

Inappropriate Prescribing in Chronic Kidney Disease (CKD): Risks, Patterns and Prevention

Nileena Anna Varghese *

Department of Pharmacy Practice, Independent Researcher, Kerala.

GSC Advanced Research and Reviews, 2025, 24(01), 240-251

Publication history: Received on 10 June 2025; revised on 16 July 2025; accepted on 19 July 2025

Article DOI: <https://doi.org/10.30574/gscarr.2025.24.1.0208>

Abstract

Chronic Kidney Disease (CKD) affects approximately 10–15% of the world's population, and is associated with significant morbidity, mortality and health care utilization. Patients with CKD have a higher risk of drug accumulation, toxicity, and adverse drug reactions as a result of impaired renal clearance. This population is plagued by inappropriate prescribing including contraindicated medications, inappropriate dose adjustments based on glomerular filtration rate (GFR), polypharmacy, and a myriad of other unrecognized issues. In fact, systematic reviews and international audits suggest that 50 - 80% of CKD patients will receive at least one renally inappropriate medication during their treatment. These inappropriate prescribing practices lead to stomaching hospitalization, accelerating decline in kidney function and poor patient outcomes.

This review uses current literature about the extent, frequency, and implications of inappropriate prescribing (IP) in CKD. We discuss important pharmacokinetic changes related to renal impairment, high-risk drug categories (e.g., NSAIDs, please note aminoglycosides, and metformin) and clinical implications of misuse. We also examine system and clinician-related factors leading to prescribing errors, including clinical inertia, weak electronic alerts, and lack of CKD-specific prescribing education. Ultimately, we summarize evidence-based interventions to prevent these errors, including pharmacist-led medication reviews, clinical decision support tools, guideline-based prescribing, and interdisciplinary care. While systemic policy changes and enhanced prescriber education are both strategies to change, shared goals should address prescribing safety in CKD to achieve nephroprotection, reduction of preventable harm, improvement of quality-of-life, and maximization of treatment efficacy in one of the highest-risk patient demographics.

Keywords: Chronic kidney disease; Prescribing errors; Renal pharmacokinetics; Drug safety; Dose adjustment; Pharmacist intervention

1. Introduction

Chronic Kidney Disease (CKD) impacts around 10 - 15% of the global populace and is exhibiting a rising trend as the prevalence of diabetes, hypertension, and aging populations proliferate [1,2]. In low- and middle-income countries, such as India, late presentation, limited access to nephrology and an unequal healthcare system dramatically increase CKD burdens [3]. CKD is not only a progressive illness leading to end stage renal disease (ESRD), but also affects both pharmacokinetics and pharmacodynamics of drugs and may complicate or interfere with pharmacotherapy in all clinical settings [4,5].

The kidneys also play an important role in excretion of drugs and their metabolites. When renal function is impaired, drug clearance is reduced, half-life is increased and patients are at an increased risk of drug accumulation and potential toxicity [6]. Patient safety which encompasses dose individualization based on renal function -classically measured via

* Corresponding author: Nileena Anna Varghese

glomerular filtration rate (GFR) or creatinine clearance (CrCl) -is a critical aspect of pharmacotherapy for CKD patients [7,8]. Despite this, there is an abundance of studies demonstrating that inappropriate prescribing (IP) -which includes dose not adjusted therapy, prescribing contraindicated drugs, and ignoring drug-to-drug interactions - remains relatively common in particular in elderly or polymorbid patients [9-11].

The consequences of inappropriate prescribing (IP) in chronic kidney disease (CKD) are significant. Drug-related problems (DRPs) caused by IP are implicated in hospital admissions, increased cost of healthcare, adverse drug reactions (ADRs), and even death [12,13]. In a systematic review, Tesfaye and colleagues [14] noted that IP was present in patients with CKD from a range of settings including CKD patients attending outpatient clinics, inpatient hospital patients, and aged care facilities. The prevalence of IP was estimated to be between 20 % and 67 % of patients and was associated with negative clinical outcomes including hospital admissions and nephrotoxicity [14]. A similar trend was observed in aged care facilities, where patients received on average 4.9 renally cleared drugs and 81% were prescribed renally cleared drugs that required dose adjustments [15,16].

Certain drug classes are more commonly misused in CKD and include nonsteroidal anti-inflammatory drugs (NSAIDs), antidiabetic medications like metformin, antibiotics (aminoglycosides, vancomycin), and cardiovascular drugs [17-19]. In advanced CKD, some of these medications have absolute or relative contraindications, whilst others require detailed dose titrations and stringent monitoring. There are clinical guidelines available to prescribers from KDIGO and national renal associations, however uptake is often poor in both inpatient and outpatient settings [20,21].

In addition to being pharmacologically complex, the role of systemic factors is also contributing to the problem, including lack of awareness, time pressures, limited access to renal dosing tools and gaps in inter-professional communication across prescriber, pharmacist and nephrologist [22,23]. The issue is more pronounced with older adults and nursing home residents where polypharmacy and cognitive decline further compound risks [24,25].

Addressing inappropriate prescribing (IP) in CKD has included computerized decision support systems (CDSS), pharmacist led medication reviews and clinician education programs [26,27]. However, demonstrable and sustained evidence of their impact remains inconsistent and barriers to implementation still constrain wider uptake.

The objective of this review is to summarize the current literature on inappropriate prescribing in CKD and to develop an understanding of the prevalence of IP, patterns of IP, clinical implications of IP, and preventative strategies. With particular emphasis on pharmacokinetic variations, risk prediction and effectiveness of interventions to inform future policy and practice.

2. Renal pharmacokinetics and drug handling in CKD

The kidneys serve as a central hub for drug excretion and metabolism. In patients with CKD, alterations in renal function can substantially affect pharmacokinetics—namely, how drugs are absorbed, distributed, metabolized, and eliminated. Tailoring drug therapy to these changes is essential for preventing toxicity and ensuring therapeutic efficacy [1,2].

2.1. Absorption and Bioavailability

While renal impairment has limited direct effects on drug absorption, several CKD-associated conditions—such as uremia, delayed gastric emptying (gastroparesis), and altered gastric pH—can influence oral drug bioavailability [3]. Moreover, commonly prescribed agents like phosphate binders and antacids may interfere with the absorption of medications such as fluoroquinolones or iron supplements [4].

2.2. Distribution

CKD frequently alters drug distribution, particularly through changes in protein binding and fluid status. Hypoalbuminemia, often seen in CKD, reduces protein binding of acidic drugs like phenytoin and warfarin, increasing their free (active) fraction and, consequently, toxicity risk [5]. On the other hand, patients with fluid overload may exhibit an increased volume of distribution (Vd) for hydrophilic drugs, such as aminoglycosides, which may reduce plasma concentrations and impact efficacy [6].

2.3. Metabolism

The kidneys contribute to drug metabolism via both enzymatic activity (e.g., Phase I and II reactions) and transporters. In CKD, impaired renal clearance may indirectly alter hepatic metabolism, possibly due to systemic inflammation or

uremic toxin accumulation [7]. Some drugs, despite being primarily hepatically cleared—such as propranolol and verapamil—may still accumulate in CKD due to altered metabolism or transporter dysfunction [9].

2.4. Excretion

Among all pharmacokinetic processes, excretion is most significantly impacted by CKD. Drugs predominantly eliminated via renal pathways (e.g., digoxin, lithium, aminoglycosides, metformin) require careful dose adjustments to match residual renal function [10]. Without dose modification, drug half-lives may be prolonged, increasing the risk of accumulation and toxicity [11].

Two primary metrics are used to estimate renal function:

- **Creatinine Clearance (CrCl)**, calculated using the Cockcroft–Gault equation [12]
- **Estimated Glomerular Filtration Rate (eGFR)**, derived via CKD-EPI or MDRD formulas [13]

Although eGFR is more accurate for staging CKD, most drug dosing recommendations are based on CrCl, leading to potential confusion in clinical practice and misapplication of eGFR for dosing decisions [14].

2.5. Time- and Concentration-Dependent Drug Effects

Renal dysfunction not only affects drug clearance but also alters pharmacodynamic responses, especially in medications with narrow therapeutic windows. For time-dependent antibiotics like beta-lactams, prolonged half-lives can result in extended drug exposure unless dosing intervals are appropriately adjusted [15]. Conversely, drugs such as aminoglycosides benefit from extended-interval dosing strategies in CKD to reduce nephrotoxicity while maintaining antimicrobial efficacy [16].

Table 1 Commonly Prescribed Drugs Requiring Dose Adjustment in CKD

Drug Class	Drug Example	Primary Route of Elimination	CKD – Related Risk	Recommended Action
Antibiotics	Aminoglycosides	Renal (Unchanged)	Nephrotoxicity, Ototoxicity	Reduced dose & extend dosing interval [1]
	Vancomycin	Renal	Accumulation → nephrotoxicity	Trough monitoring, dose adjustment [2]
	Penicillin G	Renal	CNS toxicity in severe CKD	Adjust dose based on GFR
Antidiabetics	Metformin	Renal (unchanged)	Lactic acidosis in eGFR <30 mL/min/1.73m ²	Contraindicated in eGFR <30 [3]
Cardiovascular	Digoxin	Renal (Unchanged)	Accumulation → arrhythmia	Reduce dose, monitor serum levels [4]
	Enalapril	Renal & hepatic	Hyperkalemia, hypotension	Start low, titrate slowly
CNS Agents	Gabapentin	Renal	Sedation, dizziness	Reduce dose based on CrCl [5]
	Morphine	Hepatic, with renally cleared metabolites	Respiratory depression, CNS effects	Avoid or use alternative (e.g., fentanyl)
Anticoagulants	Enoxaparin	Renal	Bleeding risk	Adjust dose for CrCl <30 mL/min [6]
Lithium	Lithium	Renal (unchanged)	Neurotoxicity, nephrotoxicity	Avoid or reduce dose; close monitoring [7]

3. Inappropriate prescribing: patterns, prevalence, and risk factors

3.1. What is Inappropriate Prescribing (IP)?

Inappropriate prescribing (IP) associated with chronic kidney disease (CKD) is the use of contraindicated medications, medications that are not renally-adjusted, and medications that are possibly inappropriate because of the effects of CKD on pharmacokinetics/Pk or pharmacodynamics/Pd [1]. IP includes:

- Not renally-adjusted dosing (CrCl or eGFR)
- Nephrotoxins prescribed without clinical need
- CKD contraindicated medications or medications with safer alternatives prescribed
- Polypharmacy without appropriate monitoring (especially in older patients)

Considering there are so many patients with CKD, especially in older patients with more comorbidities, IP represents an important safety issue.

3.2. Prevalence and Patterns of Global and Regional Prevalence

IP is often reported at high rates in CKD patients (as seen in studies around the world). The systematic review by Tesfaye et al. showed prevalence estimates between 20-67% across studies according to a variety of factors related to method, location, population and IP definition [2]. In low-resource situations, such as in India and other developing countries, the prevalence may be even greater because of the limited access to nephrologists, lack of renal dosing software, and clinical inertia. Khanal et al. observed that, in community settings and aged-care facilities, 42% of elderly patients received at least one renally inappropriate prescription [3]. Similarly, Castelino et al. found that as many as 60% of nursing home residents with CKD were prescribed at least one medication without renal adjustment that was necessary [4].

In a hospital setting, Hug et al. reported that 25% of adverse drug events (ADEs) in patients with CKD involved renally eliminated drugs and that most of these ADEs were preventable [5]. Farag et al. reported that antibiotics were the most commonly misused drugs among older patients with CKD, most commonly under- or overdosed [6].

3.3. Drug Classes Most Commonly Involved in IP

Certain classes of drugs are overrepresented in inappropriate prescribing for patients with CKD:

- Antimicrobials: including aminoglycosides, vancomycin, nitrofurantoin (contraindicated in advanced CKD)
- Antidiabetics: metformin (risk of lactic acidosis in eGFR <30), glyburide (risk hypoglycemia);
- Cardiovascular: digoxin (narrow therapeutic index); ACEI/ARBs (monitoring needed);
- NSAIDs: Risk of additional nephrotoxicity and electrolyte imbalance
- Opioids: gabapentin, morphine (active metabolites accumulate)
- Anticoagulants: low-molecular-weight heparins require care in dosing in patients with renal impairment.

This pattern was consistently observed across community and inpatient studies [7-9].

3.4. Risk Factors for Inappropriate Prescribing

Inappropriate prescribing (IP) is influenced by a variety of systemic and clinician factors identified at the clinician level

Table 2 Comparison of Systemic Factors with Clinician-Level Factors

Systemic Factors	Clinician-Level Factors
Lack of access to renal dosing tools	Inadequate training in CKD pharmacotherapy
Absence of electronic alert systems	Underestimation of CKD severity
Clinical time constraints	Lack of awareness about drug renal clearance
No pharmacist involvement	Over-reliance on fixed doses or manufacturer labels

Studies by Aronoff et al. and Salomon et al. demonstrate that even in tertiary care, differences exist in adherence to evidence-based dosing guidelines which necessitates linkage within a systems perspective with multidisciplinary supervision [13,14].

4. Clinical consequences of inappropriate prescribing in CKD

4.1. Adverse Drug Reactions (ADRs) and Toxicity

Inappropriate prescribing in CKD contributes substantially to the risk of adverse drug reactions (ADRs) because of, the potential for drug accumulation, impaired drug clearance and changes in pharmacodynamics. Toxicity from renally excreted drugs can result from even therapeutic doses if a drug's dosage is not adjusted for deteriorating renal function. Drugs commonly associated with serious ADRs in patients with CKD include digoxin, aminoglycosides, NSAIDs and gabapentin [1, 2]. Kidney Disease: Improving Global Outcomes (KDIGO) highlights the risk for nephrotoxicity and systemic side effects when using renally eliminated and/or nephrotoxic drugs [3]. For example, failure to adjust vancomycin doses, even for short courses, can have serious consequences such as ototoxicity and acute tubular necrosis. Likewise, inappropriate use of Non-Steroidal Anti-Inflammatory Drugs(NSAIDs) can cause exacerbations of interstitial nephritis and fluid retention [4].

4.2. Hospitalizations and Emergency Visits

Multiple large cohort studies have linked inappropriate prescribing in CKD to increased hospitalization rates, emergency department visits, and length of stay [5]. The misuse of renally cleared antibiotics, especially in elderly patients, has been shown to increase the chances of emergency admissions for drug-induced nephrotoxicity, bleeding, or severe infections by a significant margin [6].

Chertow et al demonstrated that providing tailored medication dosing based on renal function in hospitalized patients decreased ADR-related admissions by nearly 20% overall and demonstrated the efficacy of dose optimization [7].

4.3. Mortality and Disease Progression

Inadequate use of medications does not just lead to transient toxicity; it can also hasten disease rates of CKD, and thereby complicate mortality in a patient setting. Breton et al. found that community-based elderly patients with improper drug use and associated decline in renal function exhibited greater all-cause mortality, even after adjusting for other comorbidities and polypharmacy [8].

Nephrotoxic drugs, including contrast media, aminoglycosides, and calcineurin inhibitors are now known to lead to rapid GFR decline.

Drugs that have associated cardiovascular adverse effects (e.g., non-dosed enoxaparin, digoxin) have clear increased risks for fatal arrhythmias or stroke in this population, a higher risk population [9].

4.4. Cognitive Impairment and Quality of Life

The use of centrally acting medications—such as opioids, gabapentin, and benzodiazepines—without appropriate renal dose adjustments has been linked to a range of neurocognitive complications in older adults with CKD. These include excessive sedation, increased fall risk, delirium, and progressive cognitive decline [10]. As cognitive impairment becomes more prevalent in the aging CKD population, the implications of inappropriate prescribing extend beyond pharmacologic toxicity. They directly impact patients' ability to adhere to medication regimens and manage their health independently, further compounding morbidity in a feedback loop of worsening health outcomes [11].

Research by Johnell and Fastbom demonstrated that individuals with dementia or signs of cognitive deterioration were more than twice as likely to be prescribed potentially inappropriate medications. These patients also experienced disproportionately higher rates of adverse effects, underscoring a significant vulnerability in this subgroup [12].

4.5. Economic Burden

The financial implications of inappropriate prescribing in CKD are considerable, placing added strain on already burdened healthcare systems. Several downstream consequences drive these costs, including:

- The need for increased therapeutic monitoring (e.g., serum drug concentration assays, nephrology consultations)
- Prolonged hospital admissions due to drug-related complications
- Early initiation of dialysis and elevated rates of hospital readmissions

Salomon et al. estimated that approximately 20% of medication-related hospitalization costs among CKD patients were attributable to adverse drug reactions that could have been prevented with safer prescribing practices ^[13]. This finding highlights the economic benefit of targeted interventions—such as pharmacist involvement and prescriber education—not only in improving patient safety but also in reducing healthcare expenditure.

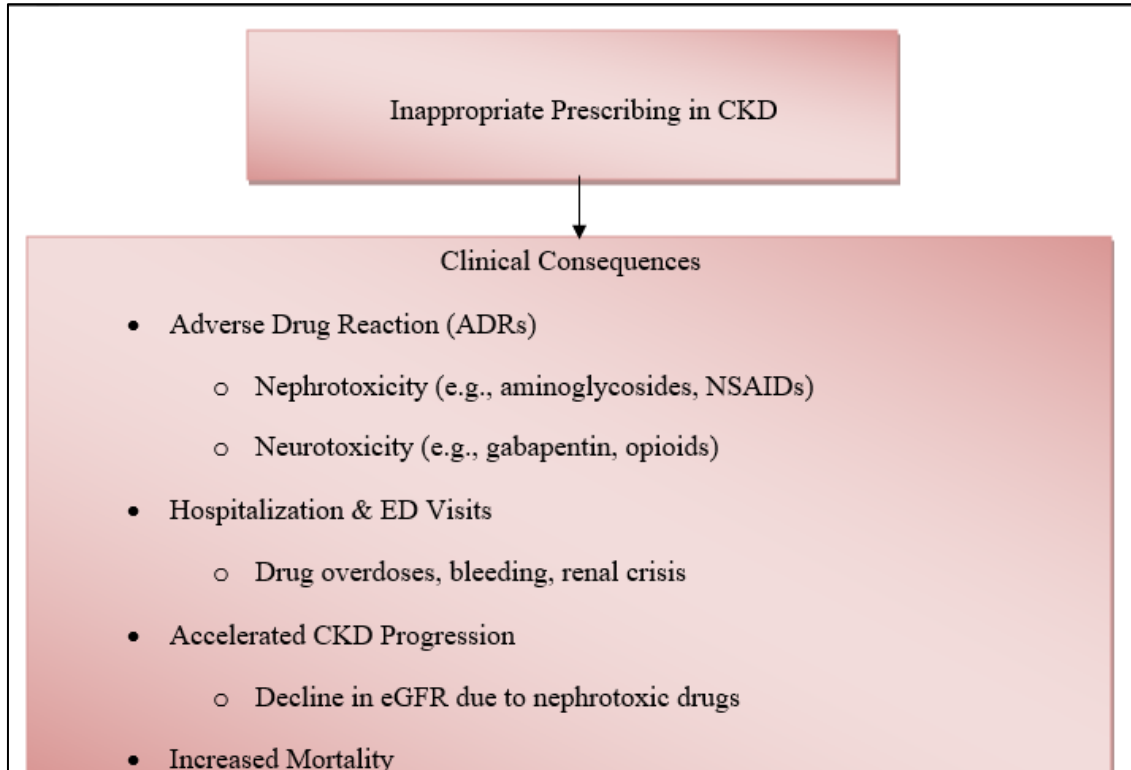


Figure 1 Clinical Consequences of Inappropriate Prescribing in CKD

5. Strategies to prevent inappropriate prescribing in CKD

5.1. Medication Reconciliation and Review

Medication reconciliation at critical transition points—such as hospital admission, discharge, or routine outpatient follow-up—is a fundamental step in minimizing prescribing errors. A prominent and systematic medication review can:

- Identify medications primarily eliminated through the kidneys
- Detect potential drug–drug interactions
- Confirm that renal dose adjustments have been made
- Suggest the discontinuation of nephrotoxic or unnecessary agents like renally cleared drugs.

Evidence from Castelino et al. demonstrated that pharmacist-led reviews in aged care settings significantly reduced the use of potentially inappropriate medications, particularly those requiring renal dosing consideration ^[1]. These findings support routine involvement of pharmacists in reviewing medication regimens for patients with CKD.

5.2. Use of Renal Dosing Guidelines and eGFR-Based Dosing

Clinical guidelines provided by organizations such as KDIGO and the National Kidney Foundation (NKF), as well as institutional formularies, offer specific recommendations for dose adjustments in patients with renal impairment. Effective application of these guidelines requires:

- Regular estimation of kidney function using validated equations such as CKD-EPI or MDRD [2]
- Recognition that serum creatinine alone may be misleading, especially in older adults with reduced muscle mass [3]
- Use of the Cockcroft–Gault or CKD-EPI formula to guide drug dosing, as both remain widely referenced in clinical pharmacotherapy [4]
- Incorporating these practices into routine care supports individualized and safe medication use in CKD populations.

5.3. Clinical Decision Support Systems (CDSS)

Embedding renal-specific alerts into electronic prescribing platforms through Clinical Decision Support Systems (CDSS) provides real-time, actionable information to prescribers. These systems can notify clinicians when:

- A prescribed drug is contraindicated in CKD
- A renal dose adjustment is required based on the patient's estimated GFR
- Safer therapeutic alternatives are available

Farag et al. reported that implementation of CDSS in inpatient care reduced dosing errors in renally eliminated antibiotics by up to 35% [5]. Similarly, research by Chertow et al. found that integrating decision-support systems into prescribing workflows resulted in fewer adverse drug reactions and reduced hospital stays among CKD patients [6].

5.4. Interdisciplinary Collaboration

Optimizing pharmacotherapy in CKD often requires input from a multidisciplinary team. Collaborative efforts between prescribers, nephrologists, pharmacists, and nursing staff have been shown to improve medication safety. Key strategies include:

- Conducting pharmacist-led medication rounds in inpatient units
- Consulting nephrology teams for complex dosing decisions
- Establishing shared care pathways in primary care for long-term follow-up
- Yahaya et al. highlighted the impact of a dedicated renal drug dosing service in a hospital setting, which led to a measurable increase in dosing accuracy and a decline in preventable medication-related complications [7].

5.5. Role of Clinical Pharmacists and Renal Pharmacology Teams

Clinical pharmacists play a vital role in safeguarding medication use among patients with impaired renal function. Their responsibilities include:

- Identifying potential dosing errors before administration
- Reviewing and managing drug–drug interactions
- Guiding prescribers toward safer alternatives
- Providing education to both healthcare providers and patients

The integration of pharmacists into multidisciplinary teams—both in acute care wards and renal outpatient clinics—has been associated with significant reductions in medication-related harm, particularly in patients with advanced CKD (stages 4–5) [9].

Table 3 Preventive Strategies Summary

Strategy	Primary Outcome
Medication reconciliation	Fewer drug duplications and omissions
eGFR-based dosing	Reduced ADRs and toxicity
CDSS alerts	Prevention of real-time prescribing errors
Pharmacist-led interventions	Increased appropriateness of prescriptions
Interdisciplinary collaboration	Holistic and safer care plans
Educational programs	Improved prescriber knowledge and confidence

6. Special considerations in elderly and poly-morbid CKD patients

6.1. Pharmacokinetic Challenges in the Elderly with CKD

Older adults comprise a large proportion of the CKD population and are particularly vulnerable to medication-related harm due to age-associated physiological changes. Declining renal and hepatic function, alterations in drug absorption and distribution (such as reduced gastric acidity and lower serum albumin), and the presence of sarcopenia all influence pharmacokinetics in this group.

Sarcopenia, in particular, can lead to deceptively low serum creatinine levels, which may falsely elevate estimated glomerular filtration rate (eGFR) if not calculated with appropriate corrections ^[1]. Consequently, elderly patients are at risk for elevated peak drug concentrations and prolonged half-lives, especially with medications cleared renally.

In this demographic, the Cockcroft–Gault equation remains the preferred method for estimating renal function, as it accounts for body weight. However, additional adjustments may be necessary in frail individuals to ensure dosing accuracy and safety ^[2].

6.2. Risks of Polypharmacy

Polypharmacy, typically defined as the concurrent use of five or more medications, is reported in over 60% of elderly individuals with CKD ^[3]. While this often happens because of the presence of multiple comorbidities, polypharmacy increases the risk of:

- Pharmacokinetic and pharmacodynamic drug–drug interactions
- Cumulative nephrotoxicity from multiple renally cleared agents
- Treatment confusion due to complex regimens
- Non-adherence, whether unintentional or deliberate

Research by Khanal et al. and Castelino et al. found a strong association between polypharmacy and inappropriate prescribing, especially within long-term care facilities and home-based elderly care settings ^[4,5]. These findings underscore the need for close medication monitoring and periodic deprescribing where appropriate.

6.3. Cognitive Impairment and Frailty

Cognitive impairment is estimated to affect between 30% and 50% of elderly patients with CKD, posing serious challenges to safe medication use. Individuals with impaired cognition may have difficulty understanding dose adjustments, are more susceptible to non-adherence and accidental overdose, and are often excluded from medication review conversations.

Johnell and Fastbom reported that older adults with dementia were twice as likely to be prescribed potentially inappropriate medications, particularly central nervous system (CNS) depressants such as opioids and sedatives ^[6].

Frailty, another prevalent condition in elderly CKD patients, further complicates prescribing. Frail individuals exhibit heightened sensitivity to pharmacologic effects and are more prone to adverse outcomes. As such, medication regimens in this group require more gradual titration and closer monitoring, especially for drugs excreted renally ^[7].

6.4. Influence of Gender, Body Composition, and Nutrition

Several patient-specific variables must also be considered when tailoring pharmacotherapy for elderly individuals with CKD:

- **Gender differences:** Women typically have lower GFR and may metabolize certain drugs differently, necessitating distinct dosing considerations ^[8].
- **Body composition:** Low body mass or hypoalbuminemia can affect drug distribution, increasing the free (active) fraction of protein-bound medications.
- **Nutritional status:** Malnutrition, commonly observed in advanced CKD, reduces physiologic reserves and can exacerbate drug toxicity.

These nuances highlight the importance of personalized medication planning rather than strict reliance on population-based guidelines.

6.5. Socioeconomic and Access Barriers

Beyond clinical variables, social determinants of health play a critical role in medication safety for elderly CKD patients. Barriers that contribute to inappropriate prescribing in this population include:

- Limited access to nephrology specialists and clinical pharmacists
- Low health literacy, which hinders understanding of medication instructions or side effect warnings
- Financial constraints, often leading to skipped doses, self-adjusted regimens, or outright discontinuation of therapy

A population-level study by Breton et al. demonstrated a clear link between socioeconomic disadvantage and increased prevalence of inappropriate prescribing, as well as elevated mortality risk among elderly individuals with CKD [9]. These findings emphasize the importance of holistic, patient-centered approaches to care, particularly for those at the intersection of aging, poverty, and chronic disease.

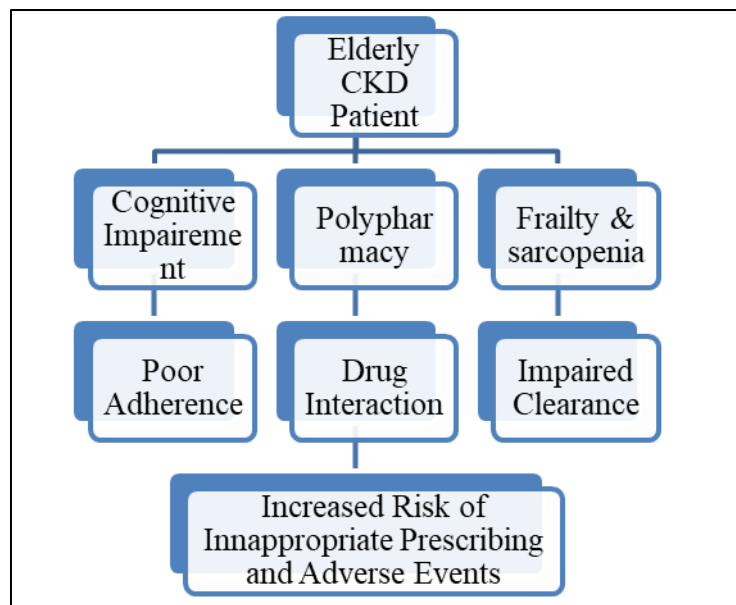


Figure 2 Socioeconomic and Access Barriers for Elderly CKD Patients

7. Conclusion

Inappropriate prescribing (IP) is an important modifiable cause of adverse outcomes in chronic kidney disease (CKD), and it is mainly caused by the change in pharmacokinetics and pharmacodynamics in CKD. CKD patients are at increased risk of adverse drug reactions such as nephrotoxicity, systemic toxicity, hospitalization, and early death. The risk is particularly high in elderly and individuals with polypharmacy or cognitive impairment.

In spite of tools for renal dose adjustment being available and increasing recognition of the risks of IP, regular application of guidelines is scarce in clinical practice.

To enhance outcomes, future strategies need to move toward precision prescribing, factoring in patient-specific variables including comorbidities, genetics, and variability in renal function. Pharmacogenomics and renal-specific pharmacokinetic modelling can aid these efforts.

Clinical decision support systems (CDSS) provide a key intervention point. Innovative EHR-integrated CDSS are able to provide real-time dosing warnings, alert for nephrotoxic hazards, and recommend safer alternatives. AI-based models further increase predictive ability for drug harm.

Deprescribing—the systematic removal of medications when the risks exceed benefits—necessitates further research among CKD populations, particularly dialysis-dependent and older adults [3,24]. Clinical trials comparing deprescribing regimens for agents most frequently prescribed, including statins, antihypertensives, and antidiabetics, are indicated.

In addition, interventions must target high-risk groups, such as rural populations, low health literacy patients, and ethnic minority groups disproportionately burdened by CKD. Prescribing patterns must be modified to improve the equity of care delivery.

Policy-level changes are also imperative. Overhauls of guidelines, especially of parameters such as Beers and STOPP/START, need to incorporate renal-specific cautions. Education reforms must institutionalize renal pharmacotherapy as an integral part of training for prescribers. Lastly, an enhanced surveillance system is needed. The majority of existing data are retrospective and are underreported. Organized registries and real-time pharmacovigilance linked to trends in renal function can early detect errors in prescribing and facilitate quality improvement.

In conclusion, IP in CKD is a chronic but manageable problem. Interventions such as accurate renal function monitoring, pharmacists' interventions, AI-assisted prescribing assistants, deprescribing interventions, and improved education and policy reform can together accomplish a safer prescription environment. With the application of IP by using a multidisciplinary, system-aligned method, we can significantly reduce avoidable harm and improve long-term outcomes for patients with CKD.

Compliance with ethical standards

Acknowledgments

The author would like to acknowledge the support of colleagues and mentors whose informal discussions on nephrology and clinical pharmacology helped refine the perspectives presented in this manuscript. No external funding was received for this work.

Disclosure of conflict of interest

The author declares no conflict of interest.

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