predictor of the need for urgent ureteral catheterization in renal colic (44) and of spontaneous ureteral stone passage specifically (45). In the analogous urethral stricture literature, NLR has shown predictive value for stricture recurrence after open urethroplasty (46), reinforcing the broader biological plausibility of a systemic-inflammation/fibrosis link even where the ureteral-specific signal has so far been weak. A related but mechanistically distinct line of inquiry examines whether pre-existing inflammation predicts technical failure of UAS insertion itself (as opposed to stricture formation downstream); at least one study has investigated this relationship directly, suggesting that periureteral and mucosal inflammatory state may influence the feasibility of primary UAS placement independent of stone burden (47).

Artificial intelligence and machine learning. Beyond classical inflammatory biomarkers, AI-based prediction tools have begun to penetrate endourology,

though almost entirely for outcomes other than ureteral stricture. Machine-learning models have demonstrated validated predictive performance for the postoperative outcome of PCNL — outperforming or matching established tools such as the Guy's Stone Score and the CROES nomogram in software-validation comparisons (62) — and for spontaneous ureteral stone passage, where a neural-network-based algorithm has shown promising discrimination (63). No validated multivariable nomogram or machine-learning model specific to post-endourological ureteral stricture itself was identified in the literature search to date; this represents a clear and currently unmet opportunity, particularly given that the analogous urethral-stricture field has already produced machine-learning models for post-TURP urethral stricture prediction using only routine preoperative blood parameters, achieving accuracy scores up to 0.91 with random-forest classifiers. Critical limitation: existing AI/ML work in urolithiasis is concentrated on stone passage, sepsis, and PCNL outcome prediction — outcomes with abundant historical data — while ureteral stricture, precisely because it is a delayed, under-surveilled outcome, lacks the labelled longitudinal datasets that supervised learning requires; closing this gap will likely depend on the same prospective, structured follow-up registries advocated for in Section 10 and Section 13. Table 6 consolidates the biomarker and prediction-model evidence discussed above.

Table 6. Biomarkers and prediction models

Biomarker	Study / N	Outcome studied	Key finding	Reference
NLR	Ordulu 2024; n = 130	Ureteral stricture after endoscopy	NLR 2.62 vs 2.29 (stricture vs no stricture); p = 0.139 — not significant	(43)
PLR	Ordulu 2024; n = 130	Ureteral stricture after endoscopy	PLR 136.6 vs 118.7; p = 0.076 — not significant	(43)
NLR	Meta-analysis; 10 cohort studies, 4,859 pts	Spontaneous stone passage / ureteric sepsis	Elevated NLR: OR 0.46 (95% CI 0.33–0.64) for stone passage; OR 2.50 (95% CI 1.31–4.76) for sepsis	(42)
NLR	Elsaraya 2022; retrospective	Need for urgent ureteral catheterization in renal colic	Elevated NLR predicts urgent intervention need	(44)
NLR	Lee 2017; retrospective	Spontaneous ureteral stone passage	Higher NLR associated with lower passage rate	(45)
NLR / hematologic parameters	Topaktaş 2019	Urethral stricture recurrence after urethroplasty	NLR predictive of recurrence — biological plausibility for fibrosis–inflammation link	(46)
TGF- β 1 (translational)	Ueshima 2019; swine model	Fibroblast activation and stricture formation	Macrophage-secreted TGF- β 1 drives fibroblast proliferation, α -SMA expression, collagen deposition	(40)
ML — PCNL outcome	Aminsharifi 2020	Postoperative PCNL outcome	ML model matches/outperforms Guy's Stone Score and CROES nomogram	(62)
ML — stone passage	Solakhan 2020	Spontaneous ureteral stone passage	Neural-network algorithm shows promising discrimination	(63)
AI/ML prediction models	Literature search 2015–2025	Post-endourological ureteral stricture	No validated multivariable nomogram or machine-learning model identified to date	—

Prevention Strategies

Prevention evidence in this literature clusters around four broadly modifiable domains: pre-procedural ureteral preparation, instrument and sheath selection, energy/irrigation parameter control, and postoperative drainage practice.

Pre-stenting. The single most consistently supported preventive maneuver is pre-stenting a ureter anticipated to be difficult, narrow, or likely to require UAS use. Pre-stenting allows gradual, passive ureteral dilation over days to weeks rather than acute, forced dilation at the time of UAS insertion, and is associated with a roughly sevenfold reduction in high-grade UAS injury risk in the foundational classification study (26). Population data on how often a “difficult ureter” is encountered, and how this relates to the decision to pre-stent, provide useful context for when this strategy should be considered proactively rather than reactively (48), and at least one technique series has explored whether a smaller-caliber semirigid ureteroscope can

obviate the need for balloon or stent dilation altogether in adults with a difficult ureter, offering a less resource-intensive alternative pathway (49).

Instrument and sheath selection. Matching UAS outer diameter to the individual patient's ureteral caliber, rather than defaulting to a single institutional standard size, is supported by the dedicated sizing-outcome study discussed in Section 7 (29), and deployment technique itself matters: porcine force-sensor data indicate that minimizing insertion force during UAS placement reduces injury risk independent of sheath size (30). Where a UAS is not strictly necessary — for example, a straightforward distal ureteral stone — its omission removes one entire injury mechanism at the cost of potentially higher intrarenal pressure during irrigation, reinforcing that UAS use should be a deliberate case-by-case decision rather than a routine default (33).

Laser energy and irrigation pressure control. The randomized comparison of holmium:YAG versus thulium-fiber laser, in which the thulium-fiber arm paradoxically showed a higher stricture rate despite its theoretical thermal-safety profile, is the most direct evidence available on energy-setting risk, and the accompanying editorial explicitly recommends standardized reporting and capping of total laser power and frequency in future studies — citing the French Urological Association's existing recommendation of a maximal intraureteral laser power of 10–15 W as a starting reference point pending better-quality comparative data (58,59). In vitro thermal-injury modelling supports the underlying principle that higher power settings increase ureteral thermal damage even when they shorten operative time, regardless of which laser technology is used (60). Pressure-controlled irrigation, while mechanistically well-justified by the intrarenal-pressure modelling discussed in Section 7 (33), has not yet been isolated as an independently quantified variable in a dedicated stricture-outcome study, and remains a prevention strategy better supported by physiological plausibility than by direct clinical-outcome data at present.

Infection prevention. Given the mechanistic and clinical evidence linking active or recent urinary tract infection to both UAS-related injury (34) and impaired urothelial healing (38), preoperative urine culture-directed antibiotic treatment and deferral of elective instrumentation in the setting of active infection represent a low-cost, biologically well-

justified preventive measure, even though no dedicated randomized trial isolating infection control as a stricture-prevention intervention was identified.

Postoperative drainage practice. As discussed in Section 5.4, the historical but still-instructive observation that 8 of 11 patients left with an unstented, traumatized ureter and a free-draining nephrostomy developed stricture, versus none of 7 who were instead stented or had the nephrostomy closed, supports a simple, low-cost rule: a ureter known to be significantly traumatized during the index procedure should not be left both unstented and freely draining (22).

Practical prevention framework: Step 1 — at the preprocedural planning stage, identify high-risk anatomy (impacted, proximal, or large-burden stone; anticipated difficult ureter) and pre-stent where indicated. Step 2 — intraoperatively, select UAS size to match ureteral caliber, minimize insertion force, and use the lowest laser power/frequency combination compatible with effective fragmentation, with pressure-controlled irrigation where available. Step 3 — if intraoperative perforation, high-grade UAS injury, or extensive mucosal trauma occurs, place a double-J stent (do not leave the ureter unstented) and flag the patient for the structured early-surveillance pathway described in Section 10 rather than the standard follow-up schedule. Step 4 — treat active urinary infection before elective reintervention and maintain a low threshold for staged, rather than single-session, management of high-risk impacted stones.

Follow-Up and Early Detection

Postoperative imaging surveillance after endourological stone surgery has been a live, unresolved controversy in this literature for more than two decades, and the debate is directly relevant to stricture detection because — unlike most endourological complications — stricture is frequently asymptomatic until renal function is already compromised.

The routine-versus-selective imaging controversy. An early, influential series reviewing 241 patients at a mean of 5.4 months post-ureteroscopy found that, among 188 patients who were pain-free at follow-up, seven (3.7%) nonetheless had obstruction on postoperative imaging, leading the authors to argue that routine imaging is necessary because symptoms cannot reliably exclude obstruction (64). This was directly challenged by contemporaneous and subsequent series: one retrospective review found that none of 110 asymptomatic patients had obstruction on routine follow-up imaging, while obstruction was identified in 13 of 21 symptomatic patients, supporting

a symptom-triggered rather than routine imaging strategy (65); another concluded that functional radiographic follow-up is not mandatory for all patients, reserving it for those with risk features or symptoms (66). A subsequent selective-imaging cohort attempted to reconcile this divide by stratifying follow-up according to intraoperative complexity: patients with an impacted stone, balloon dilation, intraoperative perforation, or postoperative pain after stent removal underwent early selective imaging, while uncomplicated cases were followed clinically with imaging reserved for new symptoms or routine longer-term stone surveillance; this approach detected an overall stricture rate of 1.4%, with 5.3% in the selectively imaged “complicated” group versus 0% in the uncomplicated group, and notably found that postoperative pain after stent removal was not itself predictive of stricture (67). This selective, complexity-triggered model — image early and proactively after perforation, impaction, or balloon dilation; rely on symptom-triggered imaging otherwise — is the most

defensible synthesis of an otherwise conflicting twenty-year evidence base, and aligns directly with the risk-stratified prevention algorithm proposed in Section 9.

Imaging modality selection. Once the decision to image has been made, modality choice depends on the clinical question. CT urography offers the highest anatomic resolution for localizing and measuring stricture length and is generally preferred when reconstructive planning is anticipated. Diuretic renography with Tc-99m-MAG3 remains the reference standard for quantifying split renal function and distinguishing true obstruction from non-obstructive dilation, and is the modality of choice when the clinical question is “how much functioning kidney is at stake” rather than “exactly where is the narrowing” — a distinction reflected in published institutional protocols for ureteral stricture work-up, which typically combine an initial MAG3 renal scan to establish differential renal function with axial imaging (ultrasound or CT) for anatomic localization before committing to a management pathway. Renal ultrasound remains the lowest-cost, radiation-free first-line tool for detecting new or worsening hydronephrosis and is well suited to serial surveillance, though it cannot reliably distinguish stricture from other causes of dilation or quantify functional impact on its own.

Timing of follow-up and certainty of evidence. No single universally validated or guideline-endorsed surveillance schedule exists. The available evidence is dominated by historical and retrospective cohorts comparing routine, symptom-triggered, and selective imaging. Accordingly, the intervals below should be interpreted as a pragmatic clinical framework rather than a formal evidence-based mandate. For uncomplicated, low-risk URS/RIRS, symptom-triggered imaging is reasonable, with ultrasound at 6–12 months considered mainly for ongoing upper-tract/stone surveillance. For high-risk procedures (impacted/proximal stone, perforation, high-grade UAS injury, difficult or prolonged instrumentation), early imaging approximately 4–6 weeks after stent removal is reasonable; persistent hydronephrosis or functional concern can then be evaluated with MAG3 renography or CT urography at approximately 3–6 months. Certainty for these timing recommendations is low because no randomized trial has validated a specific schedule; the rationale is based on observational evidence, the possibility of silent obstruction, and risk enrichment after complicated procedures (64–67).

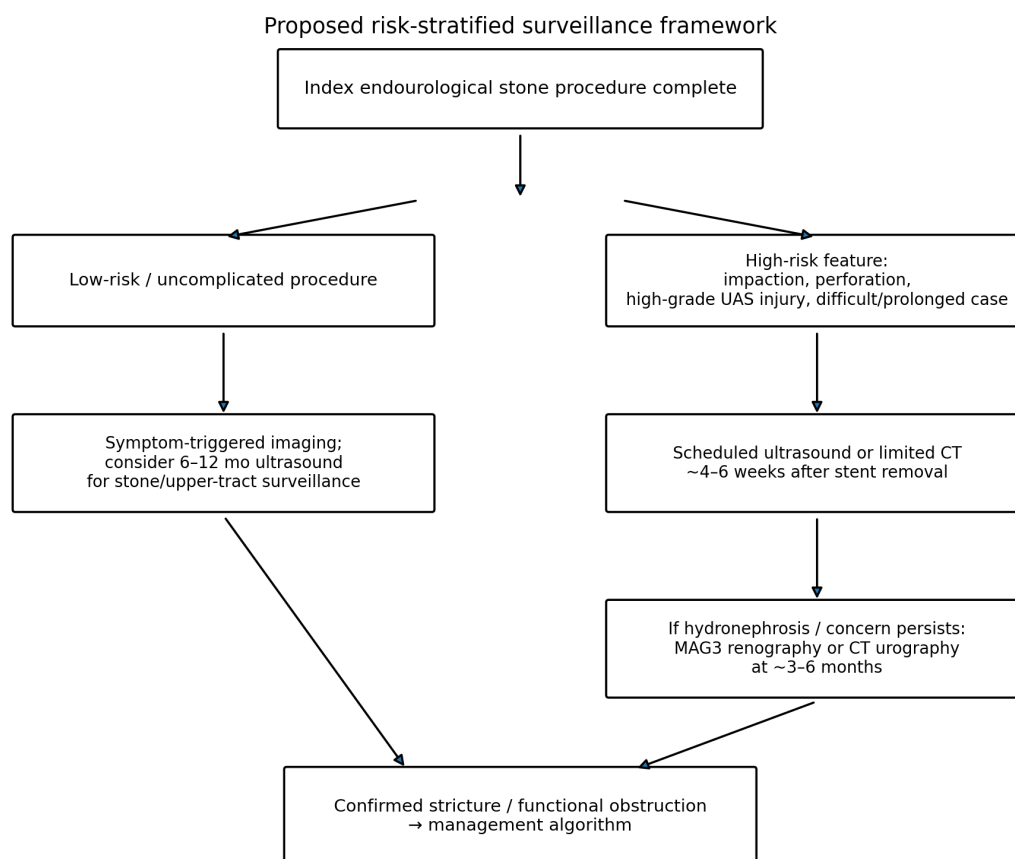


Figure 4. Proposed risk-stratified follow-up framework. The timing is a pragmatic synthesis of low-certainty observational evidence, not a validated guideline schedule.

Management

Endoscopic management: balloon dilation and endoureterotomy

Endoscopic techniques remain the first-line management for most benign post-endourological ureteral strictures because they are markedly less morbid than open or robotic reconstruction, even though they carry a higher recurrence rate (50,53). A meta-analysis pooling the balloon-dilation literature reported a combined technical success rate of $89\pm4\%$, with a short-term (3-month) success rate of $60\pm10\%$ and a longer-term (6–12 month) success rate of $54\pm14\%$ using a random-effects model (54) — figures that illustrate the well-recognized pattern of early technical success eroding over time as some strictures recur.

A large, contemporary multicenter retrospective cohort (127 patients with complete follow-up) refined this picture by procedure subtype and stricture location (50). For lower-ureteral strictures, balloon dilation alone achieved success rates of 81.1%, 78.4%, and 78.4% at 3, 6, and 12 months, while balloon dilation combined with endoureterotomy achieved higher rates of 90%, 90%, and 86.7% at the same intervals — indicating a meaningful incremental benefit from adding endoureterotomy in this location (50). For upper-ureteral strictures recurring after failed pyeloplasty, primary balloon dilation outperformed balloon dilation used as salvage after a failed open repair (80%, 80%, 73.3% vs 73.3%, 60%, 53.3% at 3/6/12 months), and an analogous pattern held for lower-ureteral strictures recurring after failed reimplantation or endoureterotomy (85.3%, 79.4%, 79.4% for primary treatment vs 75%, 75%, 75% for salvage treatment) (50) — the clinical implication being that the choice of first-line treatment materially affects the probability of success, since failed index procedures select for more fibrotic, less favorable ureters.

On multivariable analysis, balloon circumference (OR 1.221, 95% CI 1.002–1.491, $p = 0.05$) and the presence of multiple/multi-segmental strictures (OR 0.143, 95% CI 0.023–0.895, $p = 0.038$, expressed as the inverse — i.e., multiplicity independently predicted failure) were the only independent predictors of balloon-dilation failure identified in this cohort, while preoperative renal function, stricture length, hydronephrosis grade, and dilation duration were not significant once adjusted (50). This is a clinically important — if somewhat counterintuitive — finding: it suggests outcomes are driven more by anatomic complexity (multiple strictures) and possibly by over-aggressive balloon sizing than by baseline renal function, at least within the range of strictures (predominantly ≤ 2 cm) studied in this cohort (50). Older endoureterotomy series have similarly emphasized

stricture length as a key determinant, with intralesional triamcinolone injection reported to improve success specifically in strictures longer than 1 cm (51), and historical comparative work has highlighted that strictures associated with compromised vascular supply (e.g., post-irradiation or post-major-vessel-injury strictures) respond less well to any endoluminal technique than purely iatrogenic, well-vascularized strictures (57).

Reconstructive surgery

When endoscopic management fails, recurs, or is anatomically unsuitable (typically longer or multi-segment strictures, or strictures associated with devascularized ureter), reconstructive surgery is considered the more durable option, and minimally invasive robotic approaches have substantially reduced the morbidity historically associated with open reconstruction (52). Reconstructive techniques include ureteroureterostomy for short mid-to-proximal strictures, ureteroneocystostomy (with psoas hitch or Boari flap as needed) for longer distal strictures, buccal or lingual mucosal graft (BMG/LMG) ureteroplasty for longer proximal/mid strictures that exceed what a tension-free end-to-end anastomosis can bridge, and bowel (ileal) interposition as a last-resort option for extensive ureteral loss (55). In a dedicated case series of posteriorly augmented anastomotic ureteroplasty with lingual mucosal onlay grafts for long proximal strictures (median defect length 3 cm, range 3–5 cm), all 10 patients achieved successful treatment criteria at a median follow-up of 11 months, supporting graft-augmented reconstruction as a feasible option specifically for strictures marginally too long for safe primary anastomosis (55). Comparative reviews report reconstructive surgery as significantly more successful than repeat endourological procedures in cumulative success rate, at the cost of greater procedural invasiveness and recovery time (9,53).

Table 7 summarizes comparative success rates across endoscopic and reconstructive strategies.

Table 7. Management strategies and outcomes

Strategy	N	Success rate (timepoint)	Key predictors / notes	Reference
Balloon dilation (pooled, meta-analysis)	Multiple studies	89±4% technical; 60±10% (3 mo); 54±14% (6–12 mo)	Stricture location, number, prior treatment history	Lu 2019 (54)
Balloon dilation alone — lower ureteral	n = 37	81.1% / 78.4% / 78.4% (3/6/12 mo)	Balloon circumference, multi-segmental stricture	Wang 2023 (50)
Balloon dilation + endoureterotomy — lower ureteral	n = 30	90% / 90% / 86.7% (3/6/12 mo)	Combined approach superior to dilation alone	Wang 2023 (50)
Balloon dilation, primary — upper ureteral	n = 30	80% / 80% / 73.3% (3/6/12 mo)	Primary treatment superior to salvage	Wang 2023 (50)
Balloon dilation, salvage — failed pyeloplasty	n = 15	73.3% / 60% / 53.3% (3/6/12 mo)	Worse outcomes after prior failed repair	Wang 2023 (50)
Balloon dilation, primary — lower ureteral (overall cohort)	n = 34	85.3% / 79.4% / 79.4% (3/6/12 mo)	Primary treatment superior to salvage	Wang 2023 (50)
Balloon dilation, salvage — failed reimplant/endoureterotomy	n = 4	75% / 75% / 75% (3/6/12 mo)	Worse outcomes after prior failed repair	Wang 2023 (50)
Endoureterotomy ± intralesional triamcinolone	77 cases	Improved success for strictures >1 cm with triamcinolone	Stricture length >1 cm; vascular supply intact	Wolf 1997 (56)
Ureteroureterostomy — short proximal/mid strictures	Comparative literature	High success for short (<2 cm), well-vascularized strictures	Stricture length, tension-free anastomosis feasibility	Bilotta 2021 (52)
Ureteroneocystostomy ± psoas hitch/Boari flap	Comparative literature	Preferred for distal strictures >2 cm	Bladder capacity, ureteral length defect	Bilotta 2021 (52)
Lingual/buccal mucosal graft (augmented anastomotic) ureteroplasty	Fan 2021; n = 10	100% (10/10) at median 11-month follow-up (range 7–20 mo)	Defect length 3–5 cm; robotic/laparoscopic technique	Fan 2021 (55)

mo = months. Figures are reproduced as reported in each source and are not pooled across studies.

Clinical Decision-Making Algorithm

Synthesizing Sections 5 through 11 into a single actionable pathway, the evidence supports a four-stage framework moving from risk stratification through to definitive management:

Stage 1 — Risk stratification (pre- and intra-operative): Patients/procedures are flagged as elevated-risk when any of the following are present: impacted or proximal stone, anticipated or encountered difficult ureter, intraoperative perforation or high-grade mucosal injury, prolonged operative or lasting time, or active/recent urinary tract infection (Sections 5–7).

Stage 2 — Prevention (intra- and immediate postoperative): For elevated-risk cases, apply pre-stenting where feasible, individualized UAS sizing with

low-force deployment, conservative laser energy/frequency settings, infection control, and strong consideration of drainage/stenting after significant ureteral trauma (Section 9).

Stage 3 — Diagnosis (structured surveillance): Elevated-risk patients enter an early-imaging pathway (4–6

weeks post-stent removal) rather than the standard symptom-triggered pathway used for uncomplicated cases, with confirmatory MAG3 renography or CT urography for any abnormal finding (Section 10).

Stage 4 — Management (stratified by stricture characteristics): Short (<2 cm), single-segment, well-

vascularized strictures are managed first-line with balloon dilation, with endoureterotomy added for lower-ureteral strictures or when initial dilation fails; multi-segment, longer, or devascularized strictures, or those recurring after a failed primary endoscopic attempt, proceed directly to reconstructive surgery

(ureteroureterostomy, ureteroneocystostomy, BMG/LMG ureteroplasty, or ileal substitution as anatomically indicated) rather than a second endoscopic attempt, given the consistently lower yield of salvage endoscopic management after a failed index procedure (Section 11).

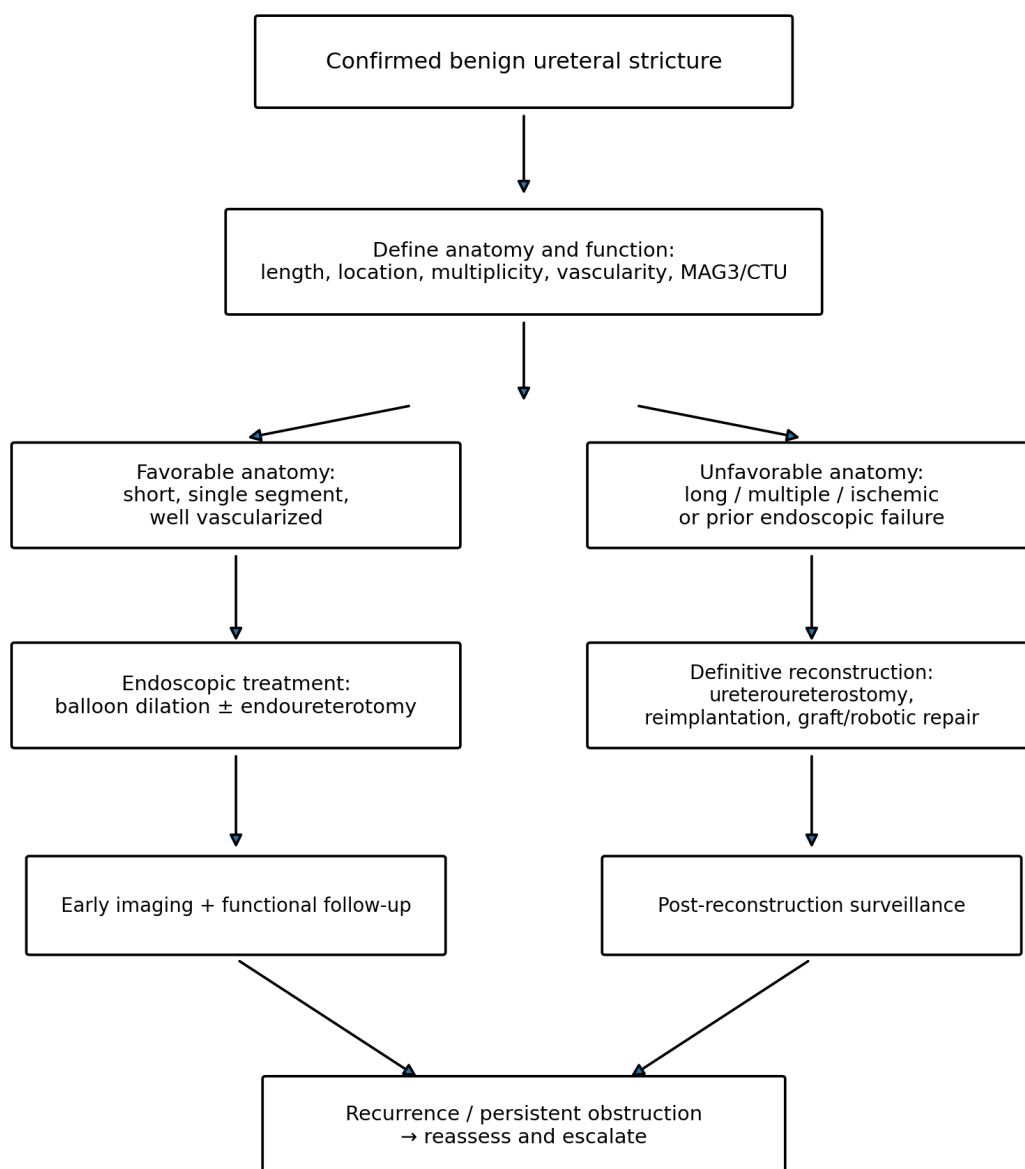


Figure 5. Clinical management algorithm for confirmed benign ureteral stricture based on anatomy, functional assessment, and prior treatment.

Future Directions

AI-assisted prediction. As discussed in Section 8, machine-learning models already outperform or match traditional nomograms for PCNL outcome prediction (62) and spontaneous stone-passage prediction (63), and an analogous post-TURP urethral-stricture model built from routine preoperative blood

parameters achieved strong discrimination using readily available inputs. Extending this approach to post-endourological ureteral stricture specifically — combining intraoperative variables (perforation, UAS grade, operative/lasing time) with routine postoperative laboratory data — is a logical and

currently unrealized next step, contingent on the structured prospective data collection discussed below.

Drug-eluting and biodegradable stents. Translational work has moved beyond simple antifibrotic concept studies toward device-level innovation. A biodegradable stent eluting the mTOR inhibitor rapamycin reduced fibrotic markers (collagen deposition, α -SMA, Smad, SNAI1 expression) in a rabbit model of thermal-injury-induced ureteral stricture, directly operationalizing the TGF- β /mTOR fibrosis pathway described in Section 4 as a treatable target rather than merely a descriptive mechanism. More broadly, biodegradable ureteral stents incorporating anti-proliferative agents (paclitaxel, rapamycin, sunitinib) are under active development, with dual-layer polymer constructs designed to provide sustained, controlled drug release specifically to inhibit ureteral scar proliferation after reconstructive surgery or thermal injury (61). These remain preclinical, but represent the most concrete bridge currently available between the mechanistic pathophysiology described in Section 4 and a deployable clinical prevention tool.

Antifibrotic pharmacotherapy. Pirfenidone's demonstrated in vitro suppression of macrophage TGF- β 1 secretion and fibroblast scar-forming activity (40) positions it, and related antifibrotic agents, as repurposing candidates specifically for high-risk ureteral injury (e.g., known high-grade UAS injury or perforation at the time of index surgery), an approach that would require prospective clinical evaluation but has clear biological rationale and an existing safety record in other fibrotic diseases.

Precision medicine and biomarker development. The current biomarker evidence base (NLR, PLR) is informative chiefly by its negative findings for stricture prediction specifically (43), which itself argues for development of more mechanistically targeted biomarkers — for example, direct or surrogate measures of TGF- β 1 activity, collagen turnover, or matrix metalloproteinase balance — rather than continued reliance on generic systemic inflammatory ratios that were validated for different outcomes (stone passage, sepsis) (42,44,45).

Prospective registries and multicenter collaboration. The FLEXOR registry model (34,35) demonstrates the value of large, prospectively collected, standardized multicenter data for characterizing acute UAS-related injury; the field's single largest unmet need is an analogous registry with long-term (≥ 1 –2 year) structured imaging follow-up specifically powered to capture late stricture development, which the FLEXOR registry's short observation window could not do. Such a registry

would simultaneously resolve the routine-versus-selective imaging controversy described in Section 10, generate the labelled longitudinal dataset that AI/ML stricture-prediction models require, and provide the adequately powered multivariable framework needed to finally disentangle the patient-, stone-, and procedure-level risk factors discussed in Section 5.

Limitations of Current Evidence

The evidence base synthesized in this review carries several structural limitations that temper the strength of its conclusions. First, the overwhelming majority of included studies are retrospective, single-center cohorts, with only a small number of randomized comparisons (notably the holmium:YAG versus thulium-fiber laser trial) (58) and almost no prospective, adequately powered multivariable analyses spanning patient, stone, and procedural factors simultaneously. Second, the definition of “ureteral stricture” itself is inconsistently applied across studies — some require radiological confirmation of obstruction, others rely on symptomatic presentation, and follow-up duration ranges from weeks to years — meaning that pooled incidence figures, however useful for orientation, mask substantial underlying heterogeneity. Third, because postoperative imaging surveillance is itself inconsistent and contested (Section 10), ascertainment bias is likely pervasive: cohorts with more intensive follow-up almost certainly detect more strictures, complicating any direct comparison of reported rates across studies or institutions. Fourth, PCNL- and SWL-specific primary literature isolating ureteral (rather than infundibular, pelvicalyceal, or skin-to-stone tract) complications remains comparatively underdeveloped relative to the URS/RIRS literature, limiting the strength of conclusions in Sections 3.3 and 3.4 specifically. Fifth, translational and mechanistic studies, while mechanistically illuminating, are drawn from animal models or small in vitro systems and have not yet been validated in human ureteral tissue at the scale needed to confirm the macrophage–TGF- β 1 axis as a clinically actionable target rather than a plausible hypothesis. Finally, this review used a structured five-database literature search but remains a narrative synthesis rather than an exhaustive systematic review; quantitative estimates should therefore be interpreted as a clinically oriented synthesis of the best identified evidence rather than as a definitive, fully comprehensive meta-analytic dataset. A future systematic review with prospectively specified screening, formal study-level quality appraisal, and de novo meta-analytic pooling would be an appropriate next step.

Conclusion

Ureteral stricture after endourological treatment of urolithiasis is an uncommon but consequential complication whose risk is concentrated overwhelmingly in a specific, identifiable clinical scenario: the impacted or proximal stone in which perforation or high-grade mucosal injury occurs during retrieval, frequently compounded by ureteral access sheath-related trauma during retrograde intrarenal surgery. The pathophysiology converges on a macrophage–fibroblast–TGF- β 1 axis that is mechanistically tractable and, for the first time, beginning to be addressed directly through drug-eluting stent and antifibrotic pharmacotherapy research rather than through prevention alone. Clinically, the evidence supports a risk-stratified approach — proactive pre-stenting and careful instrument/energy selection for high-risk anatomy, strong consideration of

drainage/stenting after significant ureteral trauma, an early and structured imaging pathway for flagged high-risk procedures rather than reliance on symptoms alone, and a management strategy that reserves endoscopic balloon dilation and endoureterotomy for short, single-segment, well-vascularized strictures while directing longer, multi-segment, or previously failed strictures toward definitive reconstructive surgery. The single most valuable next investment for this field is not another retrospective single-center series, but a prospective, multicenter registry with structured long-term imaging follow-up — the only design capable of simultaneously resolving the surveillance controversy, powering a true multivariable risk model, and generating the dataset on which the next generation of AI-assisted prediction tools will depend.

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