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RESEARCH ARTICLE

Paediatric Urinary Tract Infections: Clinical Spectrum, Epidemiological Insights, and Therapeutic Evolution

Pranuthi Roy Jamparapu[1], Sathasivam Sivamalar[1]*, Shanmugam Saravanan[2] and Pachamuthu Balakrishnan[1]

[1]Department of Research, Meenakshi Academy of Higher Education and Research (MAHER), Chennai-600078, Tamil Nadu, India
[2]Centre for Infectious Diseases Saveetha Medical College & Hospitals [SMCH], Saveetha Institute of Medical and Technical Sciences [SIMATS], Saveetha University, Thandalam, Chennai

*Corresponding Author
Sathasivam Sivamalar

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Abstract: Urinary tract infections (UTIs) are among the most frequently diagnosed bacterial infections in children, with serious implications for health in both the short- and long-term. UTIs in children are predominantly caused by Escherichia coli, but other microbes such as Klebsiella pneumoniae, Proteus mirabilis, and Enterococcus faecalis can also cause UTIs, particularly in patients with congenital anomalies of the kidneys and urinary tract (CAKUT) or those who are immunocompromised, with the causative organism varying for each. The incidence of infection demonstrates a pattern based on age, sex, and circumcision status, with male infants representing a high-risk group (especially for uncircumcised boys), and females having an increased incidence, especially after infancy, due to their anatomy. Diagnosis of UTI can be complicated by the quiet or nonspecific nature of their clinical signs and symptoms (especially in infants), as well as safely obtaining urine samples without contamination. The usual recommendations for diagnosis include urinalysis and urine cultures - they are considered gold standards. In young children, urine should typically be collected by catheter or suprapubic aspirate. In the context of patients with at-risk kidney and urinary tract imaging studies showing anatomical abnormalities (e.g., vesicoureteral reflux, obstructive uropathies, inadequate bladder emptying), UTI risk is further elevated, and most of these patients have higher genetic and immunologic factors influencing host defences against the process of urinary tract infection. Pathogenesis process involves the three pillars of bacterial adhesion, biofilm, and toxin-induced tissue damage. Infant immune immaturity is a hindrance to clearance and leads to recurrence UTI risk. Acute sequelae like sepsis and pyelonephritis and chronic renal scarring, hypertension, and chronic kidney disease may result from UTIs. Additionally, the increase in antimicrobial resistance, particularly among uropathogenic E. coli, has complicated treatment options. New alternatives, like biomarkers, molecular diagnostics, vaccines, and probiotics, can fortify the prevention and treatment of UTIs. Distant detection, proper diagnosis, and specific treatment are necessary to reduce recurrence risk in order to preserve function and reduce long-term morbidity in this vulnerable group.

Keywords: Urinary tract Infection, Clinical Spectrum, Therapeutic evolution, Pediatrics.

INTRODUCTION

Urinary tract infections (UTIs) are the most frequent bacterial infection in children with substantial short-term morbidity and long-term renal implications (Barola et al., 2024; Yang et al., 2022). UTIs result from microorganisms' colonization and ascent of the urinary tract, leading to cystitis and, in more severe cases, pyelonephritis (Kumar Shrestha et al., 2022; Zhou et al., 2023). The most common etiologic agent of paediatric UTIs is Escherichia coli (E. coli), which causes 70% to 90% of infections (Kumar Shrestha et al., 2022). Other opportunistic pathogens, like Klebsiella pneumoniae, Proteus mirabilis, and Enterococcus faecalis also cause infection, particularly in patients with congenital anomalies of the kidneys and urinary tract (CAKUT) or other related immune risk factors (Mahmoud et al., 2024). Epidemiological evidence is such that 6% to 8% of febrile infants present with a UTI, thereby proving its clinical significance (Daniel et al., 2023; Liang et al., 2024).It is also important to note that populations of children do not experience risk in the same way: the highest risk takes place among uncircumcised male neonates while female children present a higher probability of UTI than their male peers once past the neonatal period due to anatomical predisposition (Ahmad et al., 2024). Given their high incidence, diagnostic challenges, and potential for long-term renal sequelae, the prevention through early recognition or management of UTIs is a clinically important topic in the paediatric population (Alsaywid et al., 2022).

Diagnosing urinary tract infections (UTIs) in paediatric populations can be particularly challenging because of age-specific differences that can occur in clinical presentation, as well as ability to obtain uncontaminated urine samples, which is often particularly difficult in infants and toddlers (Barola et al., 2024). While urinalysis and urine culture are the cornerstone of diagnosis, the chosen urine collection method—in particular catheterization versus suprapubic aspiration versus midstream clean-catch— may significantly influence diagnostic accuracy (Alsaywid et al., 2023). In addition, children with pyelonephritis, a renal infection, necessarily require different evaluation and potentially even treatment than for a lower urinary tract infection. The management of pyelonephritis is important because of renal scarring (Belyayeva et al.2024).

Infants and toddlers may exhibit nonspecific symptoms such as fever, irritability, or poor feeding, which can make diagnosing UTI more difficult (Sujith et al., 2024). In addition, the increasing prevalence of antibiotic-resistant uropathogens creates challenges regarding treatment strategies and decisions about the selection of antimicrobial agents (Shkalim Zemer et al., 2024; TK et al., 2024). This review will summarize the epidemiology, clinical presentations, diagnostic approaches, and management of paediatric UTIs. In addition, this review will discuss new evidence regarding risk factors, prevention strategies, and new therapeutic candidates (Barola et al., 2024; Sujith et al., 2024). By synthesizing the existing knowledge, this article aims to inform clinicians, researchers and policymakers in health and education settings about best practices related to the identification, management, and long-term care of children with UTIs.

INCIDENCE AND RECURRENCE PATTERNS

Population-based and cohort studies from 2024–2025 have reinforced that the epidemiology of infant UTIs is significantly variable by age, sex, and circumcision status, and incidence in infants under 12 months has remained constant at about 0.86–0.87 UTIs per 100 patient-years overall (Barola et al., 2024); specifically, uncircumcised males have the highest rate of 1.42 UTIs per 100 patient-years, followed by females at 0.94 UTIs per 100 patient-years, and circumcised males have the lowest rate at 0.49 UTIs per 100 patient-years (Barola et al., 2024). The risk is markedly higher for febrile infants, which adds additional risk, to 20%, to uncircumcised males under 3 months of age compared to circumcised males who have a 2.4% risk (Barola et al., 2024). Girls under 12 months and uncircumcised young boys remain the highest risk groups, however, new born boys, especially uncircumcised males, have the highest risk of UTI in the immediate neonatal period (Barola et al., 2024); subsequent prevalence in girls will be higher with increasing age. The cumulative rates of UTI risk in children prior to age seven have been reported as 8.4% for girls and 1.7% for boys (Barola et al., 2024). Recurrence, as noted above with regard to circumcision, continues to be common and relevant with 30–40% or those with a first UTI experiencing another UTI within 1 year, especially with those infants and children with physician-diagnosed vesicoureteral reflux or bladder dysfunction (Barola et al., 2024). Other risk factors for UTI include: young age, race (white), prior antibiotic use, anatomical abnormality, catheterization, and immune compromised (Barola et al., 2024). Global consideration shows even greater diversity: resource-limited environments marked significantly enhanced prevalence, with recent studies demonstrating up to 19.5% rates in febrile paediatric samples (Masu et al., 2025) and meta-analyses of the literature with estimates ranging from 4% to almost 40%, depending on patient type, age, and health care context and availability (Masu et al., 2025). These findings highlight the relevance of contextually responsive approaches to diagnosis and treatment of UTIs, paying due attention to the dynamic interactions of biological, environmental, and social factors contributing to paediatric UTI risk and outcomes, as illustrated in publications from 2024 and 2025 (Barola et al., 2024; Masu et al., 2025)

RISK FACTORS OF UTIS

Urinary tract infections (UTIs) in infants are one of the most common causes of febrile illness and UTI is responsible for approximately 7% of all febrile presentations among children under 12 months (Daniel et al., 2023). The acute effect of infection can be severe, causing systemic illness, dehydration, and, in some cases, invasive disease including bacteraemia or meningitis, particularly among neonates (Barola et al., 2024). Equally troubling, if not more so, are the long-term complications. About 15% of infants will develop renal scarring after a febrile UTI, and this can be a marker for an increased risk in the future of developing hypertension, proteinuria, and progressive CKD (Hughes et al., 2024; Rosenblad et al., 2024). In the worst cases of CKD, patients can go on to end-stage renal disease (ESRD) which can necessitate dialysis or transplant in later life (Hughes et al., 2024). One of the heavy pressures on the healthcare system also linked with repeated infection is the heightened hospitalization footprint and the expensive downstream cost of diagnostic imaging or antibiotics utilized towards the latter part of the hospital stay (Meena et al., 2024). Long-term effects of repeated infections go beyond the direct dollar price to scenarios of parental stress, fragmented family life, and a reduced quality of life for the child (Barola et al., 2024). UTIs in infants need to be viewed not simply as an acute illness but as a chronic illness with future health implications and socioeconomic impact (Yang et al., 2024).

Table 1: Urinary Tract Infection Causes, Risks, Symptoms, Management

Category	Common Findings	Important Notes	references
Infection Causes	E. coli, Klebsiella, Proteus, Enterococcus, S. aureus, Candida	E. coli most common; Candida in preterm/ICU babies	Van K *et al*.,2024
Risk Factors	Urinary tract abnormalities, weak immunity, constipation, family history	Increase chance of infection and kidney damage	Maringhini S et al.,2024

Symptoms	Fever, poor feeding, irritability, diarrhea, jaundice	Signs often nonspecific; neonates high risk of sepsis	Patel P H *et al*.,2024
Possible Complications	Sepsis, kidney scarring, high blood pressure, ESRD	Recurrent infections worsen outcomes	Petcu C T *et al*.,2021
Diagnosis & Care	Urine tests, imaging, antibiotics, hydration, preventive steps	Urine culture is gold standard; imaging detects kidney problems	Nelson Z *et al*.,2024

Anatomical and Physiological Risk Factors

Infants are especially vulnerable to urinary tract infections because of a combination of anatomical and physiological abnormalities that compromise normal urinary flow and enhance bacterial colonization (Mahmoud et al., 2024). Congenital defects, such as vesicoureteral reflux (VUR), posterior urethral valves, duplex collecting systems, and other obstructions uropathies, dramatically raise the risk of infection as they introduce settings in which urine pools, offering a medium for growth of bacteria (Mahmoud et al., 2024; Meena et al., 2024). Even without structural defects, physiology in infancy predisposes to susceptibility. For instance, the improper emptying of the bladder is a frequent occurrence among neonates because of underdeveloped detrusor muscle function, and frequent diaper usage creates an environment of warmth and moisture, which promotes bacterial growth in the perineum (Barola et al., 2024). Constipation can also cause an increase in intra-abdominal and bladder pressure, with impaired complete voiding and bacterial retention within the urinary tract (Daniel et al., 2023). Males' circumcision status also comes into play; uncircumcised new-borns have increased UTI prevalence because of the existence of the foreskin as a potential reservoir of uropathogenic bacteria (Ahmad et al., 2024). Knowledge of these factors is crucial for the identification of high-risk infants and the implementation of preventive measures like early detection of anatomical abnormalities or hygiene and voiding habits counselling (Mahmoud et al., 2024).

Genetic and Immunological Factors

Besides anatomical and physiologic contributors, both genetic and immunologic predispositions are powerful in determining infant susceptibility to UTIs. . Family history of UTI or pyelonephritis-associated renal scarring suggests inherited susceptibility, possibly mediated by polymorphisms in genes coding for innate immune receptors, such as Toll-like receptors (TLRs), and cytokines that regulate inflammatory response (Rosenblad et al., 2024). Such genetic variation could alter the ability of the urinary tract to sense and respond to bacterial invasion, leading to persistent or recurring infections (Rosenblad et al., 2024). Neonates and young infants also have immature immune systems with reduced secretory IgA, impaired neutrophil chemotaxis and phagocytosis, and reduced antimicrobial peptide synthesis such as defensins and cathelicidins (Sujith et al., 2024). These immune impairments compromise effective removal of bacteria, increasing the frequency and severity of UTIs (Barola et al., 2024). Furthermore, comorbid children, preterm infants, and malnutrition or immunodeficiency are most vulnerable to complicated infection (Daniel et al., 2023). Genetic and immune-related risk factor research could help to identify susceptible populations and inform the development of targeted preventive and therapeutic approaches, such as immunomodulation or early screening programs (Rosenblad et al., 2024).

Causative Organisms in Infant UTIs

The most common causative agent of UTI during infancy is E. coli and accounts for 50–90% of the infections (Kumar Shrestha et al., 2022). They are usually from uropathogenic lineages and carry virulence determinants such as fimbrial adhesins, toxins, and iron-acquisition systems that enhance their ability to colonize and damage the urinary tract (Zhou et al., 2023). Other gram-negative bacteria, such as K. pneumoniae, Proteus mirabilis (which is known for favouring urinary stone development), Enterobacter spp., and Pseudomonas aeruginosa, are especially linked with complicated infections or infants with congenital abnormalities (Barola et al., 2024). Gram-positive bacteria like Enterococcus faecalis, Staphylococcus aureus, and group B Streptococcus are less frequent but more often present in neonates, catheterized infants, and immunocompromised individuals (Barola et al., 2024). Fungal infections by Candida spp. can also be seen in infants with extended hospitalization, antibiotic use, or catheterizations (Barola et al., 2024).

Bacterial Mechanisms and Host Response

The infant UTI pathogenesis commences with bacterial colonization of the periurethral area, where it originates from the gastrointestinal tract (Zhou et al., 2023). Uropathogens , most notably E. coli, migrate up the urethra and adhere to the uroepithelium through adhesins like type 1 and P fimbriae. These structural elements enable bacteria to adhere firmly to surface receptors, resist urinary flushing, and initiate infection (Zhou et al., 2023). Once attached, bacteria may invade epithelial cells, develop intracellular bacterial communities, and form biofilms, which enhance persistence and resistance to host immune response and antibiotics (Zhou et al., 2023). Toxins such as haemolysins and siderophores cause tissue damage and enhance bacterial survival through the delivery of nutrients (Kumar Shrestha et al., 2022).Host response is dominated by innate immunity, with neutrophils, cytokines, and antimicrobial peptides playing central roles. However,

owing to the immaturity of these responses in the infant, bacterial clearance is impaired and recurrence is promoted (Sujith et al., 2024). This virulence-host defence imbalance explains the predominance of severe infections, bacteraemia, and renal damage within this group (Barola et al., 2024). Biomarkers such as urinary neutrophil gelatinase–associated lipocalin (uNGAL) are also proving to be very promising in assessing the extent of infection, in predicting recurrence, and in guiding early treatment (Liu et al., 2024).

Clinical Features and Diagnostic Challenges

Infant UTIs typically present with nonspecific systemic symptoms, and thus diagnosis is often challenging. The most common presentation includes fever, irritability, oral intolerance, vomiting, diarrhoea, and lethargy (Barola et al., 2024). Neonates may present with hyperbilirubinemia, failure to thrive, or signs of systemic sepsis (Barola et al., 2024). These nonspecific presentations are the cause of delayed diagnosis and development of complications. Uncommon presentations include respiratory distress, fever in febrile seizures, or repeated unexplained febrile seizure (Barola et al., 2024). In infants with intrinsic structural abnormalities such as VUR or obstructive uropathies, recurrent infections may be the first manifestation of disease (Mahmoud et al., 2024). With this diversity, clinicians need a high level of suspicion, especially in infants with fever of unknown origin (Barola et al., 2024).

Acute and Chronic UTI Complications in Infants

Infant urinary tract infection (UTI) can cause both acute and chronic complications. Acutely, UTIs can quickly ascend to systemic illness such as sepsis, bacteraemia, and less often, meningitis, especially in neonates with underdeveloped immune systems (Barola et al., 2024). Another overlooked complication is acute pyelonephritis with the potential for renal parenchymal injury or abscess formation (Belyayeva et al., 2024). Even a single UTI with fever can trigger renal scarring (Hughes et al., 2024). In the long run, recurrent UTIs and renal scarring raise the risk of hypertension, proteinuria, and chronic kidney disease (Hughes et al., 2024). About 15% of infants develop renal scars following a febrile UTI, which can affect the function of nephrons and, in certain instances, end-stage renal disease (ESRD) (Hughes et al., 2024). Moreover, repeated severe infections in early infancy have implications for growth and neurodevelopment as an indicator of the systemic severity of this infection. (Barola et al., 2024) (Figure1)**.**

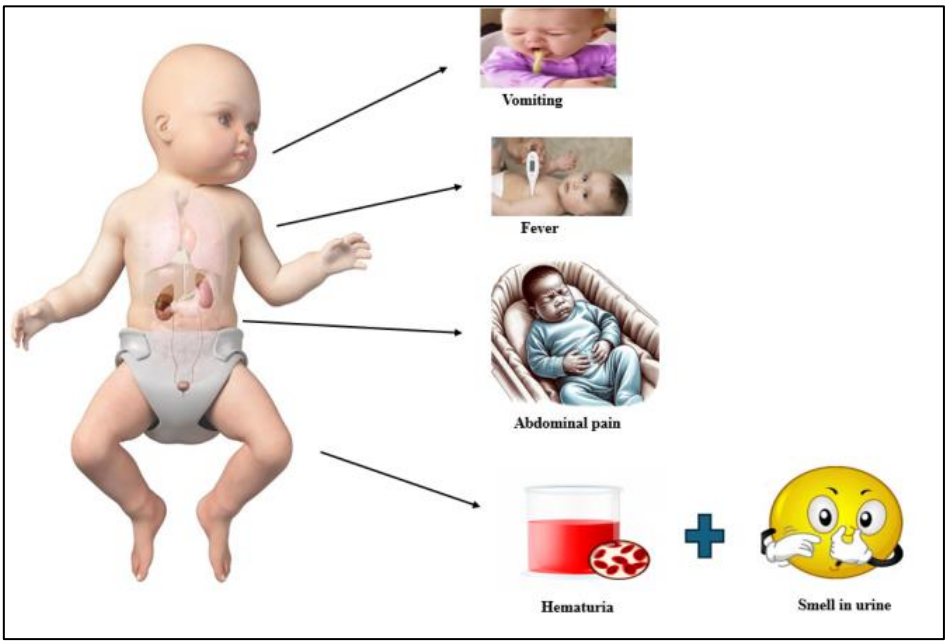

Figure1: Typical Clinical Indications of Infection of the Urinary Tract

CHALLENGES AND APPROACHES IN INFANT UTI DIAGNOSIS

Correct diagnosis of UTI in infants is important but elusive because of nonspecific presentations and difficulty in collecting uncontaminated urine samples (Barola et al., 2024). Although bag specimens are highly contaminated, catheterization and suprapubic aspiration yield good-quality specimens for culture, which is still the gold standard for diagnosis (Alsaywid et al., 2023). Screening investigations like urinalysis for leukocyte esterase and nitrites may assist in early detection, and novel molecular tests and urinary biomarkers hold promise for rapid diagnosis (Liu et al., 2024). Imaging is essential for identifying underlying structural abnormalities: renal and bladder ultrasound (RBUS) detects hydronephrosis or congenital anomalies, voiding cystourethrography (VCUG) remains the gold standard for diagnosing vesicoureteral reflux, and DMSA

scintigraphy is sensitive for detecting acute pyelonephritis and renal scarring (Aldughiem, 2025; Meena et al., 2024). These approaches collectively guide early intervention, risk stratification, and prevention of recurrent or complicated infections.

Emerging Antimicrobial Resistance in Paediatric UTIs

The increasing rate of antimicrobial resistance (AMR) in paediatric UTIs is a serious challenge to efficient control (Shkalim Zemer et al., 2024; Kılıç et al., 2025). E. coli, the most common cause, increasingly shows resistance to ampicillin, trimethoprim-sulfamethoxazole, and even third-generation cephalosporins, which are commonly applied in empirical therapy (Shkalim Zemer et al., 2024). Extended-spectrum β-lactamase (ESBL)–producing strains are rapidly on the rise all over the world, leading to scarce treatment options and prolonged hospital stays (Shkalim Zemer et al., 2024; Aqsa et al., 2025). The problem is most critical in low- and middle-income countries, where antimicrobial misuse and diminished diagnostic capacity drive resistance trends (Muteeb et al., 2023). Multidrug-resistant (MDR) and carbapenem-resistant bacterial dissemination threatens to annihilate traditional therapeutic strategies (Shkalim Zemer et al., 2024).This trend underscores the urgent necessity for antimicrobial stewardship, symbolized by appropriate use of antibiotics, therapy based on culture, and ongoing surveillance of local resistance patterns (Alkhawaldeh et al., 2022; TK et al., 2024). Research into non-antibiotic prophylactic options, like vaccines, probiotics, and immunomodulatory interventions, may have the potential to be a mainstay in preventing this new phenomenon (Xiong et al., 2024; Serrano-Arevalo et al., 2024).

CONCLUSION:

Paediatric UTIs are a significant clinical and public health problem due to their high prevalence, diagnostic subtlety, and potential for long-term renal complications. Young children and infants are particularly vulnerable due to reasons of anatomical, physiological, genetic, and immunological underpinnings, which together are determinants of increased susceptibility and complexity of management. Appropriate collection of urine, urinalysis, culture, and imaging, which are useful for early and accurate diagnosis, are necessary to prevent acute complications and chronic renal damage. The increasing prevalence of antimicrobial-resistant uropathogens indicates the necessity for responsible antibiotic use and ongoing monitoring to guide therapy. Preventive measures like hygiene, circumcision, early detection of anatomical abnormalities, and new measures such as vaccines and probiotics can prevent recurrence and improve outcomes. In conclusion, an integrated, evidence-based approach incorporating early diagnosis, individualized treatment, and preventative interventions is required to preserve renal function as well as overall health in children with UTIs.

Conflict of interest

The authors affirm that none of their known conflicting financial interests or personal connections could have an impact on the research presented in this study.

Authors Contributions

PR: Composing an initial draft, reviewing and revising it, and conducting a formal analysis. SSM: Writing, editing, and review; supervision; final draft. SS: Investigation, Formal analysis. PB: Investigation, Conceptualization.

Ethics statement

Not Applicable

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