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KIDNEY STONES: ETIOLOGY, PATHOGENESIS, AND TREATMENT METHODS

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Abstract. Kidney stones (urolithiasis) are one of the most common diseases of the urinary system and develop under the influence of metabolic, infectious, and environmental factors. The disease may present with pain syndrome, urinary dysfunction, and various complications. This article analyzes the mechanisms of kidney stone formation, risk factors, clinical manifestations, and modern diagnostic and treatment methods.

Keywords: kidney stone, urolithiasis, nephrolithiasis, urinary system, metabolic disorder, lithotripsy.

Introduction. Urolithiasis is a pathological process characterized by the crystallization of mineral salts in the kidneys and urinary tract, affecting 5–15% of the population. It is more common in men; however, in recent years, the incidence among women has also increased. Hot climate, high mineral content of drinking water, dietary habits, and physical inactivity are among the main factors contributing to the development of the disease.

Etiology of Kidney Stones. Kidney stones (urolithiasis) are a multifactorial disease in which metabolic, genetic, infectious, anatomical, and lifestyle factors play an important role. These factors alter the physicochemical properties of urine and activate the crystallization process [1].

Metabolic disorders play a leading role in the etiology. Hypercalciuria, hyperoxaluria, and hyperuricosuria increase the concentration of salts in the urine and accelerate crystal formation [2]. Hypocitraturia weakens the natural inhibitory mechanisms of crystallization.

Genetic predisposition, particularly cystinuria and primary hypercalciuria, increases the risk of stone formation. Urinary tract infections, especially those caused by urease-producing bacteria, alkalinize the urine and contribute to the development of struvite stones.

Impaired urine flow, low fluid intake, excessive consumption of salt and animal proteins, obesity, and metabolic syndrome are also important risk factors. Recent studies indicate that oxidative stress and inflammatory processes enhance the adhesion of crystals to the epithelium.

Pathogenesis of Kidney Stones

The pathogenesis of kidney stones (urolithiasis) is a complex, multistage process that develops as a result of changes in the physicochemical properties of urine, crystal nucleation, aggregation, retention, and the interaction of local inflammatory and oxidative stress mechanisms. Stone formation is a dynamic process associated with an imbalance between the body's protective mechanisms and pathological factors [3].

Urine Supersaturation. The initial stage of pathogenesis is the supersaturation of urine with certain salts (calcium, oxalate, phosphate, uric acid, and others). Under normal conditions, urinary citrate, magnesium, and other inhibitors limit crystallization. However, due to metabolic disorders or insufficient fluid intake, the balance between inhibitory and promotive factors is disrupted. As a result, a favorable environment for crystal nucleation is created.

Nucleation and Crystal Growth [4]. Under conditions of supersaturation, ions combine to form microscopic crystal nuclei. This process is called "nucleation." Nucleation may occur homogeneously (within the urine itself) or heterogeneously (on the epithelial surface or on an existing crystal).

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The formed crystals may be washed away by urine flow; however, if they aggregate and enlarge or adhere to the renal tubular epithelium, the pathological process continues. Crystal growth and aggregation represent crucial stages in stone formation [5].

Epithelial Injury and Crystal Retention. Damage to the renal tubular epithelium plays a central role in the pathogenesis of kidney stones. Oxidative stress, free radicals, and metabolic disturbances injure cell membranes [6]. The damaged epithelial surface serves as a "retention site" for crystal adhesion.

In addition, Randall's plaques (calcium phosphate deposits in the renal papilla) have been identified as a foundation for calcium oxalate stone formation. Crystal aggregation accelerates on these plaques, leading to the formation of macroscopic stones [7].

Oxidative Stress and Inflammatory Mechanisms. Recent studies highlight the significant role of oxidative stress in the pathogenesis of urolithiasis. Reactive oxygen species (ROS) damage renal epithelial cells and enhance the release of inflammatory mediators.

Activation of the NF-κB signaling pathway increases the production of cytokines such as TNF-α, IL-1β, and IL-6. As a result, a local inflammatory process develops, and crystal adhesion is enhanced. Thus, crystallization and inflammation form a closely interconnected pathological chain.

Immune Response and Cellular Changes. Macrophages and other immune cells are activated in response to crystals. They attempt to phagocytose the crystals; however, under conditions of excessive crystal load, this process becomes insufficient [8]. Consequently, inflammation intensifies and may lead to fibrosis and tissue remodeling. The characteristics of the immune response depend on the type of stone and the underlying metabolic background, resulting in individual variations.

Urinary pH and Microbiological Factors. Urinary pH significantly influences the crystallization process. In an alkaline environment, phosphate and struvite stones form more rapidly, whereas an acidic environment promotes the development of urate stones [9].

During infectious processes, urease produced by bacteria alkalinizes the urine and accelerates crystallization.

Treatment of Kidney Stones

The treatment of kidney stones is determined individually, depending on the size, location, chemical composition of the stone, and the patient's overall condition. In cases of small stones, a conservative approach is applied: nonsteroidal anti-inflammatory drugs (NSAIDs) and antispasmodics are administered to relieve pain, fluid intake is increased, and alpha-blockers are prescribed to facilitate the natural passage of the stone [10].

When metabolic abnormalities are identified, targeted pharmacotherapy is initiated. For example, allopurinol is prescribed in cases of hyperuricemia, potassium citrate in hypocitraturia, and thiazide diuretics in hypercalciuria. Monitoring and regulating urinary pH is of great importance.

For medium- and large-sized stones, minimally invasive methods are used, including extracorporeal shock wave lithotripsy (ESWL), ureterorenoscopy, or percutaneous nephrolithotomy [11]. In cases of severe complications or complex anatomical conditions, surgical intervention may be required.

An important stage of treatment is the prevention of recurrence, which includes maintaining adequate fluid intake, dietary modification, and metabolic monitoring.

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