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Clinical Interpretation of Urinalysis for Early Detection of Kidney Disorders: A Narrative Review

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ABSTRACT

Background: Chronic kidney disease (CKD) is a global health issue with a steadily increasing prevalence and often remains asymptomatic in its early stages. This silent progression contributes to delayed diagnosis and limited therapeutic options. Urinalysis is a simple, inexpensive, and noninvasive examination that remains relevant as an early screening tool to detect renal abnormalities before clinical manifestations appear. **Methods:** This narrative review summarizes the latest scientific evidence regarding the diagnostic value of urinalysis in the early detection of kidney disorders by highlighting the physical, chemical, and microscopic parameters of urine. Literature searches were conducted using PubMed, Scopus, and Google Scholar databases for studies published between 2020 and 2025 with the keywords urinalysis, kidney disease, early detection, uACR, and eGFR. Only English- or Indonesian-language articles relevant to the topic and containing empirical data were included. **Results:** Urinalysis has been shown to provide early indicators of proteinuria, hematuria, and pathological casts that reflect glomerular and tubular injury. Integration of urinalysis results with uACR and eGFR measurements, as recommended by KDIGO 2024, improves diagnostic accuracy and risk stratification. Additionally, automated digital microscopy and emerging biomarkers such as NGAL and KIM-1 show substantial potential in strengthening early detection capabilities. Urinalysis not only serves as a screening tool but also holds prognostic value in guiding follow-up and clinical management of high-risk individuals. Proper interpretation of urinalysis findings can assist clinicians in determining the need for further assessment, initiating earlier interventions, and optimizing prevention of CKD progression. **Conclusion:** Urinalysis remains an essential basic examination for the early detection of kidney impairment. Its integrated application with modern laboratory parameters can enhance diagnostic effectiveness, accelerate clinical intervention, and reduce the global burden of chronic kidney disease.

Keywords: Urinalysis; Kidney Disease; Early Diagnosis; uACR; eGFR; Biomarkers.

INTRODUCTION

Chronic kidney disease (CKD) is a global public health concern with a steadily increasing prevalence over the past two decades. According to the Global Burden of Disease Study, approximately 850 million people worldwide are estimated to have various forms of kidney impairment, and this number continues to rise in parallel with the increasing prevalence of diabetes mellitus and hypertension[1]. CKD not only heightens the risk of end-stage renal disease but also significantly contributes to cardiovascular morbidity and mortality, ultimately imposing a substantial burden on healthcare systems[2,3].

In Indonesia, national survey data show an upward trend in CKD prevalence, particularly among individuals of productive age. Consequently, the need for renal replacement therapies such as hemodialysis has markedly increased in recent years[4,5]. One of the major challenges in CKD

management is delayed diagnosis since the disease is commonly regarded as a silent condition; clinical symptoms often manifest only after extensive loss of kidney function[1]. Most patients are diagnosed at an advanced stage when therapeutic interventions are limited to dialysis or kidney transplantation[6]. Therefore, early detection and periodic monitoring of kidney function are essential to slow disease progression and improve clinical outcomes.

Urinalysis remains a fundamental yet crucial diagnostic tool for detecting renal abnormalities. This examination assesses the physical, chemical, and microscopic characteristics of urine to evaluate glomerular and tubular function and identify signs of inflammation or infection in the urinary tract[7]. Despite its simplicity, urinalysis continues to hold diagnostic value due to its noninvasive nature, cost-effectiveness, and accessibility in primary care settings. In the context of early detection, urinalysis plays a strategic role by identifying proteinuria, hematuria, and urinary sediment abnormalities indicative of kidney damage before significant changes occur in serum creatinine levels or estimated glomerular filtration rate (eGFR)[8].

Recent international guidelines, such as KDIGO 2024, emphasize the importance of routine urine testing in high-risk populations, including individuals with diabetes, hypertension, cardiovascular diseases, and those with a family history of CKD[6]. Abnormal urinalysis findings should be interpreted alongside the urine albumin-to-creatinine ratio (uACR) and eGFR to improve diagnostic accuracy and risk classification using the G–A grid framework[9]. This integrative approach is considered more effective in determining disease severity and tailoring preventive strategies to slow CKD progression on an individual basis.

In addition to conventional parameters, technological advancements have expanded the role of urinalysis in modern clinical practice. Automated digital microscopy has improved consistency and objectivity in urinary sediment interpretation, while artificial intelligence–based algorithms are increasingly being utilized to detect pathological patterns with high accuracy[10]. Emerging urinary biomarkers, such as neutrophil gelatinase–associated lipocalin (NGAL) and kidney injury molecule-1 (KIM-1), also demonstrate significant potential in detecting acute kidney injury earlier than conventional serum creatinine measurements[11,12].

Furthermore, the strong interplay between CKD and hypertension has garnered significant research attention. Hypertension is not only a major risk factor for CKD but also accelerates disease progression through increased vascular resistance and renal inflammation[13]. Blood pressure regulation is influenced by the molecular pathways of cyclooxygenase-2 (COX-2), where the –1195G/A genetic polymorphism may alter enzyme expression and exacerbate kidney injury via glomerulosclerosis and interstitial fibrosis[14,15]. Increased COX-2 activity may be reflected in urinalysis findings such as proteinuria and hematuria as early indicators of renal inflammatory involvement.

Metabolic disturbances, including hypercholesterolemia, hyperglycemia, and hyperuricemia, also have strong associations with hypertension and CKD progression. These conditions contribute to endothelial dysfunction and oxidative stress that accelerate kidney damage[16,17,18,19]. Hyperuricemia is an independent risk factor for hypertension through activation of the renin–angiotensin–aldosterone system and renal inflammation[20]. Additionally, poor nutritional knowledge and imbalanced dietary status increase metabolic risk, further elevating the likelihood of hypertension and its renal consequences[21,22]. Therefore, metabolic factors must be considered when interpreting urinalysis findings in early detection efforts, as they are interlinked components of CKD pathophysiology.

Taken together, urinalysis remains an essential tool in the early detection of renal impairment, particularly in developing countries where access to advanced diagnostic modalities is limited. Integrating urinalysis results with uACR, eGFR, and emerging digital and molecular approaches

offers opportunities to enhance diagnostic accuracy and early intervention strategies[1,6]. This narrative review aims to discuss the clinical interpretation of urinalysis in the context of early kidney disease diagnosis, elaborate on the diagnostic value of each parameter, and highlight recent innovations in clinical practice based on scientific evidence from 2020 to 2025.

MATERIALS AND METHODS

This narrative review was developed based on a comprehensive synthesis of recent international literature regarding the role of urinalysis in the early detection of kidney disorders. A systematic literature search was conducted in the PubMed, Scopus, and Google Scholar databases using the following keyword combinations: *"urinalysis"*, *"kidney disease"*, *"early detection"*, *"albumin-creatinine ratio (uACR)"*, and *"estimated glomerular filtration rate (eGFR)"*.

Inclusion criteria consisted of articles published in English between 2020 and 2025, including clinical practice guidelines, systematic reviews, meta-analyses, and original research with robust study designs. Literature addressing novel biomarkers and advancements in digital urinalysis technologies was also considered. Article selection was performed based on topic relevance, methodological quality, and contribution to clinical understanding.

RESULTS

Urinalysis consists of a series of evaluations encompassing the physical, chemical, and microscopic characteristics of urine to assess kidney function and detect abnormalities within the urinary system. Each component provides distinct yet complementary diagnostic information, ranging from the identification of visible urine changes to the detection of specific biomarkers indicative of kidney injury. Table 1 summarizes the main aspects of urinalysis, including evaluated parameters, clinical implications, and supporting scientific evidence.

DISCUSSION

Physical Examination of Urine

Physical examination of urine serves as an essential initial step in the interpretation of urinalysis, as it provides general information regarding kidney function and urinary tract integrity before chemical or microscopic analyses are performed. This examination is noninvasive, easy to perform, and highly valuable for early screening of metabolic and nephrological abnormalities. Normal urine color typically ranges from pale yellow to deep yellow, depending on the concentration of urochrome derived from hemoglobin catabolism. Deviations from normal color may signal pathological processes, such as red discoloration due to hematuria or hemoglobinuria, which is often associated with glomerular disorders, urinary tract stones, or bleeding secondary to infection[26].

In addition to color, urine clarity is an important indicator that may provide insights into infectious or metabolic conditions. Clear urine indicates normal filtration and excretion, whereas cloudy urine indicates the presence of inflammatory cells, bacteria, or precipitated crystals. Turbidity may also result from phosphate precipitation in alkaline urine or urate precipitation in acidic urine[24]. Thus, visual assessment of clarity can guide subsequent microscopic sediment examination to determine specific etiologies of turbidity.

Another important parameter is urine odor, which may help direct clinical reasoning. A strong ammonia-like odor is often linked to urinary tract infections caused by urease-producing bacteria such as *Proteus mirabilis*, whereas a fruity or sweet odor suggests the presence of ketone bodies associated with diabetic ketoacidosis [23]. Although subjective, odor assessment retains clinical relevance, especially when interpreted in conjunction with chemical dipstick findings such as positive nitrites or glucose.

Table 1. Key Aspects and Clinical Implications of Urinalysis

No.	Examination Aspect	Focus Parameters	Clinical Findings and Implications
1	Physical Examination	Color, clarity, odor, foam	Changes in urine color, such as red or brown, may indicate hematuria or hemoglobinuria due to glomerular abnormalities; cloudy urine suggests infection; persistent foaming indicates proteinuria. Physical assessment serves as an important initial step in detecting renal or urinary tract disorders prior to further analysis[23,24,25,26].
2	Chemical Analysis (Dipstick Test)	Protein, blood, nitrite, glucose, pH	Persistent proteinuria is an indicator of glomerular damage; positive nitrite and leukocyte esterase results suggest urinary tract infection; glucosuria and ketonuria signify metabolic disturbances such as diabetes; extreme pH levels reflect acid–base imbalance or urease-positive infections. This examination is fast, cost-effective, and useful as an initial screening tool for kidney disease; however, findings require confirmation using uACR and eGFR[27,28,29,30,31].
3	Microscopic Sediment Examination	Blood cells, casts, crystals	Dysmorphic red blood cells and erythrocyte casts suggest glomerulonephritis; granular “muddy brown” casts indicate acute tubular injury; specific crystals such as cystine or struvite imply nephrolithiasis or infection. Sediment analysis contributes to identifying the etiology of kidney disease and is essential for differential diagnosis[32,33,34,35].
4	Integration of Urinalysis with uACR and eGFR	uACR, eGFR, biomarkers (NGAL, KIM-1)	Combining urinalysis results with uACR and eGFR enhances diagnostic accuracy and risk stratification of CKD. Emerging biomarkers such as NGAL and KIM-1 allow earlier detection than serum creatinine-based assessments. This integrative approach is recommended by KDIGO (2024) for CKD evaluation and monitoring[6,36,37,38,39].

The final physical feature of clinical significance is urine foaming, which is frequently overlooked but has notable diagnostic value. Persistent foam after agitation indicates the presence of excess protein (proteinuria), which reflects increased permeability of the glomerular basement membrane[25]. This manifestation is commonly observed in chronic kidney disease, diabetic nephropathy, and various forms of glomerulonephritis. Overall, physical examination remains a vital component of clinical practice and public health screening because it allows for the early detection

of renal or urinary tract abnormalities and serves as an initial basis for further laboratory investigations.

Chemical Analysis (Dipstick Test)

Chemical analysis of urine using dipstick testing is a rapid, practical, and low-cost diagnostic procedure that provides semi-quantitative information on key parameters such as protein, blood, nitrite, glucose, and urine pH. This method is widely utilized in both primary care and hospital settings because it is simple to perform and does not require complex laboratory equipment. Each reagent pad on the strip detects a specific analyte through a colorimetric reaction, which is then compared to a reference chart for interpretation. Abnormal dipstick results often serve as an initial indication of renal or metabolic disorders that warrant confirmatory diagnostic evaluation[29].

One of the most clinically relevant findings from dipstick testing is proteinuria, which, when persistent, signifies glomerular damage. Proteinuria may be transient due to fever, strenuous exercise, or dehydration, but recurrent or sustained positivity reflects increased permeability of the glomerular filtration barrier. Therefore, positive dipstick protein should be confirmed using a urinary albumin-to-creatinine ratio (uACR) to differentiate physiological from pathological conditions[29]. This confirmation is essential for early detection of chronic kidney disease (CKD), particularly in individuals with risk factors such as hypertension or diabetes mellitus.

Nitrite and leukocyte esterase are commonly evaluated markers for diagnosing urinary tract infections (UTIs). A positive nitrite result indicates gram-negative bacteria capable of nitrate reduction, such as *Escherichia coli*, whereas a positive leukocyte esterase result reflects leukocyturia associated with inflammation. In addition, glucosuria and ketonuria are diagnostically important for identifying metabolic disturbances, especially diabetes mellitus and diabetic ketoacidosis[27]. Urine pH also provides valuable diagnostic insight: acidic urine is often observed in metabolic acidosis or prolonged fasting, while alkaline urine may indicate infection by urease-producing bacteria such as *Proteus* spp.[36].

With advancing technology, automated analyzers and artificial intelligence (AI)-based interpretation are increasingly applied to enhance accuracy and reduce subjective variability in dipstick assessments. Automated platforms digitally analyze color changes, minimize inter-operator variability, and shorten reporting time[30]. Furthermore, machine learning algorithms have shown improved ability to detect early CKD by leveraging longitudinal dipstick data patterns[27,28]. Therefore, while the dipstick test remains a primary and efficient screening tool for evaluating renal and urinary tract function, its findings must be confirmed using complementary assessments such as uACR and estimated glomerular filtration rate (eGFR) to achieve a comprehensive diagnostic understanding.

Microscopic Urinary Sediment Examination

Microscopic examination of urinary sediment is a critical, advanced step in urinalysis, as it enables direct identification of cellular and non-cellular elements that reflect pathological processes within the kidneys or urinary tract. This analysis is performed following urine centrifugation to allow for careful evaluation of the sediment under light microscopy. Components typically assessed include red blood cells, white blood cells, epithelial cells, casts, bacteria, fungi, and crystals. With accurate interpretation, this examination provides not only evidence of abnormality but also insights into the anatomical location and underlying mechanisms of renal injury[34].

One of the most diagnostically significant findings is the presence of dysmorphic red blood cells and erythrocyte casts, characteristic indicators of glomerular bleeding as observed in acute or

chronic glomerulonephritis. Dysmorphic red blood cells signify deformation during passage through a damaged glomerular basement membrane, while erythrocyte casts indicate their entrapment within the distal tubules facilitated by Tamm–Horsfall protein[32]. Conversely, granular "muddy brown" casts are commonly associated with acute tubular necrosis and may result from ischemia, nephrotoxic drugs, or sepsis. Differentiating these findings is essential, as glomerular versus tubular involvement has distinct therapeutic implications.

In addition to erythrocyte and granular casts, leukocyte casts serve as an important marker of renal infection or inflammation, such as pyelonephritis, whereas an increased number of tubular epithelial cells suggests tubular necrosis due to direct epithelial damage[33]. The combination of cast types and associated cellular elements provides key information about the precise site of pathology along the nephron—whether glomerular, tubular, or interstitial. Thus, microscopic evaluation must be performed systematically and correlated with clinical presentation and chemical urinalysis findings to arrive at an accurate diagnostic conclusion.

Another valuable component of sediment analysis is crystal identification, which offers insight into metabolic processes and specific pathological conditions. Calcium oxalate crystals are frequently observed in nephrolithiasis or in individuals with high oxalate intake, whereas cystine crystals are indicative of the genetic disorder cystinuria, which leads to excessive urinary cystine excretion. Struvite (magnesium ammonium phosphate) crystals, on the other hand, are typically associated with chronic urinary tract infections caused by urease-producing bacteria such as *Proteus mirabilis*[35]. Therefore, microscopic urinary sediment analysis remains an indispensable method for identifying the underlying etiology of kidney disease, providing depth and specificity that reinforce chemical and clinical assessments in establishing a comprehensive diagnosis.

Integration of Urinalysis with uACR and eGFR

Modern approaches to kidney function evaluation emphasize the integration of conventional urinalysis with quantitative assessments such as the urinary albumin-to-creatinine ratio (uACR), estimated glomerular filtration rate (eGFR), and emerging biomarkers including neutrophil gelatinase–associated lipocalin (NGAL) and kidney injury molecule-1 (KIM-1). The combination of these parameters enables a more comprehensive and precise assessment of renal function and injury. Such integration is strongly recommended by Kidney Disease: Improving Global Outcomes (KDIGO, 2024) because it enhances diagnostic accuracy and improves risk stratification for chronic kidney disease (CKD). Consequently, kidney function evaluation should no longer rely solely on serum creatinine or isolated urinalysis results, but rather utilize a multimodal and complementary diagnostic strategy.

uACR plays a key role in detecting microalbuminuria—small elevations in urinary albumin excretion that often go undetected by standard dipstick testing. Microalbuminuria is an early marker of glomerular injury, particularly in patients with diabetes mellitus or hypertension. uACR is also essential for monitoring CKD progression and evaluating response to renoprotective therapies. Meanwhile, eGFR provides a quantitative estimate of glomerular filtration rate based on serum creatinine levels combined with age, sex, and race, enabling classification of kidney function decline. The integration of uACR and eGFR supports accurate staging of CKD, prognostic predictions, and clinical decision-making for long-term management.

Advancements in biomedical science have introduced novel biomarkers such as NGAL and KIM-1, which demonstrate superior sensitivity for detecting acute kidney injury (AKI) prior to significant rises in serum creatinine. NGAL is released by tubular epithelial cells in response to stress or injury, while KIM-1 reflects proximal tubular epithelial damage and regeneration[38,39]. These

biomarkers enable earlier and more accurate diagnosis of AKI, allowing timely interventions to prevent irreversible renal damage. Additionally, findings by Trachtman et al. (2023) reported that achieving complete remission of proteinuria in patients with focal segmental glomerulosclerosis (FSGS) is strongly associated with improved long-term renal prognosis, underscoring the importance of urinary biomarker monitoring in therapeutic evaluation.

Through the integration of urinalysis, uACR, eGFR, and modern biomarkers, diagnostic strategies in nephrology have become more predictive and personalized. Urinalysis remains a foundational test that identifies macroscopic abnormalities such as hematuria, infection, or proteinuria, while chemical and microscopic analyses provide more specific etiological insights. When combined with quantitative markers and molecular biomarkers, urinalysis transforms from a simple screening tool into an integral component of a comprehensive diagnostic system for early detection, disease monitoring, and treatment response evaluation in CKD. This integrated approach not only enhances clinical precision but also supports the implementation of precision medicine in modern nephrology[6].

CONCLUSION

Urinalysis is a fundamental diagnostic test that plays a vital role in detecting, assessing, and monitoring kidney function as well as urinary tract disorders. By integrating physical, chemical, and microscopic analyses, it provides comprehensive diagnostic information ranging from macroscopic characteristics such as color and clarity to microscopic findings including pathological cells, casts, and crystals. When combined with quantitative biomarkers such as uACR and eGFR and supported by advancements in automation and artificial intelligence, urinalysis demonstrates improved accuracy, efficiency, and clinical applicability. Therefore, it serves not only as an early screening tool but also as an essential component of modern diagnostic systems for the early detection and continuous monitoring of kidney diseases.

Competing Interests

The authors declare that they have no financial or non-financial conflicts of interest that could have influenced the content or outcomes of this article. They are solely responsible for the accuracy, integrity, and presentation of the data and interpretations provided, and no funding or external affiliations affected the research.

Authors' contributions

All authors contributed equally to the conceptualization, literature review, data acquisition and analysis, manuscript drafting, and critical revisions. All authors have reviewed, approved the final manuscript, and agreed to be accountable for all aspects of the work, ensuring its accuracy and integrity.

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