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# RENAL FIBROSIS IN CHRONIC KIDNEY DISEASE: RADIOLOGICAL IMAGING MARKERS AND PREDICTIVE VALUE

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**Resume.** Renal fibrosis plays a central role in the development and progression of chronic kidney disease (CKD) and ultimately leads to irreversible loss of renal function. Early detection of fibrotic changes is important for assessing disease prognosis and selecting appropriate management strategies. In this context, radiological imaging methods are increasingly used as non-invasive tools for evaluating structural and functional changes in renal tissue.

This review summarizes the main radiological markers of renal fibrosis identified by ultrasound and computed tomography. These include reduced kidney size, cortical thinning, increased parenchymal echogenicity, altered renal blood flow, and increased tissue stiffness. The association of these imaging findings with CKD stage and clinical parameters is highlighted.

Radiological markers show significant prognostic value and may be useful for early detection of renal fibrosis, risk stratification, and follow-up of patients with CKD. Their use contributes to improved diagnostic accuracy and better prediction of disease progression.

**Keywords:** renal fibrosis; chronic kidney disease; radiological markers; ultrasound; computed tomography; elastography; imaging; prognosis.

# ПОЧЕЧНЫЙ ФИБРОЗ ПРИ ХРОНИЧЕСКОЙ БОЛЕЗНИ ПОЧЕК: РАДИОЛОГИЧЕСКИЕ МАРКЕРЫ ВИЗУАЛИЗАЦИИ И ИХ ПРОГНОСТИЧЕСКОЕ ЗНАЧЕНИЕ

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**Резюме.** Резюме. Почечный фиброз играет ключевую роль в развитии и прогрессировании хронической болезни почек (ХБП) и со временем приводит к снижению функции почек. Раннее выявление фиброзных изменений важно для оценки прогноза заболевания и выбора правильной тактики лечения. В связи с этим методы лучевой диагностики всё чаще используются как неинвазивные способы оценки состояния почечной ткани.

В обзоре рассматриваются основные радиологические маркеры почечного фиброза, выявляемые при ультразвуковом исследовании и компьютерной томографии. К ним относятся уменьшение размеров почек, истончение коркового слоя, повышение эхогенности паренхимы, изменения почечного кровотока и увеличение жёсткости ткани. Отмечается связь этих признаков со стадией ХБП и клиническими показателями.

Показано, что радиологические маркеры могут быть полезны для раннего выявления фиброза, оценки риска прогрессирования заболевания и наблюдения за пациентами в динамике. Их использование помогает улучшить диагностику и прогнозирование течения ХБП.

**Ключевые слова:** почечный фиброз; хроническая болезнь почек; радиологические маркеры; ультразвуковое исследование; компьютерная томография; эластография; визуализация; прогнозирование.

**Introduction.** Chronic kidney disease (CKD) is a major global health problem associated with high morbidity, mortality, and healthcare costs. The disease is characterized by a progressive decline in renal function, often leading to end-stage renal disease. Regardless of the initial cause, renal fibrosis represents the final common pathological pathway of CKD progression. It is marked by excessive accumulation of extracellular matrix, tubular atrophy, and

irreversible structural damage to the renal parenchyma.

Early detection of renal fibrosis is crucial for predicting disease progression and optimizing patient management. Although renal biopsy remains the gold standard for diagnosing fibrosis, its invasive nature, risk of complications, and limited feasibility for repeated assessments restrict its routine use. As a result, non-invasive imaging techniques have gained increasing attention as potential tools for evaluating renal fibrosis and monitoring CKD progression.

This review focuses on radiological markers of renal fibrosis identified by ultrasound and computed tomography (CT) and discusses their clinical and prognostic significance in patients with CKD.

Renal fibrosis develops as a consequence of sustained inflammation, ischemia, and activation of profibrotic signaling pathways. Key cellular mechanisms include activation of fibroblasts and myofibroblasts, epithelial-to-mesenchymal transition, and increased production of collagen and other extracellular matrix components. These processes lead to stiffening of renal tissue, disruption of normal microarchitecture, and progressive loss of nephron function.

As fibrosis advances, structural changes become detectable by imaging modalities, providing an opportunity for non-invasive assessment of disease severity.

Ultrasound is widely used as the first-line imaging modality in CKD due to its accessibility, safety, and low cost. Reduced kidney length and volume are well-recognized indicators of chronic irreversible renal damage. Cortical thinning reflects loss of functional nephrons and correlates with the degree of interstitial fibrosis.

Increased renal parenchymal echogenicity compared to the liver or spleen is a common ultrasound finding in CKD. This change is associated with fibrotic tissue replacement and correlates with histological fibrosis and declining glomerular filtration rate (GFR).

Doppler ultrasound provides functional information on renal perfusion. Elevated resistive index (RI) values reflect increased vascular resistance caused by interstitial fibrosis and vascular remodeling. Several studies have demonstrated a relationship between increased RI and disease severity, as well as adverse renal outcomes.

Elastography is an emerging technique that measures tissue stiffness. Since fibrotic tissue is mechanically stiffer than normal parenchyma, elastography has shown promising results in detecting and quantifying renal fibrosis. Increased renal stiffness has been associated with advanced CKD stages and reduced renal function, suggesting its potential role as a quantitative imaging biomarker.

Computed tomography allows detailed anatomical evaluation of the kidneys and surrounding structures. In CKD patients, CT may reveal reduced renal size, cortical thinning, and parenchymal atrophy, which indirectly reflect fibrotic changes.

Non-contrast CT is commonly used to avoid nephrotoxic contrast agents. Changes in parenchymal density and structural heterogeneity have been investigated as potential markers of chronic damage. Although CT provides less functional information than ultrasound, it remains valuable in complex diagnostic cases and in patients with inconclusive ultrasound findings.

Radiological markers of renal fibrosis have demonstrated significant prognostic value. Imaging findings such as cortical thinning, increased echogenicity, elevated resistive index, and increased tissue stiffness correlate with faster decline in renal function and higher risk of progression to advanced CKD stages.

Non-invasive imaging allows repeated assessments over time, making it useful for monitoring disease progression and evaluating treatment response. Integration of radiological markers with clinical and laboratory data enhances risk stratification and supports personalized patient management.

The use of radiological imaging in the assessment of renal fibrosis provides clinicians with valuable information beyond traditional laboratory parameters. Ultrasound, particularly when combined with Doppler and elastography, offers a practical and effective approach for

routine clinical practice.

Future research should focus on standardization of imaging protocols, validation of quantitative imaging biomarkers, and correlation with histopathological findings. Advances in imaging technology and artificial intelligence may further improve the accuracy and reproducibility of fibrosis assessment.

The increasing prevalence of chronic kidney disease worldwide highlights the urgent need for reliable, non-invasive tools to assess renal damage and predict disease progression. Radiological imaging plays an important role in routine clinical practice, as it allows repeated evaluation of renal structure and function without the risks associated with invasive procedures. The identification of imaging-based markers of renal fibrosis has significant clinical implications for nephrologists, radiologists, and healthcare systems.

In daily practice, ultrasound remains the most accessible and widely used imaging modality for patients with CKD. Conventional ultrasound parameters such as kidney size, cortical thickness, and parenchymal echogenicity provide valuable baseline information and help differentiate acute from chronic renal pathology. When combined with Doppler assessment, ultrasound can also offer insights into renal hemodynamics, allowing indirect evaluation of microvascular damage associated with fibrosis. These findings are particularly useful in patients with advanced CKD, where laboratory markers alone may not fully reflect structural disease severity.

The integration of ultrasound elastography into clinical workflows represents an important step toward quantitative assessment of renal fibrosis. Elastography has the potential to detect subtle changes in tissue stiffness before irreversible structural damage becomes apparent on conventional imaging. This may allow earlier identification of high-risk patients and facilitate timely therapeutic interventions aimed at slowing disease progression. Moreover, elastography can be repeated over time, making it a promising tool for monitoring treatment response and disease dynamics.

From a prognostic perspective, radiological markers can assist in risk stratification of CKD patients. Imaging findings associated with advanced fibrosis have been linked to faster decline in renal function, increased likelihood of progression to end-stage renal disease, and poorer overall outcomes. Incorporating imaging data into clinical decision-making may help clinicians individualize follow-up intervals, optimize therapeutic strategies, and identify patients who may benefit from closer monitoring or early referral for renal replacement therapy planning.

Computed tomography, although less frequently used due to radiation exposure and contrast-related risks, retains an important role in selected clinical scenarios. Non-contrast CT can provide detailed anatomical information when ultrasound findings are inconclusive or limited by patient-related factors such as obesity or bowel gas. CT-based structural markers of chronic damage may complement ultrasound findings and contribute to a more comprehensive assessment of renal fibrosis in complex cases.

Despite these advantages, several challenges remain. One major limitation is the lack of standardized imaging protocols and universally accepted cutoff values for radiological markers of renal fibrosis. Variability in equipment, operator experience, and measurement techniques can affect reproducibility and limit comparison between studies. Therefore, large-scale, multicenter studies are needed to validate imaging biomarkers and establish standardized reference ranges.

Future perspectives in this field include the integration of advanced imaging techniques, such as multiparametric ultrasound, texture analysis, and machine learning–based image interpretation. Artificial intelligence may help identify subtle imaging patterns associated with early fibrosis and improve diagnostic accuracy while reducing operator dependence. Combining radiological markers with clinical, laboratory, and molecular data may lead to the development of comprehensive predictive models for CKD progression.

Ultimately, the goal is to move toward a more personalized approach to CKD management, where imaging biomarkers of renal fibrosis guide clinical decisions, improve

prognostication, and support timely intervention. Continued collaboration between radiologists, nephrologists, and researchers will be essential to translate these advances into routine clinical practice.

**Conclusion.** Renal fibrosis is a fundamental pathological process underlying the progression of chronic kidney disease and represents a key determinant of long-term renal outcomes. While renal biopsy remains the reference standard for fibrosis assessment, its limitations necessitate the use of non-invasive alternatives in routine clinical care.

Radiological imaging, particularly ultrasound with Doppler and elastography, provides valuable structural and functional information that reflects the extent of fibrotic changes in the renal parenchyma. Computed tomography serves as a complementary tool in selected cases, offering detailed anatomical assessment when ultrasound is insufficient. Radiological markers demonstrate significant prognostic value and contribute to early detection, risk stratification, and longitudinal monitoring of patients with CKD.

Advances in imaging technologies and data analysis hold promise for improving the accuracy and clinical utility of non-invasive fibrosis assessment. The integration of radiological markers into multidisciplinary CKD management may enhance diagnostic precision, support personalized treatment strategies, and ultimately improve patient outcomes. Further research and standardization efforts are required to fully establish imaging-based biomarkers as routine tools in the evaluation of renal fibrosis.

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