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REVIEW

Epidemiology and Management of Kidney Stone Disease – Current Insights

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Abstract: Nephrolithiasis is a common global urological disorder, with incidence rates being as high as 13% in some regions of North America, contributing to substantial healthcare burdens. In 2021, 106 million new cases were reported worldwide, predominantly in men, reflecting a 27% rise since 2000. Regional disparities are notable, with Eastern Europe showing the highest rates (3,560 per 100,000). Management has evolved from open surgery to minimally invasive, precision endourological techniques, driven by innovations such as advanced lasers, digital ureteroscopes, artificial intelligence, virtual reality training, and robotic-assisted procedures, these advances have enhanced stone-free rates and reduced complications This review provides a comprehensive analysis of the epidemiology and contemporary management of kidney stone disease especially analysing variables affecting the disease including gender, age, geography and climate, occupational exposure, dietary lifestyle, and systemic diseases. Understanding the multifactorial epidemiology of nephrolithiasis is essential for effective prevention, while modern technological interventions are reshaping treatment standards and improving patient outcomes by offering individualized treatment options.

Keywords: kidney calculi, epidemiology, ureteroscopy, PCNL, incidence, laser

Introduction

Kidney stone disease (KSD) is a highly prevalent condition worldwide, representing one of the most common urological diseases, with reported incidence rates ranging from approximately 1% in parts of Asia to as high as 13% in North America.[1] Whilst regional variations exist, the global incidence of the disease is rising, exerting a detrimental impact on public health and quality of life worldwide.

In addition, KSD, characterized by substantial acute and chronic morbidity, imposes a considerable financial burden on healthcare systems and ranks as the second most costly urological disorder.[2] Given the multifactorial nature of urolithiasis, understanding the epidemiological insights, provide valuable information in management and reducing the risk of stone formation. Epidemiology refers to the study of determinants and distribution of a disease, it can be used to analyse both the frequency and patterns of stone disease, as well as the biological, environmental, and social determinants that contribute to it.

Although the precise pathophysiological mechanisms underlying nephrolithiasis remain incompletely understood, and no single theory can fully account for its development, the combined influence of factors such as age, sex, metabolic status, geography, climatic conditions, genetic predisposition, and dietary habits on its occurrence highlights the inherently multifactorial nature of the disease.[3] Moreover, studies have identified kidney stones to be both influenced by and associated with systemic conditions such as diabetes, cardiovascular disease, and chronic kidney disease (CKD), likely due to the presence of shared risk factors that contribute to their development.[4]

With the rising incidence of the disease, management strategies have likewise experienced substantial advancements, enabling earlier diagnosis and the provision of individualized treatment approaches. Numerous comprehensive guidelines on the management of urolithiasis have been issued by leading institutions globally, such as the American Urological Association (AUA) and the European Association of Urology (EAU) which are routinely utilized by clinicians to guide

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Table 1 Epidemiological Characteristics of Kidney Stone Disease

Epidemiological Factor	Key Findings	Supporting Data
Incidence & Prevalence	Rising global incidence with significant regional variation	106 million new cases globally (2021); 26.7% increase since 2000; US prevalence: approximately 9.25%; UK lifetime prevalence: approximately 14%; Asian "stone belt": 5–19%
Gender Distribution	Male predominance with narrowing gender gap	Males: approximately 67% of cases; US prevalence: 10.9% (men) vs 9.4% (women); Rising incidence in young Black women; Testosterone increases risk; oestrogen protective; Women report lower quality of life impact
Age-Related Patterns	Prevalence increases with advancing age	Ages 20–39: approximately 5%; Men >80 years: approximately 19.7%; Regional variations
Occupational Risk Factors	High-risk occupations associated with dehydration and chemical exposure	Low hydration/high-heat environments; Increased risk: drivers, steelworkers
Geographic & Climatic Influence	Warm, humid climates significantly increase risk	"Stone-belt" regions (SE USA, tropics) have prevalence ~5–10% vs ~1–5% in cold climates. Southern China prevalence much higher than northern regions.
Racial & Ethnic Disparities	Significant variation by ethnicity, influenced by environmental and lifestyle factors	Non-Hispanic Whites: approximately 12% (highest); Hispanics: approximately 9%; Asian/Black populations: approximately 4–6% (lowest); Disparities reflect environmental and lifestyle differences
Dietary & Fluid Factors	Diet composition and hydration status are major modifiable risk factors	Risk Factors: High sodium intake; Excessive animal protein; Sugary beverages; Protective Factors: Adequate fluid intake; Fruits and vegetables; Appropriate calcium intake; Tea and coffee consumption; Recommendations: Sodium: <4–5g/day; Protein: approximately 0.8–1.0g/kg body weight
Comorbid Conditions	Strong associations with metabolic disorders and Systemic diseases	Stones associated with metabolic syndrome, obesity, hypertension, diabetes, and Chronic Kidney Disease (CKD). Obesity and insulin resistance increase urinary calcium/oxalate; diabetes linked with acidic urine. Stone disease raises End Stage Renal Disease (ESRD) risk (~5%).

the diagnosis, management, and follow-up of patients with kidney stone disease.[5–7] Recent advances in technology, focusing on modern lasers, ureteroscopes, AI- and VR-based training, robotic systems, vacuum-assisted sheaths, and novel lithotripters have markedly improved clinical outcomes, ushering in a new era of endourological management for kidney stone disease.[8]

With this review, we seek to examine the key epidemiological determinants of kidney stone disease, while offering an updated perspective on contemporary management approaches (Table 1).

Incidence and Prevalence

Epidemiological research has demonstrated that the incidence, described as the onset of an individual's first kidney stone, shows variation according to age, sex, and race, with incidence estimates frequently obtained from retrospective review of clinical records or diagnostic coding systems.[9] Conducted as a comprehensive systematic review, the Global Burden of Disease (GBD) 2021 study evaluates published and publicly accessible evidence on the incidence, prevalence, and mortality of 371 diseases and injuries in 204 countries and territories, spanning 21 regions from 1990 to 2021, and provides valuable insight on the incidence and prevalence of urinary calculus disease.[10] A systematic review of GBD 2021, conducted by the urolithiasis collaborators of the GBD study, highlights the burden of disease over the study period, with the key findings regarding the incidence of nephrolithiasis summarized as follows.[11] In 2021, there were 106 million new cases of urolithiasis globally, with men comprising over 67% of cases, reflecting a 26.7% increase since 2000. Incidence among women has also risen steadily over the past 30 years, although still less than male population, with the female-to-male ratio shifting from 1:2.21 in 1990 to 1:2.04 by 2021. Regionally, the highest age-standardized incidence rates were reported in Eastern Europe (3560 per 100,000), Central Asia (1880 per 100,000), and Andean Latin America (1730 per 100,000), while Western sub-Saharan Africa had the lowest rate (606 per 100,000). Central and Tropical Latin America experienced the largest relative increases in age-standardized incidence at 32.1% and 16.9%, respectively. Between 2000 and 2021, 179 countries saw rising case numbers, with 112 also showing increases in age-standardized incidence. China (19.1 million), India (18.6 million), Russia (7.0 million), and the United States (4.23 million) bore the highest absolute burden. The overall rise in incident cases, despite declining age-standardized rates, suggests that population growth and demographic shifts are key drivers, alongside improvements in preventive strategies and reductions in specific risk exposures.

Over the last 3 decades 86% of the countries have seen an increase in the prevalence of kidney stone disease with rates ranging from 1.7 to 14.8%,[12] in addition, these rates appear to be increasing consistently across all investigated countries, as well as across sex, race and age groups.[13] The National Health and Nutrition Examination Survey (NHANES) serve as an important resource for assessing the prevalence of kidney stones in the United States. Approximately 1 in 11 persons suffer from urolithiasis in the US, compared to 1 in 20 in 1994,[14] currently 9.25% of the US population suffers from the disease.[15] In the United Kingdom, the lifetime prevalence of urolithiasis was reported to be 14% for 2013/2014, based on data from hospital admissions and related interventions.[16] Accounting for age differences, the prevalence of nephrolithiasis in the Spanish population has been reported to be approximately 14.6%,[17] and 12.85% in Poland.[18] A "stone-forming belt" has been identified in Asia, encompassing West, Southeast, and South Asia along with developed countries like South Korea and Japan, where prevalence ranges from 5% to 19.1%, while the rest of the continent reports lower rates of 1%–8%.[19] The Eastern Mediterranean region, encompassing 21 countries with a combined population of 745 million, reported an adult urolithiasis prevalence of 14.17%, with men more frequently affected than women, in line with global patterns.[20]

Gender

According to the most recent NHANES data from 2013–2014, the overall prevalence of kidney stone disease was 10.9% in men and 9.4% in women in the US. Historically, the disease has been more common among men. However, studies report a rising incidence among younger, non-Hispanic Black women.[21] Comparable patterns have been observed in other regions, with a higher prevalence among men in China (odds ratio 1.67), and again, the gender gap has narrowed considerably since 2006.[22] Women suffering from nephrolithiasis, however, report markedly lower quality of life across all domains, social, emotional, and related to disease, relative to men.[23]

Diet-related disturbances contribute more prominently to kidney stone disease in male patients, whereas intrinsic physiological risks are more characteristic of females, and older patients.[24] A study found, that among males, the intake of calories, protein, calcium, and fibre was significantly higher in stone formers than in controls, whereas, in females, no significant differences were observed except for a lower intake of oxalate and a higher intake of fat in cases, indicating sex-specific dietary patterns that may influence stone risk.[25] Additionally, testosterone has been implicated in promoting stone formation, whereas oestrogen appears to play a protective role, by influencing the synthesis of 1,25-dihydroxy-vitamin D.[19,26]

Age

Age is a significant determinant of kidney stone prevalence, with the burden increasing progressively in older men. Rates have been described, lowest in those aged 20–39 years (5.1%), rising to 11.5% in the 40–59 year group, 18.8% among those aged 60–79 years, and peaking at 19.7% in men over 80 years.[4,27] Romero et al, reported similar findings, with prevalence generally rising with age In several countries, including Germany, Iceland, Iran, Italy, Greece, Turkey, and the United States, however, observed an exception in Milan, Italy, where prevalence sharply declined in individuals over 60 years, In Korea, prevalence patterns differed by sex, with rates declined with age in men, while, in women they increased, peaking between 60 and 69 years.[13]

Occupation

Despite the focus on other major risk factors for kidney stones, the contribution of occupation is often underestimated. However, limited opportunities for hydration and restroom use during work can nonetheless increase the risk of stone formation. Occupations associated with low urine volume, including taxi cab drivers, unable to take breaks ("taxi cab syndrome"),[28] work in hot conditions, that concentrate urine and elevate supersaturation, and sedentary jobs, may all be linked to an increased likelihood of developing renal tract calculi.[28] A ninefold increased risk of urolithiasis has been reported for those working in high-temperature environments, with 1.75% of steel industry workers developing urinary stones, the majority of whom were employed in hotter areas.[29] Likewise, occupational exposure to chemicals such as trimethyltin (TMT), a plastic stabilizer by-product, has been linked to a higher prevalence of kidney stones (18.06%) compared with 5.88% in unexposed control workers.[30]

Geography and Climate

Weather, geographical factors, and nephrolithiasis are all interconnected, greenhouse gas emissions contributing to global warming and increasing global temperature, have been observed to be directly linked with the prevalence of the disease.

Sweating induced by high temperatures causes fluid loss, and raised serum osmolality, triggering vasopressin release, the resulting concentrated urine increases supersaturation of insoluble salts like calcium oxalate, which precipitate as crystals and may form kidney stones.[31] Across all geographical regions, higher ambient temperatures correlate with supersaturation of calcium oxalate and calcium phosphate, elevated urinary calcium, and lower urinary sodium, suggesting these factors as the underlying mechanism for temperature-related stone formation.[32] Further evidence shows that even short-term exposure to desert conditions significantly elevates the supersaturation of uric acid and sodium urate, which quickly normalizes once the individual is removed from the desert environment.[33]

The American Southeast is often referred to as the “Stone Belt” because of its comparatively high prevalence of urinary stone disease, which is thought to be linked to the region’s elevated temperatures. Both higher precipitation, and increased mean temperatures, have been independently associated with a greater operative burden of stone disease in this region, a pattern that aligns with observations from other parts of the United States where warm, humid climates correspond to the highest stone prevalence.[34] Globally regions located in tropical and subtropical climates exhibit a greater prevalence of urolithiasis (5%–10%) than those in temperate or cold climates (1%–5%).[19] Likewise in southern China, urolithiasis prevalence ranges from 22% to 45%, markedly exceeding the approximately 14% reported in northern China.[35]

Race and Ethnicity

The relation between ethnicity, and race, and KSD has long been debated, distinguishing between stone prevalence differences due to geographic location, and those attributable to racial or ethnic characteristics, is essential, and these should be considered as social constructs, not biological constructs.

In the Asian continent, Miao and Han nationals show a higher incidence of the disease within China.[36] Within Turkey, the incidence of urinary stones is lower in individuals of Turkish ethnicity than in other resident ethnic populations.[37] In the US, from 2007–2008 to 2015–2016, non-Hispanic whites had the greatest kidney stone prevalence (9.8% rising to 12.1%), whereas non-Hispanic Asians and Blacks had the lowest rates (4.4%–4.6% and 4.8%–5.7%, respectively), and Hispanics experienced a modest rise from 7.6% to 9.1%.[27]

It is crucial to acknowledge that dietary patterns, and genetic factors, differ widely among nationalities. Some studies explore the link between race, and nephrolithiasis, while others do not incorporate these demographic characteristics into their epidemiological analyses. The classification of race, and ethnicity, has inherent limitations. For example, unequal access to healthcare for a particular racial group can result in underdiagnosis. Therefore, given these constraints, race and ethnicity can only be loosely associated with the biological determinants of kidney stone disease.[38]

Fluid and Dietary Intake

Dietary factors are key contributors to the epidemiology of kidney stone disease. Numerous studies have demonstrated that diets high in protein, and salt, are directly associated with stone formation, whereas increased intake of fluids, fruits, and vegetables appears to have a protective effect. Urinary pH increases as a result of the alkalinity of a vegetarian diet, and, in addition, fruit and vegetables also have a high water content contributing to daily fluid requirements.

Urinary calcium excretion is closely linked to both dietary sodium intake, and urinary sodium levels, and patients with high sodium concentrations in spot urine are generally advised to follow a low sodium diet to lower the risk of kidney stone formation.[39] EAU recommends daily sodium intake, not more than 4–5g, as higher levels can cause reduction in urinary citrate, increase in calcium excretion, and increase in sodium urate crystal formation.[6]

Contrary to earlier recommendations, dietary calcium should generally not be restricted unless clinically indicated, as dietary calcium intake is inversely associated with the risk of stone formation. While dietary calcium intake may reduce stone risk, supplemental calcium should only be used when clinically indicated, for instance, in cases of enteric hyperoxaluria, and should be paired with higher fluid intake to prevent increases in urinary calcium. Daily oral recommendation is between 1000–1200mg.[40]

Animal protein intake should be limited to the recommended daily intake, 0.8–1.0 g/kg body weight, and excess should be avoided, as it leads to several biochemical alterations such as hyperuricosuria, hyperoxaluria, low urine pH and hypocitraturia, all of which increase the risk of nephrolithiasis.[6] Findings from animal models indicate that protein-rich diets trigger pro-inflammatory responses in the gut, enhance colonization by harmful microorganisms, and diminish levels of oxalate-degrading bacteria.[41]

Managing oxalate intake is a key strategy in stone prevention, particularly for individuals with high oxalate excretion, yet recommending a low-oxalate diet is debated because many oxalate-containing foods are plant-based, and typically considered health-promoting. Evidence from cohort studies indicates that high oxalate consumption is linked to a greater risk of KSD in men, and in older women, with the risk being especially pronounced in men with low dietary calcium, while no significant association has been observed in younger females.[4,42]

Insufficient urine volume plays a critical role in the pathogenesis of nephrolithiasis, and high fluid consumption is the cornerstone of initial management, aimed at reducing the likelihood of recurrent stone episodes. However, the protective benefits against kidney stones are not uniform across all types of fluid intake. High intake of sugar-sweetened cola, and noncola beverages, is associated with a 23%, and 33%, increased risk of kidney stones, respectively when compared with low consumption group, while artificially sweetened non-cola drinks, shows a borderline significant association ($P=0.05$), and punch consumption is linked to an 18% higher risk.[43] Caffeine, tea, and coffee appear to lower the risk of nephrolithiasis, likely due to their diuretic properties, increased fluid intake, and the presence of antioxidant compounds, with caffeine showing the strongest evidence. Alcohol, and beer, have also been linked to stone risk reduction in some studies, but these associations remain uncertain. The protective effects of these beverages are thought to arise primarily from enhanced urine output, and, in the case of tea and coffee, additional antioxidant components that may inhibit stone formation.[39]

A practical approach to diet for stone prevention involves maintaining a balanced, varied diet across all food groups, without overconsumption. The “Dietary Advice for Stone Formers” leaflet, published by the British Association of Urological Surgeons (BAUS) serves as a valuable resource to help patients make dietary modifications, that reduce the risk of kidney stone formation.[44]

Systemic Diseases and Kidney Stones

As the epidemiology of urolithiasis becomes better understood, it is clear that the condition extends beyond a simple urinary disorder. The disease is frequently associated with systemic disorders, including metabolic syndrome, hypertension, cardiovascular disease, obesity, diabetes, and chronic kidney disease, which can both predispose to stone formation, and occur as sequelae of nephrolithiasis.

Although the precise mechanisms linking obesity to kidney stone formation remain unclear, it is recognized that obesity is associated with insulin resistance, and compensatory hyperinsulinemia, metabolic disturbances that may promote the development of calcium-based stones. Additionally, increased body mass can lead to higher urinary excretion of uric acid, and oxalate, both of which are established risk factors for calcium oxalate stone formation.[45] A cross sectional, and longitudinal cohort study identifying the association between KSD and eight different obesity related indices found all indices to be significantly associated with increased risk of disease, with 10.95 of males and 4.0% of females affected with the diseases.[46] Certain bariatric surgeries such as the Roux En Y gastric bypass is also associated with an increase in stone burden.[47]

Insulin resistance, a hallmark of type 2 diabetes mellitus, is a metabolic abnormality that may contribute to increased kidney stone risk. Metabolic studies have shown that insulin resistance is linked to impaired renal ammonium production, and individuals with diabetes, who form stones, tend to have more acidic urine compared with non-diabetic stone formers, diabetes is therefore strongly associated with nephrolithiasis, independent of age, BMI, diet or thiazide diuretic use.[48] In addition, greater diabetic severity, reflected by increased HbA1c and fasting glucose, correlates with an elevated likelihood of developing kidney stones.[49]

Kidney stone history appears to be associated with increased cardiovascular risk, yet the precise pathogenic pathways are not fully elucidated. Contemporary studies have confirmed that stone formers are more likely to develop hypertension, although evidence regarding the reciprocal risk of nephrolithiasis in hypertensive patients remains variable.[4] Increased urinary calcium excretion, commonly seen in patients with hypertension, may underlie the observed relationship between hypertension and kidney stone formation.[50]

The presence of symptomatic kidney stones increases the likelihood of chronic, and end-stage renal disease (ESRD), independent of established cardiovascular risk factors, with attributable risk of ESRD from symptomatic urolithiasis being approximately 5.1%.[51] Although nephrolithiasis is rarely the primary driver of ESRD, it remains an important contributing factor. The development of chronic kidney disease (CKD) in the context of kidney stones is primarily attributed to obstructive uropathy, or pyelonephritis. However, additional mechanisms such as crystal deposition in the ducts of Bellini, and parenchymal injury from shockwave lithotripsy, may also play a role. Among individuals with nephrolithiasis, those at highest risk for CKD include patients with rare hereditary disorders, (such as cystinuria, primary hyperoxaluria), hypertension, recurrent urinary tract infections (rUTIs), diabetes and struvite stones.[52] CKD, and ESRD patients are commonly comorbid with other serious ailments, overshadowing the effects of kidney stones, complicating the assessment of nephrolithiasis as a contributing factor. Either way, preserving renal function should thus be a key priority in healthcare, to reduce associated morbidity and mortality.

Management of KSD, Current Insights

Evaluation

Patients with urolithiasis may experience a wide array of symptoms, including fever, nausea, and loin pain, or may remain asymptomatic. Additionally, bladder stones typically manifest through recurrent infections, frequent urination, terminal hematuria, or suprapubic pain. Careful evaluation, including a detailed history, and physical examination, is recommended for all patients.

Imaging Modality

For symptomatic kidney stone patients, non-contrast CT provides comprehensive assessment of stone parameters, such as volume, size, density, and anatomical relationships, aiding in treatment planning. Ultrasound, however, remains a useful initial investigation for patients without symptoms.[6] Knowing the exact chemistry of a patient's stone is critical for optimal therapy, accurate preoperative compositional data directly informs treatment choice, Dual-energy (spectral CT (DECT) aids in this, by exploiting two X-ray energy spectra to noninvasively characterize urinary calculi by leveraging material-specific attenuation differences.[53] DECT provides highly accurate, non-invasive stone analysis, meaning it can significantly enhance clinical decision-making by supplying clinicians with precise, composition driven guidance for urolithiasis management.[54]

Innovations in Treatment Options

Lasers

Achieving disintegration by the photothermal phenomenon, next generation Holmium: yttrium-aluminum-garnet (Ho: YAG) lasers have revolutionized endourological management of stone disease, and are the gold standard technique[8] (Table 2). New Ho:YAG machines, featuring enhanced pulse-energy, and frequency, support advanced lithotripsy modes, like dusting and pop-dusting, generating fine stone particles, that can be easily expelled from the urinary tract.[55]

The thulium fiber laser (TFL) is a novel laser technology that operates at wavelengths closer to the water absorption peak, allowing it to achieve stone ablation at a threshold approximately four times lower than that of Ho:YAG lasers.[56]

After laser application, two primary techniques are employed for stone removal: basketing and dusting. Basketing is indicated when residual fragments measure 2–4 mm, whereas dusting produces finer particles (<2 mm) that can be naturally passed in the urine. Dusting is often preferred, to reduce repeated manipulation within the ureter and kidney, thereby avoiding additional tissue injury, and longer operative durations.[57]

Table 2 Innovations and Management Principles to Improve Safety and Efficacy

Treatment Category	Innovation/Technique	Key Advantages
Laser Technology	Ho:YAG Laser (dusting and pop-dusting)	Gold standard for stone fragmentation; efficient stone disintegration; produces fine particles that are easily expelled
	Thulium Fiber Laser (TFL)	Lower ablation threshold compared to Ho:YAG; enhanced efficiency in stone ablation with reduced thermal effects
Digital Technology & Training	3D-Printed Surgical Guides (CT-based)	Enables precise and rapid renal access, particularly beneficial for percutaneous nephrolithotomy (PCNL) procedures in some studies
	Virtual Reality (VR) Simulators	Provides immersive training environment for ureteroscopy techniques; improves surgical skills without patient risk
	Artificial Intelligence (AI) Applications	Enhanced diagnostic accuracy; automated stone composition analysis; predictive modelling for bacterial susceptibility patterns
	Simulation-Based Training Programs	Comprehensive development of both technical surgical skills and non-technical competencies
Endoscopic Equipment & Robotics	Digital Ureteroscopes	Superior image quality with clearer visualization; reduced sensitivity to laser flicker artifacts
	Single-Use Ureteroscopes	Comparable clinical outcomes to reusable scopes; significantly lower infection risk; reduced operator fatigue during procedures
	Robotic-Assisted Ureteroscopy	Promising results with high stone-free rates (89%); no reported complications in initial studies; requires further research and development; Expensive
Radiation Safety	ALARA Principle Implementation	Systematic reduction in radiation exposure while maintaining procedural safety and clinical effectiveness

Virtual Reality, Artificial Intelligence and Non-Technical Skills

Modern surgical education emphasizes multi-level training, that integrates theoretical instruction with practical, hands-on experience, employing affordable, and realistic simulation platforms to develop essential skills prior to operating on patients.

Using CT images, personalized 3D-printed surgical guides have been developed to assist percutaneous nephrolithotomy (PCNL), enabling rapid, and precise needle access to the renal collecting system, as demonstrated in a study in a patient with a horseshoe kidney where the needle successfully reached the stone.[58]

In ureteroscopy and flexible ureteroscopy education, VR simulators are employed to gauge surgical competence, particularly for procedural tasks like guidewire insertion, rigid ureteroscopic navigation, and manipulation of stone baskets.[59]

The role of artificial intelligence (AI) in urolithiasis has been assessed across diagnostic processes, stone composition analysis, and different components of medical and surgical therapy. Machine learning models, including neural networks, have been used to distinguish phleboliths from kidney stones on CT scans with 100% sensitivity and to predict bacterial species susceptibility in stone disease patients with up to 87.4% accuracy, potentially reducing laboratory reporting time by nearly 24 hours.[60,61]

Additionally, the recognition for development of non-technical skills(NTS) is increasing in urology, and simulation-based programs now represent an optimal approach to deliver comprehensive NTS training for both trainees, and experienced surgeons.[62]

Ureteroscopes and Robotic Ureteroscopy

Advances in technology have transitioned ureteroscopes from fiber-optic to digital systems, reducing sensitivity to image flickering from laser-induced shockwaves and providing a clearer, uninterrupted view.[63] Single-use scopes have also been developed and, in addition to providing outcomes comparable to reusable scopes, they have been shown to decrease operator fatigue and offer the major advantage of eliminating cross-contamination risk between patients.[8] Direct in-scope suction (DISS) and flexible, navigable suction ureteral access sheaths (FANS) are recent advances in ureteroscopic stone management that actively aspirate fragments during lithotripsy. DISS-equipped ureteroscopes have an integrated suction channel, improving visualization and allowing simultaneous dust evacuation, clinical evidence indicates that DISS ensures excellent intraoperative visibility, optimal maneuverability, and reliable suction efficiency, leading to improved operative results.[64] Pooled analyses show FANS use significantly increases SFR compared to conventional sheaths (95% vs 67%), along with a marked reduction in operative time.[65] Together, these suction-enabled technologies streamline fragment extraction and substantially improve clearance efficiency and operative speed in ureteroscopic stone removal.

While the use of robotic system for urologic oncology has been well established, and documented, trials for the use of robotic system for ureteroscopy have also been very encouraging reporting 3 month stone free rate of 89% and no complications.[66]

Radiation-Free Protocols

Even though radiation exposure from ureteroscopy is far below levels needed to cause deterministic effects, fluoroscopy used in stone treatment constitutes a considerable source of radiation exposure (RE). Consequently, methods are being established to reduce RE during endourological procedures, adhering to ALARA (as low as reasonably achievable) principles, while maintaining procedural success and avoiding higher complication rates.[67]

Other Considerations for Management

The role of fluid intake in the primary prevention of KSD cannot be underestimated.[68] Similarly, while clinical outcomes are often benchmarked, patient reported outcome measures (PROMs) are often not considered in the reported outcomes.[69] Cost of treatment also needs to be considered for management of these stones, which should also look at cost of laser used.[70,71] With growing incidence of stone disease in high-risk groups, such as in pregnancy, paediatrics and obesity,[72–74] outcome reporting should be standardised and multi-disciplinary team (MDT) decision making should be embarked on.[75] More recently, there has been an increasing emphasis on the management of lower pole stones and quadrifecta in retrograde intrarenal surgery with the role of intrarenal pressure, irrigation, suction and temperature.[76,77] These will also be enhanced by integration of artificial intelligence (AI) and AI driven chatbots.[78]

Conclusion

The rising prevalence of urolithiasis over recent decades presents significant challenges for both patients, and healthcare systems. While dietary changes, and global climate shifts, may contribute, epidemiologic studies have clarified the multifactorial nature of risk, which varies for each individual, and offer insights to guide prevention strategies. Management has transitioned from open surgery to minimally invasive approaches, with technological advances, such as thulium fiber lasers, digital, and single-use ureteroscopes, novel lithotripsy modes, AI planning, and robotic systems enhancing safety, precision, and efficiency. These innovations have made kidney stone treatment less invasive while continuously improving clinical outcomes, and shaping the future of urolithiasis care.

Disclosure

The authors report no conflicts of interest in this work.

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