The Role of Imaging and Laboratory Markers in Monitoring Chronic Kidney Disease Progression and the Impact of Pharmacological Interventions

Eman Q. Almutairi[1], Rehab S. Alsunaidi[2], Sarah M. Alotaibi[3], Ruba K. Alhammad[4], Aminah K. Alanazi[5], Maryam H. Aldossari[6], Husam A. Altahan[7], Afnan D. Alotaibi[8], Zahra A. Asiri[9]

Health Affairs at the Ministry of National Guard

Abstract

Background: Chronic Kidney Disease (CKD) is a progressive condition that requires comprehensive monitoring to prevent further decline in kidney function. This study investigates the role of imaging and laboratory markers in monitoring CKD progression and evaluates the impact of pharmacological interventions.

Methods: A retrospective cohort study was conducted in a tertiary hospital involving 200 CKD patients. Laboratory markers (eGFR, creatinine) and imaging (ultrasound, MRI) were used to assess CKD progression. Pharmacological treatments, including ACE inhibitors, ARBs, and SGLT2 inhibitors, were analyzed for their effectiveness in slowing disease progression.

Results: Significant correlations were found between eGFR decline and kidney size reduction ($r = 0.68$, $p < 0.001$). Patients treated with SGLT2 inhibitors had a slower eGFR decline (1.3 mL/min/1.73 m²/year) compared to those on ACE inhibitors/ARBs (2.5 mL/min/1.73 m²/year). Imaging revealed structural changes, with 65% of patients experiencing kidney size reduction and 45% showing increased fibrosis. Pharmacist-led interventions improved treatment adherence and reduced complications.

Conclusion: Integrating laboratory markers with imaging provides a comprehensive assessment of CKD progression. SGLT2 inhibitors significantly slowed disease progression, and pharmacist involvement enhanced patient outcomes, underscoring the importance of a multidisciplinary approach to CKD management.

Keywords: Chronic Kidney Disease, eGFR, imaging, SGLT2 inhibitors, ACE inhibitors, pharmacological interventions, kidney fibrosis

Introduction

Chronic Kidney Disease (CKD) is a progressive condition characterized by the gradual loss of kidney function, often leading to end-stage renal disease (ESRD) if not properly managed. Globally, CKD affects approximately 10% of the population, making it a significant public health concern (Jha et al., 2013). CKD progression can result in severe complications, including cardiovascular disease, increased mortality, and the need for dialysis or kidney transplantation (Go et al., 2004). Early detection and continuous monitoring of CKD progression are critical to improving patient outcomes and delaying the need for renal replacement therapy.

The primary tools for monitoring CKD include laboratory markers, such as serum creatinine and estimated glomerular filtration rate (eGFR), which are commonly used to assess kidney function (Levey et al., 2007). These markers provide valuable information about the filtration efficiency of the kidneys, allowing clinicians to track disease progression. However, laboratory markers alone may not detect early structural changes in the kidneys that could signal more rapid progression. This limitation highlights the need to integrate imaging techniques with laboratory data to gain a more comprehensive understanding of CKD (Matsushita et al., 2015).

Radiological imaging, such as ultrasound and magnetic resonance imaging (MRI), plays a crucial role in assessing kidney morphology and detecting structural abnormalities, such as fibrosis, cysts, and kidney size changes, which are often associated with CKD progression (Meola et al., 2016). Imaging can complement laboratory data by providing insights into physical alterations in the kidney that may not yet affect function but could indicate potential future decline. Combining these tools allows for more accurate monitoring and personalized treatment approaches for CKD patients.

Pharmacological interventions, particularly angiotensin-converting enzyme (ACE) inhibitors, angiotensin II receptor blockers (ARBs), and newer agents like sodium-glucose co-transporter-2 (SGLT2) inhibitors, are essential in managing CKD and slowing its progression (Neuen et al., 2019). These therapies help to reduce proteinuria, lower blood pressure, and preserve kidney function, particularly in patients with comorbid conditions like diabetes and hypertension. However, the effectiveness of these treatments can vary between patients, making close monitoring through both lab markers and imaging critical for adjusting therapies and optimizing outcomes.

This study aims to investigate how the integration of laboratory markers and imaging techniques can enhance the monitoring of CKD progression and assess the impact of pharmacological interventions. By understanding the relationship between functional and structural changes in the kidneys, clinicians can improve patient management and slow disease progression.

Literature Review

1. Chronic Kidney Disease (CKD) Progression: An Overview

Chronic Kidney Disease (CKD) is a long-term condition characterized by a gradual decline in kidney function. CKD progresses through five stages, with end-stage renal disease (ESRD) being the final stage, requiring dialysis or kidney transplantation (Levey et al., 2007). The global burden of CKD has increased over the past decades, with the condition affecting millions of individuals worldwide. Factors such as diabetes, hypertension, and cardiovascular disease are the most common contributors to CKD progression (Jha et al., 2013).

Understanding CKD progression is crucial for early intervention to prevent complications and delay progression. However, detecting early kidney damage remains challenging, as patients may be asymptomatic until kidney function significantly declines (Levey et al., 2007). Therefore, reliable tools for monitoring CKD progression are essential for ensuring timely pharmacological intervention and optimal patient outcomes.

2. Laboratory Markers in Monitoring CKD

Laboratory markers such as serum creatinine, estimated glomerular filtration rate (eGFR), and urine albumin-to-creatinine ratio (ACR) are commonly used to assess kidney function and monitor CKD

progression. eGFR is the most widely used indicator, providing an estimate of kidney function based on creatinine levels, age, gender, and race (Matsushita et al., 2015). A decline in eGFR reflects worsening kidney function and advancing CKD. Similarly, elevated serum creatinine levels are indicative of decreased filtration capacity.

However, laboratory markers alone have limitations in detecting early structural damage in the kidneys. Studies show that eGFR can remain relatively stable even as kidney damage progresses at the tissue level (Meola et al., 2016). This discrepancy highlights the need for complementary diagnostic methods, such as imaging, to provide a more accurate representation of kidney health.

Urine ACR is another key marker used to detect albuminuria, which is often an early sign of kidney damage. The presence of albumin in urine correlates with a higher risk of CKD progression and cardiovascular complications (Peralta et al., 2011). However, just like creatinine and eGFR, urine ACR primarily reflects functional impairment and may not capture early structural changes.

3. Role of Radiological Imaging in CKD Monitoring

While laboratory tests are effective at measuring kidney function, imaging techniques are invaluable for detecting structural changes in the kidneys that may not be reflected in laboratory values. Ultrasound is the most commonly used imaging tool in CKD monitoring due to its non-invasive nature and widespread availability. It provides key information about kidney size, cortical thickness, and the presence of cysts or other abnormalities (Webster et al., 2017).

Studies have shown that kidney size decreases as CKD progresses, and ultrasound can detect this reduction, particularly in advanced stages. Renal ultrasound is also helpful in identifying secondary causes of CKD, such as polycystic kidney disease or hydronephrosis, which can affect treatment decisions (Meola et al., 2016).

In addition to ultrasound, Magnetic Resonance Imaging (MRI) and Magnetic Resonance Angiography (MRA) are advanced imaging modalities that provide detailed insights into kidney morphology and renal blood flow. MRI can detect subtle changes, such as fibrosis and scarring, that are critical indicators of CKD progression (Buchanan et al., 2022). These findings can help guide treatment strategies, as structural damage often correlates with a faster decline in kidney function.

Combining imaging with laboratory markers offers a more comprehensive approach to CKD monitoring. For instance, a study by Cao et al. (2017), demonstrated that integrating ultrasound findings with eGFR values provided more accurate predictions of CKD progression compared to relying on eGFR alone. This suggests that imaging could play a key role in enhancing the accuracy of CKD assessments.

4. Pharmacological Interventions in CKD Management

Pharmacological interventions are critical for slowing CKD progression and managing its complications. The most commonly used medications include angiotensin-converting enzyme (ACE) inhibitors and angiotensin II receptor blockers (ARBs), both of which help to reduce proteinuria and blood pressure, thus slowing kidney damage (Kolesnyk et al., 2010). ACE inhibitors and ARBs have been shown to delay CKD progression, particularly in patients with comorbid conditions like diabetes or hypertension (Kellum et al., 2012).

Recent studies highlight the role of newer pharmacological agents, such as sodium-glucose co-transporter 2 (SGLT2) inhibitors, in managing CKD. Originally developed for type 2 diabetes, SGLT2 inhibitors have demonstrated renal protective effects by reducing proteinuria and lowering the rate of eGFR decline (Neuen et al., 2019). Trials like CREDENCE and DAPA-CKD have shown that these drugs can significantly reduce the risk of kidney failure, making them a promising option for CKD patients, even those without diabetes (Heerspink et al., 2021).

Additionally, mineralocorticoid receptor antagonists (MRAs) such as spironolactone and eplerenone have been found to offer benefits in reducing proteinuria and delaying CKD progression, particularly in patients who are already receiving standard treatments with ACE inhibitors or ARBs (Bianchi et al., 2006). However, these treatments require close monitoring due to their potential side effects, particularly hyperkalemia.

5. Multidisciplinary Approaches in CKD Monitoring and Treatment

A growing body of evidence supports the need for a multidisciplinary approach in managing CKD, integrating laboratory testing, imaging, and pharmacological treatments to ensure comprehensive monitoring and timely interventions. The combination of functional markers (eGFR, creatinine, ACR) with structural assessments through imaging can provide clinicians with a fuller picture of disease progression and help tailor treatment strategies more effectively (Buchanan et al., 2022).

Multidisciplinary care models have been shown to improve outcomes for CKD patients, particularly when they involve collaboration between nephrologists, radiologists, and clinical pharmacists (Heerspink et al., 2021). Such models enable more personalized care, allowing clinicians to make informed decisions based on both functional and structural kidney assessments.

Methodology

1. Study Design

This study employed a retrospective cohort design to investigate the relationship between imaging findings, laboratory markers, and the effectiveness of pharmacological interventions in patients with Chronic Kidney Disease (CKD). The study was conducted at a tertiary care center with a dedicated nephrology unit. The study period extended during which patients with diagnosed CKD were monitored through regular laboratory tests, imaging assessments, and pharmacological treatment.

2. Study Setting

The study took place in the nephrology department of Tertiary Hospital , which serves a large population of CKD patients. The hospital's integrated diagnostic and imaging departments provided access to ultrasound, magnetic resonance imaging (MRI), and a comprehensive range of laboratory testing facilities. The pharmacology department collaborated closely with nephrologists to manage CKD pharmacotherapy, including prescribing and monitoring ACE inhibitors, ARBs, and SGLT2 inhibitors.

3. Participants

The study analyzed data from 200 adult CKD patients who were regularly monitored at the hospital over the study period.

Inclusion Criteria:

- Patients aged 18 years or older.

- Diagnosed with CKD (stages 2-4) based on eGFR values.
- Undergoing regular follow-up with both laboratory tests (e.g., eGFR, creatinine, ACR) and imaging (ultrasound or MRI).
- Receiving pharmacological treatment, including ACE inhibitors, ARBs, SGLT2 inhibitors, or other CKD-related medications.

Exclusion Criteria:
- Patients with a history of kidney transplantation or on dialysis at the start of the study.
- Patients with incomplete medical records, particularly missing imaging data or laboratory results.
- Pregnant women or individuals with contraindications to the pharmacological treatments under study.

4. Data Collection

Data were retrospectively extracted from the hospital's electronic health record (EHR) system. The following variables were collected for each patient:

4.1. Laboratory Data:
- eGFR: Estimated glomerular filtration rate was recorded at baseline and at each follow-up visit to assess kidney function decline over time.
- Serum creatinine: Creatinine levels were used in conjunction with eGFR to monitor kidney function.
- Urine albumin-to-creatinine ratio (ACR): ACR was used to assess proteinuria, an important marker of CKD progression.
- Other biomarkers: Serum potassium and sodium were collected to monitor electrolyte imbalances that might arise due to pharmacological treatment.

4.2. Imaging Data:
- Ultrasound: Kidney size, cortical thickness, and evidence of cysts or hydronephrosis were recorded from baseline and follow-up ultrasounds.
- MRI: In patients undergoing MRI, detailed assessment of fibrosis, scarring, and renal blood flow was documented, especially in patients where ultrasound findings were inconclusive or insufficient.
- Imaging intervals: Baseline imaging and follow-up imaging were compared over time to assess structural changes.

4.3. Pharmacological Treatment:
- ACE inhibitors or ARBs: Dosage, frequency, and duration of treatment were recorded for each patient.
- SGLT2 inhibitors: Initiation, dosage, and treatment adherence were documented, particularly for diabetic CKD patients.
- Other medications: Information on the use of diuretics, mineralocorticoid receptor antagonists (MRAs), and any changes in pharmacological therapy were noted.
- Pharmacist interventions: Any dose adjustments or therapy modifications made by pharmacists based on lab and imaging results were also recorded.

4.4. Patient Outcomes:
- CKD progression: The primary outcome was the rate of decline in eGFR over the study period.
- Imaging findings: Structural changes, such as reduced kidney size, increased fibrosis, or the development of cysts, were noted as secondary outcomes.

- Pharmacological efficacy: The impact of pharmacological interventions on CKD progression was evaluated by comparing eGFR decline and imaging findings in patients receiving different treatment regimens.

5. Data Analysis

Data were analyzed using SPSS software. The following statistical methods were employed:

5.1. Descriptive Statistics:

- Baseline patient demographics (age, gender, comorbidities), laboratory results, imaging findings, and pharmacological treatments were summarized using means, standard deviations, and percentages.

5.2. Correlation Between Laboratory and Imaging Findings:

- Pearson's correlation coefficient was used to assess the relationship between changes in eGFR and imaging findings (e.g., kidney size, cortical thickness, fibrosis) over time.

5.3. Impact of Pharmacological Interventions:

- A comparison of CKD progression (rate of eGFR decline) was made between patients receiving ACE inhibitors/ARBs and those on SGLT2 inhibitors using analysis of variance (ANOVA).
- Kaplan-Meier survival curves were used to assess the time to a significant decline in kidney function (eGFR <30 mL/min/1.73 m^2) in different pharmacological treatment groups.

5.4. Multivariate Analysis:

- A multivariate regression model was used to identify predictors of CKD progression, including age, comorbidities (e.g., diabetes, hypertension), baseline eGFR, and imaging findings (e.g., fibrosis or reduced kidney size).

6. Ethical Considerations

Ethical approval was obtained from the ethics committee. As this was a retrospective study, informed consent was waived. All patient data were de-identified prior to analysis to ensure confidentiality and compliance with data protection regulations. Access to patient records was restricted to the research team, and data were stored securely.

7. Trustworthiness and Rigor

To ensure data reliability, two independent researchers performed the data extraction and validation process. Any discrepancies in data collection were resolved by consensus. The accuracy of the statistical analysis was verified by a senior statistician, ensuring that all results were robust and reproducible. The use of both imaging and laboratory markers provided a comprehensive approach to CKD monitoring, reducing the risk of bias due to reliance on a single diagnostic method.

Findings

This study analyzed data from 200 patients diagnosed with Chronic Kidney Disease (CKD) and monitored through laboratory markers (eGFR, creatinine, ACR), imaging (ultrasound, MRI), and pharmacological interventions (ACE inhibitors, ARBs, SGLT2 inhibitors). The findings highlight correlations between laboratory and imaging results, the progression of CKD, and the effectiveness of different pharmacological treatments in slowing disease progression.

1. Patient Demographics and Baseline Characteristics

Table 1 summarizes the demographic and clinical characteristics of the study population. The mean age of the patients was 60.7 years, with a slightly higher prevalence of CKD in males. The majority of patients had comorbidities such as hypertension and diabetes, which are known risk factors for CKD progression.

Table 1: Patient Demographics and Baseline Characteristics

Characteristic	Total (n=200)
Age (mean ±SD)	60.7 ±12.3
Gender (Male)	108 (54%)
CKD Stage	
- Stage 2	48 (24%)
- Stage 3	92 (46%)
- Stage 4	60 (30%)
Comorbidities	
- Hypertension	152 (76%)
- Diabetes	96 (48%)
- Cardiovascular Disease	45 (22.5%)
Pharmacological Treatment	
- ACE inhibitors/ARBs	130 (65%)
- SGLT2 inhibitors	70 (35%)

2. Correlation Between Laboratory Markers and Imaging Findings

Changes in eGFR and creatinine were compared with structural changes observed through imaging, such as kidney size reduction and cortical thinning. The correlation analysis between laboratory markers and imaging findings revealed a significant relationship between eGFR decline and reduced kidney size, especially in patients with stage 3 and 4 CKD.

Table 2: Correlation between Laboratory Markers and Imaging Findings

Parameter	Correlation Coefficient (r)	p-value
eGFR vs. Kidney Size	0.68	<0.001
eGFR vs. Cortical Thickness	0.63	<0.01
Creatinine vs. Kidney Size	-0.59	<0.01
ACR vs. Kidney Size	-0.42	<0.05

Key Findings:

- A strong positive correlation ($r = 0.68$, $p < 0.001$) was observed between eGFR and kidney size, indicating that patients with declining kidney function also experienced a significant reduction in kidney size, particularly in later stages of CKD.
- Cortical thinning was moderately correlated with eGFR decline ($r = 0.63$, $p < 0.01$), suggesting that structural damage progressed alongside functional impairment.
- Creatinine levels were inversely correlated with kidney size ($r = -0.59$, $p < 0.01$), further supporting the relationship between increasing creatinine and worsening kidney structure.

3. Impact of Pharmacological Interventions on CKD Progression

The efficacy of pharmacological interventions in slowing CKD progression was assessed by comparing eGFR decline and creatinine changes over time between patients treated with ACE inhibitors/ARBs and those treated with SGLT2 inhibitors. Table 3 summarizes the rate of eGFR decline in these two treatment groups.

Table 3: Impact of Pharmacological Treatment on CKD Progression

Treatment	Mean eGFR Decline (mL/min/1.73 m²/year)	Creatinine Increase (mg/dL/year)
ACE inhibitors/ARBs	2.5 ±0.6	0.20 ±0.04
SGLT2 inhibitors	1.3 ±0.4	0.10 ±0.03

Key Findings:

- Patients treated with SGLT2 inhibitors showed a significantly slower decline in eGFR (1.3 mL/min/1.73 m²/year) compared to those treated with ACE inhibitors/ARBs (2.5 mL/min/1.73 m²/year).
- Creatinine levels increased more slowly in patients on SGLT2 inhibitors, with an average increase of 0.10 mg/dL per year, compared to 0.20 mg/dL per year in those on ACE inhibitors/ARBs.
- These results suggest that SGLT2 inhibitors may provide better protection against CKD progression, particularly in patients with diabetes.

4. Imaging Changes Over Time

Imaging findings over time showed structural changes in the kidneys, particularly in patients with stage 3 and 4 CKD. Table 4 presents the percentage of patients with significant changes in kidney size and cortical thickness during the follow-up period.

Table 4: Imaging Changes in CKD Patients over Time

Imaging Parameter	% of Patients with Significant Change
Kidney Size Reduction	65%
Cortical Thinning	52%
Development of Cysts	18%
Increased Fibrosis (MRI)	45%

Key Findings:

- A majority of patients (65%) experienced a significant reduction in kidney size, particularly those in stage 3 and 4 CKD.
- Cortical thinning was observed in 52% of patients, correlating with functional decline as measured by eGFR.
- Increased fibrosis, detected through MRI, was present in 45% of patients, often preceding further structural deterioration.

5. Pharmacist Interventions and Treatment Adjustments

Pharmacist interventions played a key role in managing CKD progression by adjusting dosages and ensuring treatment adherence. Table 5 highlights the impact of pharmacist-led interventions on patient outcomes, including reductions in treatment-related complications.

Table 5: Impact of Pharmacist Interventions on CKD Management

Intervention	Number of Patients (n, %)	Improved Adherence (n, %)	Reduced Complications (n, %)
Dose Adjustments	60 (30%)	50 (83.3%)	45 (75%)
Therapy Modifications	40 (20%)	32 (80%)	30 (75%)

Key Findings:

- Pharmacist interventions, such as dose adjustments and therapy modifications, significantly improved treatment adherence (83.3%) and reduced complications (75%), highlighting the importance of multidisciplinary care in managing CKD.

Discussion

This study investigated the relationship between laboratory markers, radiological imaging, and pharmacological interventions in monitoring the progression of Chronic Kidney Disease (CKD). The results demonstrate a significant correlation between functional markers, such as eGFR and creatinine, and structural changes observed through imaging, including kidney size reduction and cortical thinning. Furthermore, pharmacological treatments, especially SGLT2 inhibitors, showed a significant impact in slowing CKD progression compared to ACE inhibitors and ARBs.

1. Correlation between Laboratory Markers and Imaging

The findings reveal a strong correlation between eGFR and kidney size ($r = 0.68$, $p < 0.001$), indicating that as kidney function declines, there is a corresponding reduction in kidney size, particularly in patients with stage 3 and 4 CKD. These results align with previous studies that suggest kidney size and cortical thickness are reliable indicators of CKD progression (Meola et al., 2016). The moderate correlation between eGFR and cortical thickness ($r = 0.63$, $p < 0.01$) further supports the use of imaging as a complementary tool for assessing kidney damage.

The inverse relationship between creatinine and kidney size ($r = -0.59$, $p < 0.01$) highlights the importance of combining functional and structural assessments to obtain a comprehensive understanding of CKD progression. Creatinine levels increase as kidney function declines, reflecting the reduced capacity of the kidneys to filter waste. However, this study shows that relying solely on lab markers like creatinine may overlook significant structural damage that is detected through imaging.

These findings emphasize the need for integrating both laboratory and imaging data in CKD management. While eGFR and creatinine are essential for tracking functional decline, imaging provides critical insights into physical changes in the kidneys that may not be immediately reflected in lab values. This dual approach enhances early detection of CKD progression and facilitates timely intervention.

2. Efficacy of Pharmacological Interventions

One of the key findings of this study is the superior efficacy of SGLT2 inhibitors in slowing CKD progression compared to ACE inhibitors and ARBs. Patients treated with SGLT2 inhibitors experienced a slower rate of eGFR decline (1.3 mL/min/1.73 m^2/year) compared to those on ACE inhibitors/ARBs (2.5 mL/min/1.73 m^2/year). These results are consistent with clinical trials such as DAPA-CKD and

CREDENCE, which demonstrated the renoprotective effects of SGLT2 inhibitors, even in patients without diabetes (Heerspink et al., 2021).

The lower rate of creatinine increase in patients on SGLT2 inhibitors further supports their role in preserving kidney function. SGLT2 inhibitors reduce intraglomerular pressure and proteinuria, which are key factors in CKD progression. This study reinforces the growing evidence that SGLT2 inhibitors are a valuable addition to the treatment of CKD, particularly in patients at high risk of rapid progression.

While ACE inhibitors and ARBs remain foundational therapies in CKD management due to their ability to reduce blood pressure and proteinuria (Kolesnyk et al., 2010), the results suggest that combining these agents with SGLT2 inhibitors may provide additional benefits in slowing CKD progression. However, future research should explore long-term outcomes and the safety of dual therapy in CKD patients.

3. Importance of Imaging in CKD Monitoring

Imaging played a crucial role in detecting structural changes in the kidneys, particularly in patients with advanced CKD. Significant reductions in kidney size were observed in 65% of patients, and cortical thinning was noted in 52%. These structural changes were closely correlated with declines in eGFR, highlighting the value of imaging in identifying patients at risk of rapid disease progression.

The detection of increased fibrosis through MRI in 45% of patients provides further evidence of the importance of advanced imaging in CKD monitoring. Fibrosis is a key indicator of irreversible kidney damage, and early detection can help clinicians make informed decisions about intensifying treatment or considering alternative therapies (Buchanan et al., 2022). Ultrasound, though less sensitive in detecting subtle changes like fibrosis, remains a valuable and widely accessible tool for routine CKD monitoring, especially in resource-limited settings.

Combining imaging with laboratory markers allows for a more holistic assessment of CKD progression, particularly in patients with discrepancies between functional and structural damage. For instance, patients with stable eGFR but worsening imaging findings may benefit from earlier intervention to prevent further decline.

4. Role of Pharmacist Interventions

Pharmacist-led interventions, including dose adjustments and therapy modifications, significantly improved treatment adherence and reduced complications in this study. The high adherence rates (83.3%) among patients receiving pharmacist support underscore the importance of involving pharmacists in CKD management. Pharmacists played a crucial role in optimizing medication regimens, particularly in adjusting dosages for ACE inhibitors, ARBs, and SGLT2 inhibitors to minimize side effects such as hyperkalemia and hypoglycemia.

Pharmacists ’contributions were also essential in reducing treatment-related complications. Patients who received pharmacist-led interventions had a lower incidence of adverse events, including hyperkalemia and volume depletion, which are common concerns in CKD management (Bianchi et al., 2006). This emphasizes the value of a multidisciplinary approach to CKD care, where pharmacists, nephrologists, and radiologists collaborate to optimize treatment and improve patient outcomes.

5. Study Limitations and Future Research

Despite the strengths of this study, several limitations should be acknowledged. First, the retrospective design may introduce selection bias, as only patients with complete records for both laboratory and imaging data were included. Additionally, the study was conducted in a single tertiary hospital, which may limit the generalizability of the findings to other healthcare settings with different patient populations or resources.

Future research should explore the long-term impact of combining SGLT2 inhibitors with other pharmacological agents, such as ACE inhibitors and ARBs, on CKD progression. Prospective studies involving a larger and more diverse population are also needed to validate the findings and assess the cost-effectiveness of integrating imaging into routine CKD monitoring protocols.

6. Conclusion

This study demonstrates that combining laboratory markers with imaging provides a more comprehensive assessment of CKD progression. While eGFR and creatinine are valuable for tracking functional decline, imaging offers critical insights into structural changes that may not be immediately reflected in lab results. Pharmacological treatments, particularly SGLT2 inhibitors, showed significant benefits in slowing CKD progression, highlighting the need for personalized treatment approaches based on both functional and structural assessments. The inclusion of pharmacists in the multidisciplinary care team further enhances patient outcomes by optimizing medication management and improving treatment adherence.

References:

1. Bianchi, S., Bigazzi, R., &Campese, V. M. (2006). Long-term effects of spironolactone on proteinuria and kidney function in patients with chronic kidney disease. *Kidney international*, *70*(12), 2116-2123.
2. Buchanan, C. E., Mahmoud, H., Cox, E. F., McCulloch, T., Prestwich, B. L., Taal, M. W., ... & Francis, S. T. (2020). Quantitative assessment of renal structural and functional changes in chronic kidney disease using multi-parametric magnetic resonance imaging. *Nephrology Dialysis Transplantation*, *35*(6), 955-964.
3. Cao, W., Cui, S., Yang, L., Wu, C., Liu, J., Yang, F., ... & Hou, F. F. (2017). Contrast-enhanced ultrasound for assessing renal perfusion impairment and predicting acute kidney injury to chronic kidney disease progression. *Antioxidants & redox signaling*, *27*(17), 1397-1411.
4. Go, A. S., Chertow, G. M., Fan, D., McCulloch, C. E., & Hsu, C. Y. (2004). Chronic kidney disease and the risks of death, cardiovascular events, and hospitalization. *New England Journal of Medicine*, *351*(13), 1296-1305.
5. Heerspink, H. J. L., Langkilde, A. M., & Wheeler, D. C. (2021). Dapagliflozin in Patients with Chronic Kidney Disease. *New England Journal of Medicine*, *384*(4), 389-390.
6. Jha, V., Garcia-Garcia, G., Iseki, K., Li, Z., Naicker, S., Plattner, B., ... & Yang, C. W. (2013). Chronic kidney disease: global dimension and perspectives. *The Lancet*, *382*(9888), 260-272.
7. Kellum, J. A., Lameire, N., Aspelin, P., Barsoum, R. S., Burdmann, E. A., Goldstein, S. L., ... & Uchino, S. (2012). Kidney disease: improving global outcomes (KDIGO) acute kidney injury work group. KDIGO clinical practice guideline for acute kidney injury. *Kidney international supplements*, *2*(1), 1-138.
8. Kolesnyk, I., Struijk, D. G., Dekker, F. W., &Krediet, R. T. (2010). Effects of angiotensin-converting enzyme inhibitors and angiotensin II receptor blockers in patients with chronic kidney disease. *Neth J Med*, *68*(1), 15-23.

9. Levey, A. S., Atkins, R., Coresh, J., Cohen, E. P., Collins, A. J., Eckardt, K. U., ... &Eknoyan, G. (2007). Chronic kidney disease as a global public health problem: approaches and initiatives–a position statement from Kidney Disease Improving Global Outcomes. *Kidney international*, *72*(3), 247-259.
10. Matsushita, K., Coresh, J., Sang, Y., Chalmers, J., Fox, C., Guallar, E., ... &Ärnlöv, J. (2015). Estimated glomerular filtration rate and albuminuria for prediction of cardiovascular outcomes: a collaborative meta-analysis of individual participant data. *The lancet Diabetes & endocrinology*, *3*(7), 514-525.
11. Meola, M., Samoni, S., & Petrucci, I. (2016). Imaging in chronic kidney disease. *Ultrasound Imaging in Acute and Chronic Kidney Disease*, *188*, 69-80.
12. Neuen, B. L., Young, T., Heerspink, H. J., Neal, B., Perkovic, V., Billot, L., ... & Jardine, M. J. (2019). SGLT2 inhibitors for the prevention of kidney failure in patients with type 2 diabetes: a systematic review and meta-analysis. *The lancet Diabetes & endocrinology*, *7*(11), 845-854.
13. Peralta, C. A., Shlipak, M. G., Judd, S., Cushman, M., McClellan, W., Zakai, N. A., ... & Warnock, D. (2011). Detection of chronic kidney disease with creatinine, cystatin C, and urine albumin-to-creatinine ratio and association with progression to end-stage renal disease and mortality. *Jama*, *305*(15), 1545-1552.
14. Webster, A. C., Nagler, E. V., Morton, R. L., & Masson, P. (2017). Chronic kidney disease. *The lancet*, *389*(10075), 1238-1252.