# A Review of Treatment Strategies and Analytical Approaches for Kidney Stones

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***Abstract*—Kidney stones are mineral deposits in the renal calyces and pelvis that are either free or attached to the renal papillae. They contain crystalline and organic components and are formed when urine becomes supersaturated with respect to a mineral. Calcium oxalate is the main constituent of most stones, many of which form on a foundation of calcium phosphate called Randall's plaques, which are present on the renal papillary surface. Stone formation is highly prevalent, with rates of up to 14.8% and increasing, and a recurrence rate of up to 50% within the first five years of the initial stone episode.[1] Obesity, diabetes, hypertension, and metabolic syndrome are considered risk factors for stone formation, which can lead to hypertension, chronic kidney disease, and end-stage renal disease. The management of symptomatic kidney stones has evolved from open surgical lithotomy to minimally invasive endourological treatments, leading to a reduction in patient morbidity, improved stone-free rates, and better quality of life. The prevention of recurrence requires behavioral and nutritional interventions, as well as pharmacological treatments that are specific to the type of stone. There is a great need for recurrence prevention which requires a better understanding of the mechanisms involved in stone formation to facilitate the development of more effective drugs. [2]**

## I. INTRODUCTION

Kidney stones are hard deposits that form inside the kidneys when certain minerals in the urine build up and stick together. They are a very common health problem today, affecting millions of people, and any experience them more than once. Factors like not drinking enough water, eating too much salt or animal protein, having diabetes, obesity, infections, or certain genetic conditions can increase the chances of developing stones. Most stones are made of calcium oxalate, but other types—such as uric acid, struvite, and cystine stones also occur and are linked to specific health issues or infections. Kidney stones can cause severe pain, blood in the urine, fever, or nausea and may lead to serious complications if left untreated. Thanks to modern technology, doctors can now diagnose stones more accurately and remove them using less invasive methods. However, preventing stones through healthy habits and early detection remains the best long-term solution. Understanding what causes kidney stones and how they form helps in choosing the right treatment and reducing the chances of them coming back.[3]

## II. CAUSES [ETIOLOGY]

Most kidney stones are caused by a combination of dietary, lifestyle, genetic, and medical factors.
Diets that are high in sodium, added sugar, meat, fish, and seafood, along with insufficient fruits, vegetables, calcium, and water, can cause kidney stones in susceptible individuals.[4]
Certain diseases can increase the likelihood of kidney stones. Some of the most common medical conditions linked with kidney stones are Diabetes

Gastric bypass surgery (weight loss surgery)
Inflammatory bowel disease: Causes swelling of the gut, leading to pain, diarrhoea, and other digestive problems.

Hyperparathyroidism (hy-per-para-THY-royd-iz-um)
Polycystic kidney disease (PKD)

Gout
Chronic urinary tract infections

Eating disorders
Individuals with kidney stones are also at a higher risk of other chronic diseases, such as:

Osteopenia (ah-stee-oh-PEE-nee-uh)
High blood pressure and Heart disease[5]
These are the common Causes of kidney stone [6] :-
Kidney stones (renal calculi, urolithiasis) can form due to multiple agents and factors. These can be broadly classified into biological, chemical, and physical agents.[7]

Biological Agents
These involve living organisms or body-related factors that predispose patients to stone formation.

Microorganisms:
Urease-producing bacteria (e.g., Proteus, Klebsiella, and Pseudomonas) can cause infection induced struvite stones (magnesium ammonium phosphate).

Metabolic/Genetic factors:
Hyperparathyroidism → ↑ calcium stones o Gout → uric acid stones
Cystinuria (genetic defect in amino acid transport) → cystine stones

Chemical Agents
These substances or imbalances in urine chemistry promote crystal formation.

Excess solutes in the urine:
Calcium (hypercalciuria) → calcium oxalate/calcium phosphate stones
Oxalate (hyperoxaluria)
Uric acid (hyperuricosuria)
Cystine (cystinuria)
Reduced inhibitors of crystallization:
Low citrate (hypocitraturia)
Low magnesium

Physical Agents :-
These are non-living, mechanical, or environmental conditions that facilitate stone formation.
Dehydration / Low urine volume → concentrated urine, crystal supersaturation

Urinary stasis/obstruction (e.g., enlarged prostate, neurogenic bladder) → promotes crystal aggregation

Foreign bodies (e.g., stents, catheters) → act as a nidus for stone formation
Climatic/environmental factors: - Hot climate → dehydration risk

## III. SYMPTOMS

Kidney stones vary in size. Some kidney stones are as small as grains of sand. Others are as large as pebbles. A few were as large as golf balls! As a general rule, the larger the stone, the more noticeable are the symptoms [8].

The symptoms may include one or more of the following:
Severe pain on either side of your lower back
More vague or hard to describe pain or stomach-ache that doesn't go away

Blood in the urine
Feeling sick to the stomach (nausea) or throwing up (vomiting).

Fever and chills
Urine that smells bad or looks cloudy.

Pathogenesis [9]:-
For a stone to form, 3 process occurs
1.Superposition 2. Nucleation 3. Aggregation

Supersaturation: -
Cations and anions are charged soluble molecules, such as calcium and oxalate.
However, at a specific concentration and pH, the equilibrium state of these molecules reaches a critical point called supersaturation.
Beyond this point, these molecules cannot remain dissolved and become insoluble and precipitate.

Nucleation: -
Nucleation presents a focus where crystals start to precipitate.

Aggregation
Aggregation is the process in which precipitating crystals accumulate on each other and form larger crystals in a geometrical and organized manner.

## IV. TYPES OF KIDNEYS STONES [10]

There are four main types of stones: calcium, uric acid, struvite, and cystine. Calcium: Calcium kidney stones can be composed of calcium oxalate or calcium phosphate.

Calcium oxalate kidney stones are the most common type of kidney stones. They are usually caused by a combination of dietary, genetic, and medical factors. Excessive intake of sodium, added sugar, and protein from meat, poultry, and fish can cause calcium kidney stones. Insufficient calcium intake can contribute to the formation of calcium oxalate kidney stones.

Calcium phosphate stones are less common than other stone types. They can form when urine is too alkaline (say: AL-kuh-line), which means urine is not very acidic—more like plain water. Certain health problems or medications can cause this and increase the risk of developing these stones.

Uric acid: Another common type of kidney stone is uric acid. Uric acid kidney stones are often caused by gout or excessive consumption of animal protein from meat, poultry, fish, or seafood. Individuals with diabetes are more likely to develop uric acid kidney stones.

Struvite: These stones are rare and are usually caused by urinary tract infection.

Cystine: These stones are rare and are caused by a rare genetic disorder called cystinuria.

If you pass a kidney stone, try to catch it and give it to your doctor for testing. If your stone is removed by surgery, your doctor should save pieces of your kidney stone for analysis.

Common Kidney Stone Compositions

Kidney stones are typically classified into four major types based on their primary chemical composition: -

Risk factors [11] :-

Factors that increase the risk of kidney stones include:

Family or personal history: If someone in your family has had kidney stones, you are more likely to develop stones. If you have already had one or more kidney stones, you are at a higher risk of developing another stone.

Dehydration: Insufficient daily water intake can increase the risk of kidney stones. Individuals living in warm, dry climates and those who sweat profusely may be at a higher risk than others.

Diet: Eating a diet high in oxalate, protein, sodium, and sugar may increase the risk of some types of kidney stones. This is especially true for high-sodium diets. Excess sodium increases the amount of calcium that the kidneys must filter. This significantly increases the risk of kidney stones. iv. Obesity: This complex disease involves having too much body fat and has been linked to a higher risk of kidney stones.

Digestive diseases and surgery: Gastric bypass surgery, inflammatory bowel disease, or ongoing diarrhoea can cause changes in the digestive process. These changes affect the body's absorption of calcium and water. This, in turn, increases the amount of stone forming substances in the urine.

Other health conditions, such as renal tubular acidosis, cystinuria, hyperparathyroidism, and repeated urinary tract infections, can also increase the risk of kidney stones. A rare genetic condition, primary hyperoxaluria, increases the risk of calcium oxalate stones.

Some supplements and medicines were also included. These include vitamin C, dietary supplements, overuse of laxatives, calcium-based antacids, and some medications for migraines or depression.

## V. PREVENTION [12]

The best way to prevent kidney stones is to ensure that you drink plenty of water each day to avoid dehydration.

To prevent the return of stones, you should aim to drink up to 3 litres (5.2 pints) of fluid throughout the day, every day.

You're advised to:

drink water, but drinks like tea and coffee also count
add fresh lemon juice to your water
avoid fizzy drinks
do not eat too much salt

Keeping your urine clear helps stop waste products from becoming too concentrated and forming stones.

You can determine the dilution of your urine by observing its colour. The darker your urine, the more concentrated it is.

Your urine is usually dark yellow in the morning because it contains a build-up of waste products that your body produces overnight.
Drinks such as tea, coffee, and fruit juice can count towards your fluid intake, but water is the healthiest option and is best for preventing kidney stones from developing.
You should also ensure that you drink more when it is hot or when you are exercising to replace the fluids lost through sweating.

## VI. TREATMENT OF KIDNEY STONE [13]

Treating small kidney stones: -
Small kidney stones may cause pain until they are passed, which can take a few weeks. A GP may recommend a non-steroidal anti-inflammatory drug (NSAIDs) to help with pain.
To ease your symptoms, a General Practitioner might also recommend:
drinking plenty of fluids throughout the day
anti-sickness medicine
alpha-blockers (medicines to help stones pass)
You might be advised to drink up to 3 litres (5.2 pints) of fluid throughout the day, every day, until the stones have cleared.
To help your stones pass
drink water, but drinks like tea and coffee also count
add fresh lemon juice to your water
avoid fizzy drinks
do not eat too much salt

Ensure that you are drinking enough fluids. If your urine is dark, it means that you are not drinking enough. Your urine should be pale in colour.
You may be advised to continue drinking this much fluid to prevent the formation of new stones.
If the kidney stones cause severe pain, the GP may send the patient to the hospital for tests and treatment.
Treating large kidney stones
If the kidney stones are too large to be passed naturally, they are usually removed through surgery.
Surgery for treating kidney stones
The main types of surgery for removing kidney stones are as follows:
shockwave lithotripsy (SWL)
ureteroscopy
percutaneous nephrolithotomy (PCNL)
The type of surgery depends on the size and location of the stones.

Shock wave lithotripsy (SWL)
SWL involves the use of ultrasound (high-frequency sound waves) to pinpoint the location of a kidney stone.
Ultrasound shock waves are then sent to the stone from a machine to break it into smaller pieces so that it can be passed in the urine.
SWL can be an uncomfortable form of treatment; therefore, it is usually performed after administering painkilling medication.
You may need more than one session of SWL to successfully treat your kidney stones.

Ureteroscopy
Ureteroscopy involves passing a long, thin telescope called a ureteroscope through the tube urine passes through on its way out of the body (the urethra) and into the bladder.
It is then passed up into the ureter, which connects the bladder to the kidney.
The surgeon may either try to gently remove the stone using another instrument or use laser energy to break it into small pieces so that it can be passed naturally in the urine.
Ureteroscopy is performed under general anaesthesia.
Percutaneous nephrolithotomy (PCNL)
PCNL involves the use of a thin telescopic instrument called a nephroscope.
A small cut (incision) is made in your back, and the nephroscope is passed through it into your kidney.
The stone is either pulled out or broken into smaller pieces using lasers or pneumatic energy.
PCNL is always performed under general anaesthesia.
Complications of treatment [14]:-
Complications can occur after the treatment of large kidney stones.
Your surgeon should explain these to you before the procedure.
Possible complications depend on the type of treatment and the size and position of the stones.
The complications include:
sepsis, an infection that spreads through the blood, causing symptoms throughout the whole body
a blocked ureter caused by stone fragments (the ureter is the tube that attaches the kidney to the bladder) . an injury to the ureter .urinary tract infection (UTI)

bleeding during surgery pain Epidermally of kidney stones

(urolithiasis) in India: - Prevalence in India
An estimated 12% of the population is expected to develop urinary stones at some point.
Of these, approximately 50% may end up with significant renal damage, and approximately 10–12% can progress to kidney failure if untreated.
The lifetime risk is higher in northern and northwestern India than in the southern states.
Geographic Distribution (Stone Belt in India)
A well-recognized "stone belt" exists, covering Maharashtra, Gujarat, Rajasthan, Punjab, Haryana, Delhi, and Madhya Pradesh.
Hot climate, high dehydration risk, and dietary habits contribute to clustering.
Its prevalence is relatively lower in southern and northeastern India, although it is increasing with lifestyle changes.
Demographics xvii. Age group: Most common in the 20–40 years age group (productive age group).
Sex: More common in males (M: F ≈ 2:1), although the incidence in women is increasing.
Recurrence: Up to 30–50% recurrence within 5 years without preventive measures.

Risk Factors in Indian Context: -
Climate: Hot, arid regions → Dehydration.
Diet: High intake of oxalate-rich foods (e.g., spinach, nuts, and tea), high salt intake, low calcium intake, and vegetarian diets lacking balance.
Water quality: High mineral content ("hard water") in certain areas.
Socioeconomic factors: Poor access to healthcare delays treatment, leading to higher complications.
Stone Composition in India xxvi. Calcium oxalate stones are the most common (≈70–80%). xxvii. Uric acid and mixed stones were also observed, especially in obese/diabetic patients. xxviii. Struvite (infection) stones are associated with recurrent urinary infections.

Public Health Burden
Kidney stones are a major urological disease in India, particularly in the northern states.
High recurrence → repeated hospital visits, surgeries, and risk of chronic kidney disease.
The rising incidence has been attributed to urbanization, dietary changes, and global warming.
Kidney stones affect approximately 12% of Indians, with the highest prevalence in the northwest stone belt (Rajasthan, Punjab, Haryana, Gujarat, Maharashtra, and Delhi). They are most common in young to middle-aged men, are strongly linked to climate, diet, and water quality, and are a growing public health issue.

Pharmaceutical analysis of a kidney stone
It is a critical diagnostic procedure used to determine the chemical composition and morphology. This information is essential for identifying the underlying cause of stone formation and developing an effective treatment and prevention plan to avoid its recurrence.

## VII. METHODS OF ANALYSIS [15]

Modern medical guidelines recommend physical methods such as Fourier-transform infrared (FTIR) spectroscopy or powder X-ray diffraction (PXRD) as the standard for stone analysis, as chemical "wet" tests are considered outdated and less accurate.
Common techniques include the following:
Fourier Transform Infrared (FTIR) Spectroscopy: The most widely used and cost-effective method for identifying organic and inorganic compounds in stones. It provides a molecular "fingerprint" by measuring the absorption of infrared light by the sample and offers semiquantitative results.

Powder X-ray Diffraction (PXRD): This method identifies the specific crystalline structures of stone components based on their unique diffraction patterns.
Scanning Electron Microscopy (SEM): Often combined with energy-dispersive X-ray spectroscopy (EDX/EDS), SEM is used to study the stone's morphology, texture, and elemental composition (e.g., presence of calcium, phosphorus, and oxygen) at high resolution. This helps in understanding how the layers of stone are formed over time.

## VIII. CONCLUSION

Kidney stones are a widespread and recurrent condition influenced by dietary habits, metabolic disorders, genetics, infections, and environmental factors. Their formation follows the processes of

supersaturation, nucleation, and aggregation, resulting in various stone types— most commonly calcium oxalate. Advances such as FTIR, PXRD, and SEM have improved stone analysis, enabling accurate diagnosis and personalized treatment. Modern management relies on minimally invasive procedures like SWL, ureteroscopy, and PCNL, while prevention focuses on adequate hydration, dietary changes, and correcting metabolic abnormalities. In India, the high prevalence—especially in the northwestern "stone belt"—is driven by climate, water quality, and lifestyle factors. Overall, effective control of kidney stones requires early diagnosis, appropriate treatment, and strong preventive strategies to reduce recurrence and long-term complications.[16]

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