дослідження
Research

НИРКИ KIDNEYS

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Biochemical Markers of Diabetic Kidney Injury: A Pharmacological Perspective on Early Intervention

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ABSTRACT
Diabetic kidney injury represented a major contributor to chronic kidney disease progression and was driven by early biochemical and molecular disturbances that preceded overt functional decline. Conventional diagnostic markers often detected renal damage at advanced stages, limiting opportunities for timely therapeutic intervention. Emerging biochemical markers offered enhanced sensitivity for early detection and provided a potential framework for biomarker-guided pharmacological nephroprotection. This study aimed to synthesize clinician perspectives on biochemical markers associated with early diabetic kidney injury and to evaluate the perceived role of biomarker-guided pharmacological strategies in early renal protection. A cross-sectional, questionnaire-based observational study was conducted among 200 healthcare professionals, including nephrologists, endocrinologists, internal medicine physicians, and clinical pharmacologists. A structured, validated questionnaire assessed awareness of biochemical markers, clinical utilization patterns, and the influence of early biomarker changes on pharmacological decision-making. Descriptive and selective inferential statistical analyses were performed. Respondents demonstrated strong agreement regarding the diagnostic value of emerging biomarkers and routine biochemical monitoring for early renal injury detection. Elevated mean perception scores indicated high clinician confidence in biomarker-based approaches. Early biochemical changes were consistently perceived to influence pharmacological intervention, disease progression control, and patient outcomes. Inferential analyses revealed uniform perceptions across medical specializations and knowledge levels, suggesting consensus-driven clinical practice. The findings supported a unified biochemical–pharmacological framework for early diabetic kidney injury management. Integration of biochemical markers into routine clinical pathways was perceived to enhance early diagnosis, guide timely pharmacological intervention, and promote sustained renal preservation within preventive nephrology paradigms.

Keywords: Diabetic kidney injury; Biochemical markers; Early diagnosis; Pharmacological intervention; Nephroprotection

1. INTRODUCTION

Diabetic kidney injury constitutes one of the most prevalent and debilitating complications associated with diabetes mellitus, contributing substantially to chronic kidney disease and end-stage renal failure worldwide. The growing cases of diabetes are continuing to put pressure on renal disease, resulting in poor patient survival, costs to healthcare, and living standards. The onset of renal injury is silent in its beginning, and it is motivated by the biochemical and molecular processes that initiate the malfunction of the kidney and stress the importance of diagnostic vigilance in preventive nephrology paradigms [1]. Diabetic kidney injury pathogenesis includes a metabolic imbalance caused by

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long-term hyperglycemia, mitochondrial dysfunction, the enhancement of oxidative stress, immune response and remodeling of the extracellular matrix. These processes are interrelated and work to destroy glomerular, tubular and interstitial compartments, increasing the rate of structural damage in the kidney [2]. Traditional diagnostic indices such as serum creatinine and albuminuria are not sensitive in the initial stages of the disease and often indicate un-reversible renal damage as opposed to reversible damage [3]. The reliance on late indicators limits the provision of treatment promptly. Recent progress highlight the diagnostics significance of new biochemical indicators that can represent the early signs of renal stress and subclinical injury. Urinary and circulating inflammatory mediators, oxidative stress products, tubular injury proteins, and molecular regulators are better-sensitivity to early kidney injury in diabetes [4]. Combination of proteomic and metabolomic profiling also performs risk stratification of the disease with the aim of determining disease-specific molecular signatures to aid individualized disease monitoring plans [5].

Even though the biomarker discovery has been vast, there is overall deficiency in synthesis of the biochemical markers together with pharmacological early-intervention approaches. Existing literature tends to analysis of biomarkers or therapeutic interventions separately, and this leads to disjointed clinical translation. Although urinary proteomics was also shown to be effective in the early detection of disease and directed therapy, its widespread adoption in the pharmacological paradigm is irregular [6]. The presence of structural renal changes observed in relation to changes in biochemical parameters only contribute to the relevance of biomarkers in the early stages, but the standardization of clinical use has not been made [7].

Pharmacological evidence is often interested in results of efficacy and lacks alignment to biomarker-based disease staging. The presence of therapeutic inertia is caused by the fact that the diagnosis is delayed, and the molecular indicators are not adequately incorporated into the treatment algorithms [8]. Precision medicine directions focus on the individual intervention, but operational models incorporating biomarkers into the decision-making in pharmacological intervention are still under the process of consolidation [9].

The biochemical changes occur before the morphological damage of kidneys and this presents a very important therapeutic window. Preemptive pharmacological intervention at biomarker-stipulated phases proves to have potential in stopping or slowing down the development to irreversible loss of nephrons. Biomarker-directed therapeutic interventions are supported by evidence of molecular dysregulation linked with therapeutic modulation [10] as opposed to late-stage therapeutic intervention [10]. Recent developments in omics technologies disclose multifaceted metabolic and inflammatory circuits that cause diabetic kidney disease, which reinforces the argument of molecularly guided therapeutic interventions [11]. The involvement of inflammatory and immune modulators in the pathogenesis of disease has a significant role and making biomarker-based modulation a potential pharmacological intervention [12]. Translational experience on biomarkers adoption in acute kidney injury offers systematic path ways that can be utilized in diabetic nephropathy setting [13]. Early diagnosis followed by therapeutic escalation is becoming the priority of preventive nephrology. Biomarker-based pharmacological interventions enhance the accuracy of therapy, prediction of outcome, and the renal preservation [14]. Serum and urinary biomarker panels show a potential of improved diagnostic precision and prognostic evaluation of diabetic nephropathy population [15]. In addition, microRNAs as molecular regulators also provide an extension of therapeutic horizons due to their dual biomarker and target potential [16]. The biochemical predictors are population-specific, which enhances the universal nature of predictors in a wide range of clinical settings [17]. The process of chronic kidney disease development represents the accumulation of molecular damage, not the functional loss per se, which means that early intervention measures are essential [18]. Pharmacological interventions including sodium-glucose cotransporter-2 inhibitors have a demonstrated ability to reduce inflammatory and fibrotic biomarkers and strengthen mechanistic relationships between biochemical modulation and renal outcome advancement [19]. All these findings bolster the existence of a coherent biochemical-pharmacological model of the treatment of early diabetic kidney injury.

Research Objectives

1. To critically synthesize biochemical markers associated with early diabetic kidney injury.
2. To evaluate pharmacological strategies targeting these markers for early renal protection.

2. METHODOLOGY

2.1 Study Design

The study utilized a cross-sectional, questionnaire-administered research design in order to assess the perceptions of clinicians towards biochemical markers of diabetic kidney injury and the way they are useful in informing early pharmacological intervention. This design allowed capturing modern clinical views in the field of nephrology-related specialty in a systematic way during a specific period.

2.2 Study Population

The study population consisted of healthcare professionals actively involved in the clinical management of diabetes and kidney disease, including nephrologists, endocrinologists, internal medicine physicians, and clinical pharmacologists. Participants were required to have direct clinical exposure to diabetic patients with renal involvement, while professionals not engaged in diabetes- or kidney-related care were excluded from participation.

2.3 Sampling Technique and Sample Size

A purposive sampling technique was employed to ensure inclusion of clinicians with relevant expertise in diabetic kidney care. Stratification by medical specialization was applied to achieve balanced representation across disciplines. A total of 200

respondents were included in the final analysis, which was considered sufficient for conducting descriptive and inferential statistical analyses in perception-based clinical research.

2.4 Questionnaire Development

Data were collected using a structured, self-administered questionnaire developed specifically for this study based on an extensive review of literature related to diabetic kidney disease, biochemical markers, and pharmacological intervention strategies. The questionnaire comprised sections addressing demographic and professional characteristics, awareness of biochemical markers, clinical utilization patterns, biomarker-guided pharmacological practices, perceived effectiveness of early intervention, and challenges associated with biomarker-based care. Perception-based items were measured using a five-point Likert scale ranging from strongly disagree to strongly agree.

2.5 Validation and Reliability

The questionnaire underwent content validation by subject experts from nephrology, endocrinology, and clinical pharmacology to ensure relevance, clarity, and adequacy of domain coverage. A pilot assessment was conducted prior to full-scale data collection to evaluate comprehensibility and structural coherence. Internal consistency reliability of the questionnaire was assessed using Cronbach's alpha, demonstrating acceptable reliability for perception-based constructs.

2.6 Data Collection Procedure

Data collection was carried out using a questionnaire depending on participant accessibility. Participation was voluntary, and informed consent was obtained from all respondents before data collection. Anonymity and confidentiality of participant responses were strictly maintained throughout the study process.

2.7 Statistical Analysis

The collected data were entered in Excel. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize demographic characteristics and perception scores. Inferential statistical analyses were performed selectively and included chi-square tests to examine associations between categorical variables, correlation analysis to assess relationships between knowledge levels and intervention practices, and regression analysis where applicable to identify predictors of biomarker-guided pharmacological decision-making. A two-tailed significance level of $p < 0.05$ was considered statistically significant.

3. RESULTS

3.1 Demographic and Professional Characteristics of Respondents

The demographic and professional characteristics of the study participants are presented in Table 1. A total of 200 healthcare professionals were included in the analysis. The majority of respondents belonged to the 35–44-year age group, followed by the 45–54-year and 25–34-year categories. Male respondents constituted a higher proportion compared to female respondents. With respect to specialization, nephrologists formed the largest group, followed by endocrinologists, internal medicine physicians, and clinical pharmacologists. Most participants reported moderate to extensive clinical experience, reflecting substantial exposure to diabetic kidney disease management.

Table 1. Demographic and Professional Profile of Respondents (n = 200)

Variable	Category	n (%)
Age group	25–34 years	50 (25.0)
	35–44 years	70 (35.0)
	45–54 years	50 (25.0)
	≥55 years	30 (15.0)
Gender	Male	124 (62.0)
	Female	70 (35.0)
	Prefer not to disclose	6 (3.0)
Specialization	Nephrology	64 (32.0)
	Endocrinology	56 (28.0)
	Internal Medicine	50 (25.0)
	Clinical Pharmacology	30 (15.0)

Overall, the respondent profile reflects broad clinical representation, supporting the generalizability of findings related to biochemical marker utilization and early pharmacological intervention in diabetic kidney injury. The distribution of respondents across age groups, gender, and medical specializations is illustrated in Figure 1.

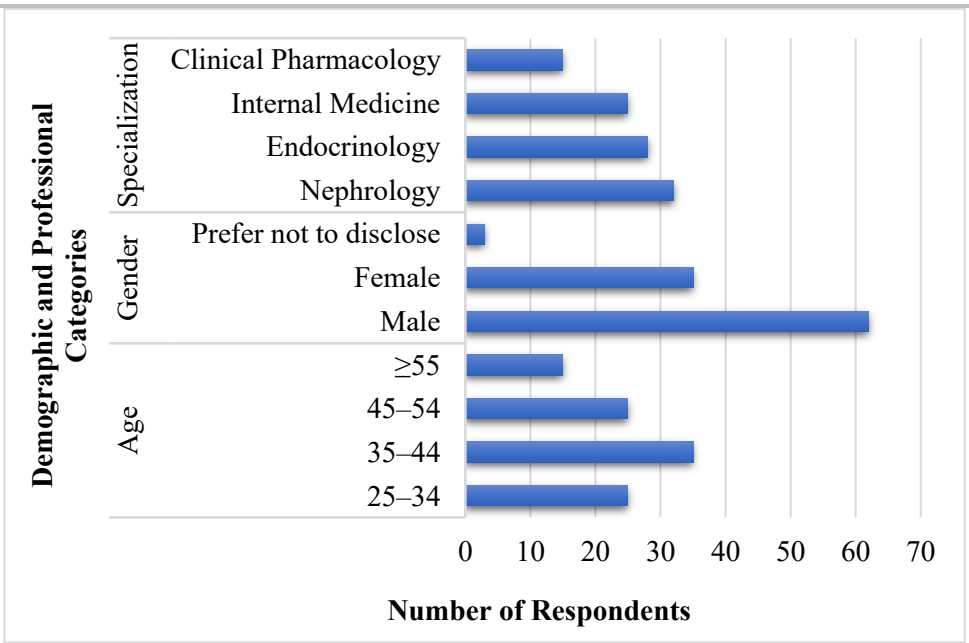

Figure 1. Demographic and Professional Distribution of Study Participants

As shown in Figure 1, respondents were well distributed across demographic categories and clinical disciplines, supporting the representativeness of the study population.

3.2 Awareness and Clinical Perception of Biochemical Markers

Clinician perceptions regarding the diagnostic value of biochemical markers for early diabetic kidney injury are summarized in Table 2. Overall, respondents expressed favorable attitudes toward biomarker-based approaches. Agreement that emerging biomarkers improve early detection accuracy and that routine biomarker monitoring enhances early diagnosis indicated strong diagnostic confidence among clinicians.

Table 2. Descriptive Statistics for Key Biomarker-Related Perceptions

Item	Mean ± SD
Emerging biomarkers improve early detection	3.67 ± 1.13
Routine biomarker monitoring improves early diagnosis	3.78 ± 1.03

Mean perception scores related to biomarker-based early detection are presented in Figure 2. The consistency of elevated mean scores across both indicators reflects a broadly shared clinical perspective regarding the importance of biochemical markers in identifying early renal involvement among patients with diabetes. Together, the table and figure provide convergent evidence supporting the perceived diagnostic relevance of biomarker-based strategies in early diabetic kidney injury.

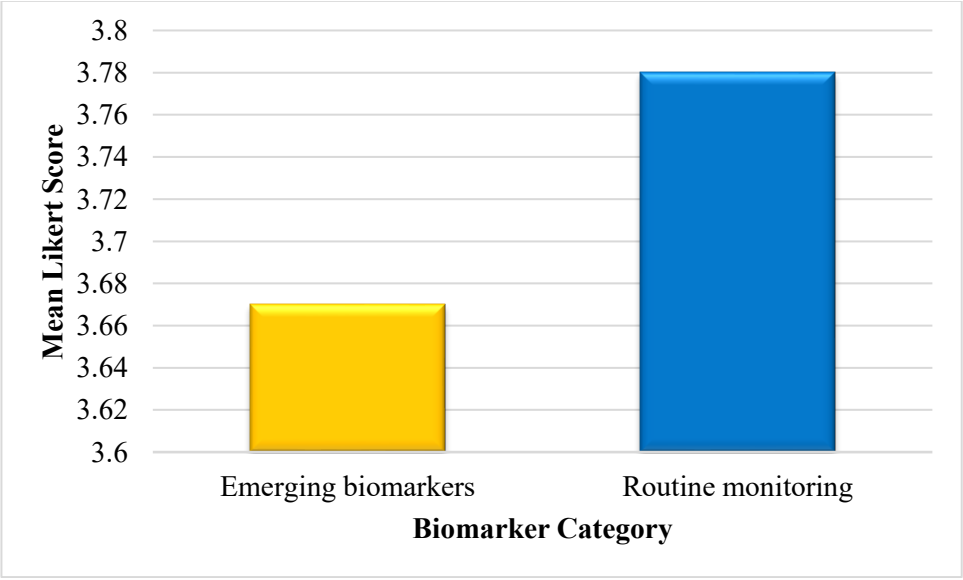

Figure 2. Clinician Perceptions of Biomarker-Based Early Detection in Diabetic Kidney Injury

As indicated in Figure 2, both emerging biomarkers and routine monitoring achieved consistently high mean scores, demonstrating strong clinician agreement regarding their diagnostic relevance.

3.3 Biomarker-Guided Pharmacological Early Intervention

Perceptions related to biomarker-guided pharmacological early intervention are presented in Table 3. Respondents indicated that early biochemical marker changes frequently influence therapeutic decision-making. High levels of agreement were observed regarding the role of early pharmacological intervention in slowing kidney disease progression, improving patient outcomes, and supporting routine clinical implementation of biomarker-guided strategies.

Table 3. Perceptions of Biomarker-Guided Pharmacological Early Intervention

Item	Mean ± SD
Influence on therapeutic decision-making	3.59 ± 1.16
Slowing of disease progression	3.80 ± 1.11
Improvement in patient outcomes	3.65 ± 1.03
Routine clinical use	3.66 ± 1.10

Clinician perceptions of biomarker-guided pharmacological early intervention are visually depicted in Figure 3. The figure highlights a progressive pattern from diagnostic insight to therapeutic action, emphasizing the perceived role of biochemical markers in guiding early nephroprotective strategies and improving clinical outcomes.

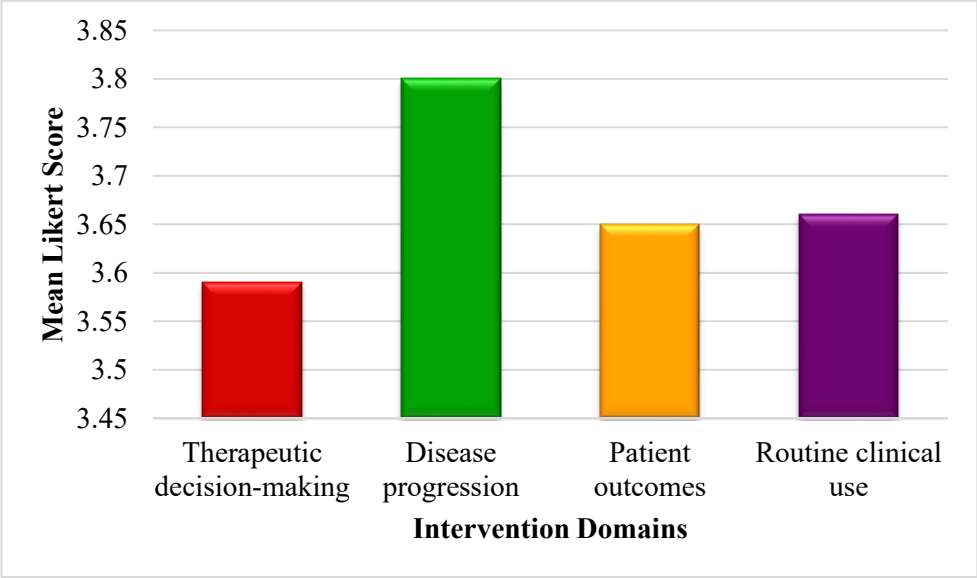

Figure 3. Clinician Perceptions of Biomarker-Guided Pharmacological Early Intervention in Diabetic Kidney Injury

As demonstrated in Figure 3, respondents reported consistently positive perceptions across all domains of biomarker-guided pharmacological intervention.

3.4 Inferential Analysis of Factors Influencing Early Pharmacological Decision-Making

Inferential statistical outcomes examining factors associated with early pharmacological decision-making are summarized in Table 4. There was no statistically significant difference in medical specialization and perceived benefit of early pharmacological intervention. In a similar manner, there were no major correlations involving the knowledge of biochemical markers and biomarker-prompted pharmacological practices. These results show that there is considerable consistency in pharmacological intervention practices in early practices across clinical disciplines and they are not significantly based on the variation of individual knowledge.

Table 4. Summary of Inferential Statistical Analyses

Analysis	Variables Examined	Test Statistic	p-value
Chi-square	Specialization × Perceived benefit of early intervention	$\chi^2 = 7.49$	0.82
Correlation	Knowledge × Intervention influence	$r = -0.09$	0.22
Regression	Knowledge → Intervention influence	$R = 0.09$	0.22

4. DISCUSSION

The present study provides structured insight into clinician perceptions regarding biochemical markers of diabetic kidney injury and their relevance in guiding early pharmacological intervention. It shows that there is a widespread professional consensus that both new biomarkers and standard biochemical surveillance can be used as diagnostic tools to identify early signs of

renal injury. This is evident in the high mean scores in perception, both diagnostic and therapeutic areas, indicating a common clinical knowledge that biochemical changes are observed before manifest expression of functional loss in diabetic kidney disease. Notably, the respondents regularly viewed the early biomarker changes to be involved in decision-making in pharmacology and this supports the idea of conceptual change of reactive management to preventive nephrology. Lack of statistically significant correlations between specialization and level of knowledge implies that there is a high level of consensus-based practice, not depending on personal knowledge and experience. This standardization is essential as it emphasizes the biomarker-consciousness maturation in the nephrology-related sphere, and the impact of standardized clinical models on the formation of early intervention plans. In combination, these results promote the incorporation of biochemical markers as the core element of early diabetic kidney injury monitoring and treatment. The findings highlight the importance of the biomarker-based pharmacotherapy in nephroprotection. By detecting the presence of renal stress at an early phase using biochemical markers, pharmacological treatment of the situation is possible at the stages of the reversible disease, which will subsequently limit the progression to the stage of irreversible loss of nephrons. The clinician belief in strategies that rely on biomarker indicates a preparedness of wider clinical application, especially in the area that focuses on early risk definitions and individually designed treatment progression. Clinically in terms of decision-making, integrating biomarkers increases the accuracy of the therapeutic intervention by matching the therapeutic intervention with molecular dysregulation as opposed to using late functional markers. The methodology will assist in the early administration of nephroprotective agents, rational prescription of drugs, and dynamical treatment modification in response to biomarker patterns. The results support the significance of adding biochemical indicators into the usual diagnostics process of diabetic patients to enhance therapy results and minimize the disease burden.

The results of the perception of this study are consistent with the growing evidence that indicates the use of molecularly informed management of diabetic kidney disease. It has been established using network pharmacology and experimental validation studies that, pharmacological agents, including resveratrol, have renoprotective effects due to the modulation of oxidative stress, inflammation, and metabolic pathways and therefore mechanistic relationships between biochemical markers and therapeutic action are observed [20]. Likewise, urinary peptide type classifiers like CKD273 have been evidenced to be useful in the early diagnosis and prediction of high-risk chronic disease of the kidney, lending credibility to practitioners who have been relying on biomarker-based diagnostic models [21]. It is also important to note that longitudinal studies of kidney functional trajectories in diabetes have shown the disease progression is an accumulation of molecular injury and not solitary functional degradation, which justifies the rationale of early biomarker-based interventions [22]. New treatment strategies that address cellular senescence further indicate that biomarker-based intervention can alter disease pathways at their core and senolytic trials in diabetic kidney disease patient groups have demonstrated [23]. The presence of other therapy systems, such as the Chinese herbal medicine, complementary evidence supports the presence of the modification of biochemical pathways in renal protection, which proves the effectiveness of biomarker-based treatment paradigms once again [24]. Furthermore, the recent recommendations of the American Diabetes Association and Kidney Disease: Improving Global Outcomes suggest risk assessment individualization and therapeutic escalation at an early stage, which is in line with the biomarker-based approaches approved by the participants of the current study [25]. Collectively, these investigations promote the alignment of clinician perceptions and the emerging evidence-based constructs on the management of early diabetic kidney injury.

The main strength of the research is that clinician perceptions regarding various disease disciplines related to nephrology were addressed, which is very useful in understanding the actual acceptance of biomarker-equipped pharmacological interventions. The questionnaire design made this possible through the systematic assessment of diagnostic confidence, therapeutic influence, and clinical readiness to engage in early intervention. Inclusion of inferential analyses further enhanced interpretation by determining patterns of practice that were driven by consensus. Nevertheless, some shortcomings must be admitted. The design is questionnaire-based, which captures perceptions as opposed to actual clinical outcomes, which result in limited causation. Recall bias or institutional practice norms may also have an effect on self-reported responses. Also, the sample size was sufficient to conduct this analysis based on perceptions, but the results might not be able to capture all regional differences in biomarker accessibility or health care infrastructure. These shortcomings show that complementary interventional and longitudinal research is required.

Biomarker-based interventional trials which directly compare clinical outcomes of early pharmacological intervention guided by biochemical markers should be the main focus of future research. The combination of multi-omics (proteomics, metabolomics and microRNA profiling) could further optimize the risk stratification and therapeutic targeting. The creation of unified biomarker-based treatment algorithms will enable a more widespread clinical use and enhance the uniformity of the medical environment. The next important step should be the advancement of precision medicine models that combine biochemical markers and pharmacogenomic and clinical information. These strategies have the potential to change the current state of diabetic kidney injury management towards proactive renal preservation rather than reactive treatment in order to match molecular knowledge with targeted therapeutic application.

5. CONCLUSION

The study highlights the increased clinical consideration of biochemical indicators as an important resource for early detection and treatment of diabetic kidney damage. The results indicate that there is a high amount of clinician agreement on the diagnostic usefulness of both new biomarkers and standard biochemical surveillance in identifying early renal involvement before a significant functional deficit occurs. High scores on the perception scales on diagnostic and treatment domains are indicative of a general recognition that biochemical changes can offer actionable information on subclinical kidney injury. The findings highlight the perceived effect of early biomarker variations on drug-related choice. Timely introduction of nephroprotective therapy, disease delays, and patient outcome were factors always linked by clinicians to biomarker-guided strategies. The lack of meaningful differences in specialty types and level of knowledge indicates that biomarker-based early intervention has already become part of the traditional clinical practice and is no longer a matter of a single intervention or a speciality issue. These results support the idea that pharmacological intervention at an early stage according to the biomarker levels is a promising chance to save renal function and reduce the burden of the disease in the long term. Routine usage of biochemical markers in clinical disease management processes better characterises therapeutic therapy, preventive nephrology interventions, and also streamlines clinical decision-making in line with underlying molecular pathology. The study contributes to a single model of dealing with early kidney injury in diabetics, where early disease diagnosis, specific treatment, and renal preservation play a central role.

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